American Society of Plumbing Engineers

Plumbing Engineering Design Handbook

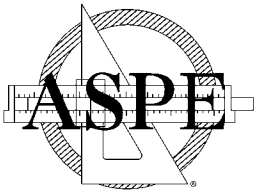
A Plumbing Engineer's Guide to System Design and Specifications

Volume 2

Plumbing Systems

American Society of Plumbing Engineers
8614 W. Catalpa Avenue, Suite 1007
Chicago, IL 60656-1116

The ASPE *Plumbing Engineering Design Handbook* is designed to provide accurate and authoritative information for the design and specification of plumbing systems. The publisher makes no guarantees or warranties, expressed or implied, regarding the data and information contained in this publication. All data and information are provided with the understanding that the publisher is not engaged in rendering legal, consulting, engineering, or other professional services. If legal, consulting, or engineering advice or other expert assistance is required, the services of a competent professional should be engaged.



American Society of Plumbing Engineers
8614 W. Catalpa Avenue, Suite 1007
Chicago, IL 60656-1116
(773) 693-ASPE • Fax: (773) 695-9007
E-mail: aspehq@aol.com • Internet: www.aspe.org

Copyright © 2006 by American Society of Plumbing Engineers

All rights reserved, including rights of reproduction and use in any form or by any means, including the making of copies by any photographic process, or by any electronic or mechanical device, printed or written or oral, or recording for sound or visual reproduction, or for use in any knowledge or retrieval system or device, unless permission in writing is obtained from the publisher.

ISBN 1-891255-24-X
Printed in China

10 9 8 7 6 5 4 3 2 1

Plumbing Engineering Design Handbook

Volume 2

Plumbing Systems

Plumbing Engineering Design Handbook Chairperson: **Alan Otts, P.E., CIPE**
ASPE Vice-Presidents, Technical: **Julius Ballanco (2005-2006)**
Technical and Editorial Review: **Jill Dirksen & Gretchen Pienta**
Chairperson: **Michael Frankel, CIPE**

CONTRIBUTORS

Chapter 1
Sanitary Drainage System
Wilson Soo Hoo
Michael Frankel, CIPE

Chapter 2
Grey Water (Water Reuse) Systems
Saum Nour, Ph.D, P.E., CPD

Chapter 3
Vents and Venting Systems
Michael Frankel, CIPE

Chapter 4
Storm Drainage Systems
Saum Nour, Ph.D, P.E., CPD
Michael Frankel, CIPE

Chapter 5
Cold Water Systems
Harold Olsen, P.E.
Sarah Balz, P.E., CPD
Thomas J. Breu, P.E., CPD, LEED AP
Richard E. Davison
Steven P. Skattebo, P.E.

Chapter 6
Domestic Water Heating Systems Fundamentals
Joe Ficek, CPD

Chapter 7
Fuel Gas Piping Systems
April Trafton
Michael Frankel, CIPE

Chapter 8
Private Sewage Disposal Systems
Lynita Docken

Chapter 9
Private Water Systems
Tim Smith, CPD

Chapter 10
Vacuum Systems
Karl Yrjanainen, P.E.

Chapter 11
Pure Water Systems
Peter Kraut, P.E.

Chapter 12
Lab Waste Systems
Renae Torborg, P.E.

About ASPE

The American Society of Plumbing Engineers (ASPE) is the international organization for professionals skilled in the design and specification of plumbing systems. ASPE is dedicated to the advancement of the science of plumbing engineering, to the professional growth and advancement of its members, and to the health, welfare, and safety of the public.

The Society disseminates technical data and information, sponsors activities that facilitate interaction with fellow professionals, and, through research and education programs, expands the base of knowledge of the plumbing engineering industry. ASPE members are leaders in innovative plumbing design, effective materials and energy use, and the application of advanced techniques from around the world.

Worldwide Membership — ASPE was founded in 1964 and currently has 6,500 members. Spanning the globe, members are located in the United States, Canada, Asia, Mexico, South America, the South Pacific, Australia, and Europe. They represent an extensive network of experienced engineers, designers, contractors, educators, code officials, and manufacturers interested in furthering their careers, their profession, and the industry. ASPE is at the forefront of technology. In addition, ASPE represents members and promotes the profession among all segments of the construction industry.

ASPE Membership Communication — All members belong to ASPE worldwide and have the opportunity to belong and participate in one of the 59 state, provincial or local chapters throughout the U.S. and Canada. ASPE chapters provide the major communication links and the first line of services and programs for the individual member. Communications with the membership is enhanced through the Society's bimonthly magazine, *Plumbing Systems and Design,* and the bimonthly newsletter ASPE *Report* which is incorporated as part of the magazine.

Technical Publications — The Society maintains a comprehensive publishing program, spearheaded by the profession's basic reference text, the ASPE *Plumbing Engineering Design Handbook.* The *Plumbing Engineering Design Handbook,* encompassing 47 chapters in four volumes, provides comprehensive details of the accepted practices and design criteria used in the field of plumbing engineering. New additions that will shortly join ASPE's published library of professional technical manuals and handbooks include: *Pharmaceutical Facilities Design Manual, Electronic Facilities Design Manual, Health Care Facilities and Hospitals Design Manual,* and *Water Reuse Design Manual.*

Convention and Technical Symposium — The Society hosts biennial Conventions in even-numbered years and Technical Symposia in odd-numbered years to allow professional plumbing engineers and designers to improve their skills, learn original concepts, and make important networking contacts to help them stay abreast of current trends and technologies. In conjunction with each Convention there is an Engineered Plumbing Exposition, the greatest, largest gathering of plumbing engineering and design products, equipment, and services. Everything from pipes to pumps to fixtures, from compressors to computers to consulting services is on display, giving engineers and specifiers the opportunity to view the newest and most innovative materials and equipment available to them.

Certified in Plumbing Design — ASPE sponsors a national certification program for engineers and designers of plumbing systems, which carries the designation "Certified in Plumbing Design" or CPD. The certification program provides the profession, the plumbing industry, and the general public with a single, comprehensive qualification of professional competence for engineers and designers of plumbing systems. The CPD, designed exclusively by and for plumbing engineers, tests hundreds of engineers and designers at centers throughout the United States biennially. Created to provide a single, uniform national credential in the field of engineered plumbing systems, the CPD program is not in any way connected to state-regulated Professional Engineer (P.E.) registration.

ASPE Research Foundation — The ASPE Research Foundation, established in 1976, is the only independent, impartial organization involved in plumbing engineering and design research. The science of plumbing engineering affects everything… from the quality of our drinking water to the conservation of our water resources to the building codes for plumbing systems. Our lives are impacted daily by the advances made in plumbing engineering technology through the Foundation's research and development.

American Society of Plumbing Engineers

Plumbing Engineering Design Handbook

(4 Volumes — 47 Chapters)

Volume 1 Fundamentals of Plumbing Engineering (Revised 2004)

Chapter 1 Formulas, Symbols, and Terminology
2 Standards for Plumbing Materials and Equipment
3 Specifications
4 Plumbing Cost Estimation
5 Job Preparation, Plumbing Drawings, and Field Reports
6 Plumbing for People (or Persons) with Disabilities
7 Energy and Resource Conservation in Plumbing Systems
8 Corrosion
9 Seismic Protection of Plumbing Equipment
10 Acoustics in Plumbing Systems
11 Basics of Value Engineering
12 Green Design for Plumbing Systems

Volume 3 Special Plumbing Systems (Estimated date: Fall 2007)

Chapter 1 Fire Protection Systems
2 Plumbing Design for Health-Care Facilities
3 Industrial Waste-Water Treatment
4 Irrigation Systems
5 Reflecting Pools and Fountains
6 Public Swimming Pools
7 Gasoline and Diesel-Oil Systems
8 Steam and Condensate Systems
9 Compressed Air Systems
10 Site Utility Systems

Volume 4 Plumbing Components and Equipment (Estimated revision date: 2008)

Chapter 1 Plumbing Fixtures
2 Piping Systems
3 Valves
4 Pumps
5 Piping Insulation
6 Hangers and Supports
7 Vibration Isolation
8 Grease Interceptors
9 Cross Connection Control
10 Water Treatment
11 Thermal Expansion
12 Potable Water Coolers and Central Water Systems
13 Bioremediation Pretreatment Systems

(The chapters and subjects listed for these volume are subject to modification, adjustment and change. The contents shown for each volume are proposed and may not represent the final contents of the volume. A final listing of included chapters for each volume will appear in the actual publication.)

Table of Contents

Chapter 1, Sanitary Drainage Systems 1

Introduction 1
Codes and Standards 1
Flow in Stacks, Building Drains, and Fixture Drains 1
Flow in Stacks 1
Flow in Building Drains 2
Flow in Fixture Drains 2
Pneumatic Pressures in a Sanitary Drainage System 2
Fixture Discharge Characteristics. 3
Stack Capacities 3
Capacities of Sloping Drains 5
Steady, Uniform Flow Conditions in Sloping Drains. 6
Slope of Horizontal Drainage Piping 6
Load or Drainage Piping 7
Components of Sanitary Drainage Systems 8
Sumps and Ejectors 8
Cleanouts 9
Floor Drains and Floor Sinks 10
Grates/Strainers 10
Flashing Ring. 11
Sediment Bucket 11
Accessories 11
BackWater Valves. 12
Oil interceptors 12
Supports 12
Materials 13
Piping 13
Joining Methods 13
Noise Transmission 14
Building Sewer installation 14
Sanitation 15
Kitchen Areas 15
Waterproofing 15

Floor Leveling . . . 16
Thermal Expansion . . . 16
Protection From Damage . . . 16
Alternate Sanitary Systems . . . 16
Sovent System . . . 17
Single-Stack System . . . 18
Reduced-Size Venting . . . 18
Vacuum Drainage System . . . 19
References . . . 19

Chapter 2, Grey Water (Water Reuse) Systems . . . 25
Introduction . . . 25
Codes and Standards . . . 25
System Description . . . 26
System Components . . . 28
Design Criteria for Gray Water Supply and Consumption . . . 28
Design Estimates for Commercial Buildings . . . 28
Gray Water Supply . . . 28
Gray Water Demand . . . 28
Design Estimates for Residential Buildings . . . 29
Design Estimates for Irrigation Systems . . . 29
Treatment Systems . . . 30
Economic Analysis—an Example . . . 32
Cost . . . 32
Precautions . . . 35
Public Concerns/Acceptance . . . 35
Conclusion . . . 35
References . . . 35

Chapter 3, Vents and Venting . . . 37
Introduction . . . 37
Definitions . . . 37
Sizing the Vent System . . . 43
Developed Length . . . 43
Fixture Units . . . 43
Size of the Soil or Waste Branch or Stack . . . 43
Calculating the Vent Size . . . 43
Vent Terminals . . . 44
Relief Vents . . . 44
Circuit and Loop Vents . . . 44
Suds Venting . . . 45
Air Admittance Valves . . . 46
Traps and Trap Seals . . . 46
References . . . 47

Chapter 4, Storm Drainage Systems 49
General Design Considerations for Buildings and Sites 49
Codes and Standard 50
Materials 50
Interior Building Drainage System Design 50
General 50
Controlled-Flow Storm-Drainage System 52
Roof Drainage 53
Secondary Roof Drainage Systems 55
Rainfall Rates 56
Interior Pipe Sizing and Layout Criteria 56
References 64
Appendix 65

Chapter 5, Cold Water Systems 67
Introduction 67
Definitions/Nomenclature 67
Codes and Standard 68
Domestic Cold Water Meters 68
Meter Types 68
Sizing the Water Meter 69
Cross Connection Controls 69
Booster Pump Systems 70
Hydropneumatic Tank 73
Elevated Water Tank System 74
Expansion Tank 76
Excess Water Pressure 77
Pressure-Regulating Valves (PRV) 78
Water Hammer 79
Shock intensity 79
System Protection 80
Sizing Water Piping 82
Hazen-Williams formula 83
Darcy-Weisbach formula 84
Factors Affecting Domestic Water Pipe Sizing 86
Review of Previous Comments and Calculations 97
Examples of Methods of Pipe Sizing 97
Velocity Method 99
Pressure Loss in Pipe Fittings and Valves 99
Testing, Cleaning, and Disinfection of Domestic Water Supply Systems 103
Testing 103
Cleaning and Disinfecting 103
References 104

Chapter 6, Domestic Water Heating Systems 107
Introduction 107

Domestic Water Heater Sizing. 108
Information Gathering 108
Water Heater Sizing Methods 108
Basic formulae and Units. 109
Heat Recovery—Electric Water Heaters. 110
Hot Water Temperature. 111
Mixed Water Temperature. 111
Water Heaters. 111
Controls 114
Stratification in Storage Type Heaters and Tanks 114
Hot Water Temperature Maintenance 115
Hot Water Circulation Systems 115
Self-Regulating Heat Trace Systems 115
Relief Valves 115
Sizing Pressure and Temperature Relief Valves 116
Thermal Expansion 116
Thermal Efficiency. 116
Safety and Health Concerns 117
Legionella Pneumophila (Legionnaires' Disease) 117
Varying Standards 118
Legionella Hot Spots 118
Controlling Legionella 120
Legionella Control Recommendations 122
Scalding 122
Codes and Standard 124
References. 124

Chapter 7, Fuel-Gas Piping Systems 125
Low and Medium-Pressure NG Systems 125
General. 125
Approvals 126
System Operating Pressure. 126
Efficiency 127
Codes and Standards 127
Gas Meters 127
Pressure Regulating Valves. 127
Pressure Control Valves 127
Appliance Control Valves. 127
Interlocks 127
Appliances 128
Allowable Gas Pressure. 128
Laboratory Usage 128
Gas Regulator Relief Vents 129
Altitude Derating Factor 129
Piping System Materials 129
Flexible Hose 129

Corrugated Stainless Steel Tubing . . . 129
Design Considerations . . . 130
Gas Boosters . . . 130
Materials of Construction . . . 130
Gas Laws for Boosters . . . 131
Interior NG Pipe Sizing . . . 134
NG Pipe Sizing Methods . . . 136
Liquefied Petroleum Gas . . . 137
Storage . . . 142
LPG Sizing . . . 142
Storage Tanks . . . 142
Glossary . . . 142
References . . . 144

Chapter 8, Private Onsite WasteWater Treatment Systems (POWTS) . 147
Introduction . . . 147
Primary Treatment . . . 147
Soil Absorption Systems . . . 147
Guide for Estimating Soil Application Rates . . . 148
Soil Absorption System Selection . . . 150
Inground Conventional Soil Absorption System . . . 150
Construction Considerations . . . 151
Site Preparation and Construction . . . 151
Alternative Soil Absorption Components . . . 152
Collection and Treatment Alternatives . . . 152
Alternatives To Gravity Collection and Distribution . . . 152
Alternatives To Conventional Primary and Secondary Treatment . . . 153
Septic (Anaerobic Treatment) Tanks . . . 153
Functions of the Septic Tank . . . 153
Septic Tank Specifications . . . 153
General Information On Septic Tanks . . . 155
Distribution Boxes . . . 156
Septic Tank/Soil Absorption Systems for Institutions and Recreational and Other Establishments . . . 156
Water Conservation . . . 157
Special Fixtures . . . 157
Alternative Systems . . . 157
Special Design . . . 157
Individual Aerobic WasteWater Treatment Plants . . . 157
Estimating Sewage Quantities . . . 158
Inspection . . . 160
References . . . 161
Bibliography . . . 161

Chapter 9, Private Water Wells 163
Introduction 163
Codes and Standards 163
Sources of Supply 163
Wells 164
Dug and Augered Wells 164
Bored Wells 164
Driven Wells 165
Jetted Wells 165
Hydraulics of Wells 165
Protection of Wells 166
Water Demand 167
Water Quality 167
Filtration 167
Softening 168
Scale and Corrosion Control 168
Taste and Odor Control 168
Prophylaxis 168
Disinfection 168
Radon Contamination 168
System Elements 168
Pumps 168
Submersible Well Pumps 169
Storage Tanks 170
Storage Tank Suction Piping 171
Pressure Regulators 171
Performance Specifications 172
Corrosion Protection 172
Initial Operation and Maintenance 172
Additional Information 172

Chapter 10, Vacuum Systems 175
Introduction 175
Fundamentals 175
Pressure Measurement 175
Units of Measurement and Reference Points 175
General Vacuum Criteria 178
Adjusting Vacuum-Pump Rating for Altitude 178
Time for Pump To Reach Rated Vacuum 178
Adjusting Pressure Drop for Different Vacuum Pressures 179
Simplified Method of Calculating Velocity 179
Vacuum Work forces 179
Vacuum Source and Source Components 179
General 179
Vacuum Pumps 180

Equipment Configuration 180
Receivers 180
Seal Liquids 181
Vacuum-Pressure Gauges 181
Ancillary Equipment 181
Laboratory Vacuum Systems 182
Codes and Standards 182
Vacuum Source 182
Distribution Network 183
General System Layout 183
Sizing Criteria 184
Vacuum-Cleaning Systems 188
Types of System and Equipment 188
Codes and Standards 188
System Components 188
Detailed System Design 189
Sizing the Piping Network 190
Vacuum-Producer (Exhauster) Sizing 193
Exhauster Rating Adjustments 194
References 196

Chapter 11, Water Treatment, Conditioning, and Purification 197
Introduction 197
Codes and Standard 197
Basic Water Chemistry 197
Water Impurities 198
Water Analysis and Impurity Measurement 201
pH 202
Specific Resistance 203
Specific Conductance 203
Total Suspended Solids 203
Total Dissolved Solids (TDS) 204
Total Organic Carbon (TOC) 204
Silt Density Index (SDI) 204
Deposits and Corrosion 205
Deposits 205
Corrosion 205
Predicting Scale Formation and Corrosion Tendencies 206
pH 206
Temperature 206
Langelier Saturation Index (LSI) 206
Ryzner Stability Index (RI) 207
Aggressiveness Index (AI) 208
Treatment Methodologies 208
Aeration 208
Clarification 208

Deaeration 209
Dealkalizing 209
Decarbonation 210
Distillation 210
Filtration 211
Ion Exchange and Removal 215
Membrane Filtration and Separation 221
Microbial Control 223
Water Treatment 225
Utility Water Treatment 225
Boiler Feed-Water Conditioning 225
Cooling-Water Conditioning 227
Potable Water Treatment 227
Water Purification 228
Codes and Standards 229
Laboratory Systems 229
Pharmaceutical Systems 229
Feed Water 230
Purification System Design 231
Central Purification Equipment 233
References 234

Chapter 12, Special-Waste Drainage Systems 237
Introduction 237
Codes and Standards 237
System Approval Requirements 237
Pipe Material and Joint Selection Considerations 238
Pipe Sizing Considerations 238
pH Definition 239
General System Design Considerations 239
Acid-Waste Drainage and Vent Systems 239
General 239
Health and Safety Concerns 239
Common Types of Acid 240
Selection of Laboratory Waste Piping and Joint Material 242
System Design Considerations 244
Acid Waste Treatment 244
Radioactive Waste Drainage and Vent System 245
General 245
The Nature of Radiation 245
Radiation Measurement 247
Allowable Radiation Levels 247
Shielding 247
Radioactive Materials 248
System Design Criteria 248
Infectious and Biological-Waste Drainage Systems 250

Codes and Standards 251
Chemical-Waste Systems 252
General 252
Codes and Standards 252
Pipe Material and Joint Selection 253
System Design Considerations 253
Fire-Suppression Water Drainage 253
System Description 253
Flammable and Volatile Liquids 254
Oil in Water 254
References 256

Index 261

Figures

Figure 1-1 Procedure for Sizing an Offset Stack 5
Figure 1-2 Typical Ejector Pump Installation 8
Figure 1-3 Typical Submerged Sump Pump Installation 9
Figure 1-4 Basic Floor-Drain Components
(A) Removable Grate; (B) Rust-Resistant Bolts;
(C) Integral, One-Piece, Flashing Ring; (D) Cast Drain Body with Sump;
(E) Sediment Bucket (optional). 10
Figure 1-5 Pattern Draft for Floor Gratings
(a) Sharp Edge, (b) Reverse Pattern. 11
Figure 1-6 Types of Floor Drain
(A) Typical Drain with Integral Trap that May Be Cleaned through Removable Strainer at Floor Level; (B) Floor Drain with Combination Cleanout and Backwater Valve, for Use Where Possibility of Backflow Exists; (C) Drain with Combined Cleanout, Backwater Valve, and Sediment Bucket.. 11
Figure 1-7 Various Types of Backwater Valve 12
Figure 1-8 Combination Floor Drain and Indirect Waste Receptor 12
Figure 1-9 Inside-Caulk Drain Body. 13
Figure 1-10 Spigot-Outlet Drain Body 13
Figure 1-11 No-Hub-Outlet Drain Body. 14
Figure 1-12 IPS or Threaded–Outlet Drain Body. 14
Figure 1-13 (A) Traditional Two-Pipe System,
(B) Typical Sovent Single-Stack Plumbing System. 17
Figure 2-1 Plumbing System Flow Charts
(A) Conventional Plumbing System; (B) Recycled-Water System.. 26
Figure 2-2 Riser Diagrams: (A) Gray-Water Plumbing System;
(B) Recycled-Water-Waste System with System Treatment Plant (STP). 27
Figure 2-3 Water Treatment Systems
(A) Types of Gray-Water Treatment System;
(B) Types of Black-Water Treatment System 31
Figure 2-4 System Design Flow Chart Example (250-Room Hotel):
(A) Conventional Plumbing System; (B) Recycling for Water Closets;
(C) Recycling for Water Closets and Cooling Tower;
(D) Recycling for Water Closets, Cooling Tower, and Irrigation 33
Figure 2-5 Nomograph for Overview of Preliminary Feasibility
of Gray-Water Systems 34
Figure 3-1 Branch Interval 38
Figure 3-2 Branch Vent 38

Figure 3-3 Building Trap. . . . 38
Figure 3-4 Common Vent 38
Figure 3-5 Circuit and Loop Vent 39
Figure 3-6 Common Vent 39
Figure 3-7 Fixture Battery 40
Figure 3-8 Individual Vent 40
Figure 3-9 Typical Offsets 40
Figure 3-10 Venting at Stack Offsets 41
Figure 3-11 Stack Vent 41
Figure 3-12 Side Vent 41
Figure 3-13 Wet Vent 43
Figure 3-14 Yoke Vent 43
Figure 3-15 Suds Pressure Zones 45
Figure 3-16 Illustration of Suds Pressure Connections 46
Figure 4-1 Typical Expansion Joint or Horizontal Offset 51
Figure 4-2 Typical Roof Drain and Roof Leader 51
Figure 4-3 Clear-Water Waste Branches for Connection to Storm System 52
Figure 4-4 Example of a Controlled-Flow Drain 53
Figure 4-5 Figure 4-5 Typical Roof-Drain Installations:
(A) Steel or Concrete Roof Deck with Insulation Tapered to the Drain;
(B) Precast or Steel Substrate with an Inverted-Membrane Type Roof;
(C) Parapet Drain in Poured Concrete Deck with Downspout Elbow;
(D) Planting Area Drain in Raised Planter Box;
(E) Indirect Waste for HVAC Equipment on Concrete Roof Deck;
(F) Promenade Drain in Precast Deck with Synthetic Flooring and Underdeck Clamp. . . . 55
Figure 4-6 Overflow (Secondary) Drainage Piping Discharge Locations, (a) Above Ground, (b) Primary Drain Connection. . . . 56
Figure 4-7 Piping Layout for Typical Building Elevation 61
Figure 4-8 Piping Layout for Typical Building Site Plan 61
Figure 4-9 4-in. (101-mm) Roof Drain Flow Chart 62
Figure 5-1 RPZ Discharge Flow Rate 70
Figure 5-2 Piping Arrangement of an Elevated Water Tank 74
Figure 5-3 Simplified Downfeed Water Supply System with Simplified Elevated Water Tank 75
Figure 5-4 Estimated Water House Tank Storage Capacity, Multiple dwellings 75
Figure 5-5(a) Illustrations of a Shock Wave 79
Figure 5-5(b) Time vs. Pressure Shockwave of System. . . . 81
Figure 5-6 Air Chambers
(a, b) Plain Air Chambers, (c) Standpipe Air Chamber, (d) Rechargeable Air Chamber 81
Figure 5-7(a) Bellows. . . . 82
Figure 5-7(b) Piston. . . . 82
Figure 5-8 Water Supply Graph 84
Figure 5-9 Kinematic Viscosity and Reynolds Number Chart 85
Figure 5-10 Friction factors for any Kind and Size of Pipe. . . . 86
Figure 5-11 Pipe Sizing Data, Smooth Pipe 87

Figure 5-12 Pipe Sizing Data, Fairly Smooth Pipe 88
Figure 5-13 Pipe Sizing Data, Fairly Rough Pipe 89
Figure 5-14 Pipe Sizing Data, Rough Pipe. 90
Figure 5-15 Conversion of Fixture Units, fu, to gpm (L/s) 93
Figure 5-16 Form to Track WSFUs and Other Data 94
Figure 5-17 Domestic Water piping Sketch 95
Figure 5-18 Method for Conducting a Water Flow Test 95
Figure 5-19 Establishing the Governing Fixture or Appliance. 97
Figure 5-20 Determining Pressure Available for Friction 98
Figure 6-1 Occupant Demographic Classifications 109
Figure 7-1 Altitude Correction Factor 129
Figure 7-2 Variations of a Basic Simplex Booster System
(A) Standby Generator Application with Accumulator Tank Having a Limitation on Maximum Pressure 131
Figure 7-2 Variations of a Basic Simplex Booster System
(B) Dual Booster System for Critical Systems Like Those in Hospitals,
(C) Heat Exchanger Loop Example—Required for High Flow Range with Low Minimum Flow. 132
Figure 7-3 Gas Demand for Multiple-unit Dwellings with More Than 50 Apartments 135
Figure 7-4 Gas Demand for Multiple-unit Dwellings with Less than 50 Apartments 136
Figure 7-5 Gas Riser Pipe Sizing for Multiple Dwellings 137
Figure 8-1 Three Legs of Disposal FieldFed from Cross Fitting Laid on Its Side . . . 150
Figure 8-2 Disposal Lines Connected by Headers to Circumvent Stoppages. 150
Figure 8-3 Transverse and Lineal Sections of Drain FieldShowing Rock and Earth Backfill around Drain Tile 151
Figure 8-4 Graph Showing RelationBetween Percolation Rate and Allowable Rate at Sewage Application. 161
Figure 9-1 Well under (A) Static and (B) Pumping Conditions 166
Figure 9-2 Typical Pitless Adaptor. 167
Figure 9-3 Typical Gravel Filter Well with a Vertical Turbine Pump 169
Figure 9-4 Graph Indicating Minimum Storage-Tank Size 171
Figure 9-5 Storage-Tank Suction Piping Detail
(A) Sump Suction Alternate, (B) Anti-Vortex Alternate 171
Figure 10-1 Conversion of Vacuum-Pressure Measurements. 177
Figure 10-2 Schematic Detail of a Typical Laboratory Vacuum-Pump Assembly . . . 182
Figure 10-3 Typical Process Vacuum-Pump Duplex Arrangement 183
Figure 10-4 Direct Reading Chart Showing Diversity for Laboratory Vacuum. 185
Figure 10-5 Acceptable Leakage in Vacuum Systems 187
Figure 10-6 Vacuum-Cleaning Piping Friction Loss Chart. 192
Figure 10-7 Schematic of a Typical Wet-Vacuum Cleaning Pump Assembly. 195
Figure 11-1 Typical Water Analysis Report 202
Figure 11-2 pH of Saturation for Water. 207
Figure 11-3 Detail of Vapor Compression Still. 212
Figure 11-4 Detail of Multi-Effect Still 214
Figure 11-5 Schematic Detail of Large-Scale, Granular-Activated Carbon Filter. . . 215

Figure 11-6 Typical Single-Bed Ion Exchanger 216
Figure 11-7 Typical Dual-Bed Ion Exchanger 217
Figure 11-8 Typical Mixed-Bed Ion Exchanger 218
Figure 11-9 Schematic Operation of a Continuous Deionization Unit. 219
Figure 11-10 Hollow-Fiber Reverse-Osmosis Configuration. 222
Figure 11-11 Spiral-Wound Reverse-Osmosis Configuration 222
Figure 11-12 Tubular Reverse Osmosis Configuration. 222
Figure 11-13 Plate-and-Frame Reverse-Osmosis Configuration 222
Figure 11-14 UV Wavelength Spectrum. 224
Figure 11-15 Principle of Corona-Discharge Ozone Generator 225
Figure 11-16 Typical Pharmaceutical Water-Flow Diagram. 232
Figure 12-1 Typical Acid-Resistant Manhole. 243
Figure 12-2 Typical Large Acid-Neutralizing Basin 244
Figure 12-3 Typical Continuous Acid-Waste Treatment System 246
Figure 12-4 Typical Oil Interceptor 254
Figure 12-5 Typical Gravity Draw-Off Installation (A) Plan and (B) Isometric 255

Tables

Table 1-1 Residential Drainage Fixture Unit (dfu) Loads 3
Table 1-2 Capacities of Stacks. 4
Table 1-3 Horizontal Fixture Branches and Stacks. 4
Table 1-4 Values of R, $R^{2/3}$, AF, and AH. 6
Table 1-5 Approximate Discharge Rates and Velocities in Sloping Drains, n = 0.015 . . . 7
Table 1-6 Slopes Of Cast Iron Soil Pipe Sanitary Sewers Required to Obtain Self-Cleansing Velocities Of 2.0 And 2.5 Ft./sec. (Rased On Mannings Formula with N = .012) 7
Table 1-7 Building Drains and Sewers 7
Table 1-8 Recommended Grate Open Areas for Various Floor Drains with Outlet Pipe Sizes 10
Table 1-9 Relative Properties of Selected Plumbing Materials for Drainage Systems 14
Table 2-1 The National Sanitation Foundation's Standard 41 26
Table 2-2 Design Criteria of Six Typical Soils 29
Table 2-2(M) Design Criteria of Six Typical Soils 29
Table 2-3 Location of the Gray Water System 30
Table 2-4 Subsurface Drip Design Criteria of Six Typical Soils 30
Table 2-5 Gray Water Treatment Processes for Normal Process Efficiency 30
Table 2-6 Comparison of Gray Water System Applications 31
Table 2-7 Life-Cycle Economic Comparison: Gray Water Systems for 250-Room Hotel 32
Table 3-1 Size and Length of Vents 42
Table 3-2 Maximum Length of Trap Arm 43
Table 3-3 Suds Pressure-Relief Vents. 45
Table 4-1 Sizes of Roof Drains and Vertical Pipes 53
Table 4-2 Discharge from Rectangular Scuppers–Gallons per Minute 56
Table 4-3 Maximum Rates of Rainfall for Various US Cities, in./h (mm/h) 57
Table 4-4 Size of Horizontal Storm Drains 62
Table 4-5 Sizes of Semicircular and Equivalent Rectangular Gutters 63
Table 5-1 Displacement-Type Meters Meeting AWWA Specifications — Flow-Pressure Loss Averages 69
Table 5-2 Compound-Type Meters Meeting AWWA Specifications — Flow-Pressure Loss Averages 69
Table 5-3 Turbine-Type Meters Meeting AWWA Specifications — Flow-Pressure Loss Averages 69

Table 5-4 BFP Flow Rate 70
Table 5-5 Pressure Losses Through RPZs 71
Table 5-6 Hydropneumatic Tank Volume Ratios 72
Table 5-6(SI) Hydropneumatic Tank Volume Ratios 72
Table 5-7 Tank Size Varying by its Location in a Building 74
Table 5-7(SI) Tank Size Varying by its Location in a Building 74
Table 5-8 Size of Gravity Tanks 76
Table 5-9 Standard Wood House Tanks 76
Table 5-10 Water Expansion Above 40°F 77
Table 5-10(SI) Water Expansion Above 40°F 77
Table 5-11 Expansion Tank Pressure Ratios 77
Table 5-11(SI) Expansion Tank Pressure Ratios 77
Table 5-12 Required Air Chambers 81
Table 5-13 Water Hammer Arrester Sizing 82
Table 5-14 Densities of Pure Waterat Various Temperatures 82
Table 5-15 Surface Roughness Coefficient (C) Values for Various Types of Pipe 83
Table 5-16 Values of ε (Absolute Roughness) 86
Table 5-17 Average Values For Coefficient of Friction, f. 86
Table 5-18 Load Values Assigned to Fixtures 91
Table 5-19 Estimating Demand 91
Table 5-20 Minimum Sizes of Fixture Water Supply Pipes 94
Table 5-21 Water Distribution System Design Criteria
Required Capacity At Fixture Supply Pipe Outlets 94
Table 5-22(a) Disc-type Positive Displacement Magnetic Drive Meter 96
Table 5-22(b) Compound Magnetic Drive Meter 96
Table 5-22(c) Horizontal Turbine Meter 96
Table 5-23 Allowance for Friction Loss in Valves and Threaded Fittings 99
Table 5-23(M) Allowance for Friction Loss in Valves and Threaded Fittings 99
Table 5-24 Typical Resistance Coefficients for Valves and Fittings 100
Table 5-25 Typical Resistance Coefficients for Valves and Fittings 101
Table 5-26 Flow Data, C_v Values for Valves 102
Table 5-27 Continuation of Flow Data C_V Values for Valves. 102
Table 6-1 Hot Water Demand per Fixture for Various Types of Buildings
(Gallons[Liters] of Water per Hour per Fixture,
Calculated at a Final Temperature of 140°F [60°C]) 109
Table 6-2 Low, Medium, and High Guidelines: Hot Water Demand and Use
for Multifamily Buildings 110
Table 6-3 Typical Hot Water Temperatures for Plumbing Fixtures and Equipment 111
Table 6-4 Hot Water Multiplier, P 112
Table 6-5 Thermal Properties of Water 117
Table 6-6 Recommended Water System Temperatures 118
Table 6-7 Time/Water Temperature Combinations Producing Skin Damage 124
Table 7-1 Average Physical Properties of Natural Gas and Propane 125
Table 7-2 Physical and Combustion Properties of Commonly Available Fuel Gases 126
Table 7-3 Approximate Gas Demand for Common Appliances 128
Table 7-4 Laboratory Diversity Factors 129

Table 7-5 Equivalent Lengths for Various Valve and Fitting Sizes 135
Table 7-6 Pressure less than 2 psi (14 kPa), loss of 0.3 in. (7.5 mm) wc 138
Table 7-7 Pressure less than 2 psi (14 kPa), loss of 0.5 in. (12.5 mm) wc 139
Table 7-8 Pressure of 5 psi (35 kPa), loss of 10 percent 140
Table 7-9 Pressure 10 psi (70 kPa), loss of 10 percent 140
Table 7-10 Pressure 20 psi (140 kPa), loss of 10 percent 140
Table 7-11 Pressure 50 psi (350 kPa), loss of 10 percent 141
Table 7-12 Specific Gravity Multipliers 141
Table 7-13 Conversion of Gas Prcssurc to Various Designations 141
Table 7-14 100% Propane for Interior Piping 142
Table 7-15 100% Propane for Site Mains 143
Table 8-1 Maximum Soil Application Rates Based on Morphological Soil Evaluation (in gals./sq.ft./day) 148
Table 8-2 Maximum Soil Application Rates Based on Percolation Rates. 148
Table 8-3 Recommended Setbacks for Soil Absorption Systems 150
Table 8-4 Liquid Capacity of Tank 153
Table 8-5 Allowable Sludge Accumulation 155
Table 8-6 Average Waste-Water Flows from Residential Sources. 158
Table 8-7 Typical Waste-Water Flows from Commercial Sources. 158
Table 8-8 Typical Waste-Water Flows from Institutional Sources 159
Table 8-9 Typical Waste-Water Flows from Recreational Sources 159
Table 8-10 Quantities of Sewage Flows 160
Table 8-11 Estimated Distribution of Sewage Flows. 161
Table 8-12 Allowable Rate of Sewage Application to a Soil-Absorption System 161
Table 10-1 Basic Vacuum–Pressure Measurements 176
Table 10-2 Conversions fromtorr to Various Vacuum-Pressure Units 176
Table 10-3 IP and SI Pressure Conversion 176
Table 10-4 Expanded Air Ratio, 29.92/P, as a Function of Pressure, P (in. Hg) 178
Table 10-5 Direct Ratio for Converting scfm to acfm (sL/s to aL/s) 178
Table 10-6 Barometric Pressure Corresponding to Altitude. 178
Table 10-7 Factor for Flow Rate Reduction Due to Altitude. 178
Table 10-8 Constant, C, for Finding Mean Air Velocity. 179
Table 10-9 Diversity Factor for LaboratoryVacuum Air Systems. 184
Table 10-10 Pressure Loss Data for Sizing Vacuum Pipe Low Pressure Vacuum System 185
Table 10-10(A) High Vacuum Pressure System. 186
Table 10-11 Vacuum – Pump Exhaust Pipe Sizing 186
Table 10-12 Recommended Sizes of Hand tools and Hose 190
Table 10-13 Flow Rate and Friction Loss for Vacuum-Cleaning tools and Hoses . . . 191
Table 10-14 Recommended Velocities for Vacuum-Cleaning Systems 191
Table 10-15 Pipe Size Based on Simultaneous Usage 193
Table 10-16 Equivalent Length (ft.) of Vacuum Cleaning Pipe Fittings 193
Table 10-17 Classification of Material for Separator Selection. 194
Table 11-1 Important Elements, Acid Radicals, andAcids in Water Chemistry 199
Table 11-2 Converting ppm of Impurities to ppm of Calcium Carbonate 202
Table 11-3 Resistivity and Conductivity Conversion. 203

Table 11-4 Prediction of Water Tendencies by the Langelier Index 206
Table 11-5 Numerical Values for Substitution in Equation 11-3 to Find the pH_s of Saturation for Water 207
Table 11-6 Prediction of Water Tendenciesby the Ryzner Index 208
Table 11-7 Typical Cations and Anions Found in Water 215
Table 11-8 Comparison of Reverse-Osmosis Polymers 223
Table 11-9 Recommended Boiler Feed-Water Limits and Steam Purity 226
Table 11-10 Water-Treatment Technology for Small Potable Water Systems 228
Table 11-11 CAP and ASTM Reagent-Grade Water Specifications 229
Table 11-12 NCCLS Reagent-Grade Water Specifications 230
Table 11-13 AAMI/ANSI Water-Quality Standards 230
Table 11-14 ASTM Electronics-Grade Water Standard. 230
Table 11-15 USP XXII Purified-Water andWFI Water-Purity Standards 231
Table 12-1 Drainage Pipe Sizing. 240
Table 12-1(M) Drainage Pipe Sizing. 241

1 Sanitary Drainage Systems

INTRODUCTION

The purpose of the sanitary drainage system is to remove effluent discharged from plumbing fixtures and other equipment to an approved point of disposal. A sanitary drainage system generally consists of horizontal branches, vertical stacks, a building drain inside the building, and a building sewer from the building wall to the point of disposal.

To economically design a sanitary drainage system, use the smallest pipes according to the code that can rapidly carry away the soiled water from individual fixtures without clogging the pipes, leaving solids in the piping, generating excessive pneumatic pressures at points where the fixture drains connect to the stack (which might cause the reduction of trap water seals and force sewer gases back through inhabitable areas), and creating undue noise.

Since vents and venting systems are described in Chapter 3 of this volume, the following discussion centers only on the design of drain and waste systems.

CODES AND STANDARDS

Plumbing codes establish a minimum acceptable standard for the design and installation of systems, including sanitary drainage. There are various model codes, but some states and large cities have adopted plumbing codes other than the ones usually associated with the region. Because of this non-standardization, the actual plumbing code used for each specific project must be obtained from a responsible code official. There are a variety of different codes used to lay out and size interior sanitary drainage system. Some codes have been adopted by major cities such as New York, Chicago, Los Angles, and others.

The information pertaining to sanitary design for any specific project appears in the approved local plumbing code and must be the primary method used for the accepted methods and sizing. The tables and charts appearing in this chapter are used only to illustrate and augment discussions of sizing methods, sizing procedures, and design methods and should not be used for actual design purposes.

FLOW IN STACKS, BUILDING DRAINS, AND FIXTURE DRAINS

Flow in Stacks

A stack is considered a main vertical pipe that carries away discharge from within a facility of water closets and urinals (soil stack) or other clear water waste from equipment and non-sanitary fixtures (waste stack). Flow in the drain empties into the vertical stack fitting, which may be a long-turn tee-wye or a short-turn or sanitary tee. Each of these fittings permits flow from the drain to enter the stack with a component directed vertically downward. Depending on the rate of flow out of the drain into the stack, the diameter of the stack, the type of stack fitting, and the flow down the stack from higher levels, if any, the discharge from the fixture drain may or may not fill the cross section of the stack at the level of entry. In any event, as soon as the water enters the stack, the force of gravity rapidly accelerates it downward, and before it falls very far, it assumes the form of a sheet around the wall of the stack, leaving the center of the pipe open for the flow of air.

This sheet of water continues to accelerate until the frictional force exerted by the wall of the stack on the falling sheet of water equals the force of gravity. From that point on—if the distance the water falls is great enough and provided that no flow enters the stack at lower levels to interfere with the sheet—the sheet remains unchanged in thickness and velocity until it reaches the bottom of the stack. The ultimate vertical velocity the sheet attains is called the "terminal velocity." The distance the sheet must fall to attain this terminal velocity is called the "terminal length." Following are the formulae developed for calculating the terminal velocity and terminal length:

Equation 1-1

$$V_T = 3.0\left(\frac{Q}{d}\right)^{2/5}$$

$$L_T = 0.052V_T^2$$

where

V_T = Terminal velocity in stack, fps (m/s)
L_T = Terminal length below point of flow entry, ft (m)
Q = Quantity rate of flow, gpm (L/s)
d = Diameter of stack, in. (mm)

Terminal velocity is approximately 10 to 15 fps (3.05 to 4.57 m/s), and this velocity is attained within 10 to 15 ft (3.05 to 4.57 m) of fall from the point of entry.

At the center of the stack is a core of air that is dragged along with the water by friction and for which a supply source must be provided if excessive pressures in the stack are to be avoided. The usual means of supplying this air are through the stack vent or vent stack. The entrained air in the stack causes a pressure reduction inside the stack, which is caused by the frictional effect of the falling sheet of water dragging the core of air along with it.

If the sheet of water falling down the stack passes a stack fitting through which the discharge from a fixture is entering the stack, the water from the branch mixes with or deflects the rapidly moving sheet of water. An excess pressure in the drain from which the water is entering the stack is required to deflect the sheet of water flowing downward or mix the branch water with it. The result is a backpressure created in the branch, which increases with the flow rate and flow velocity down the stack and with the rate of flow out of the drain.

The importance of this research is that it conclusively abolishes the myth that water falling from a great height will destroy the fittings at the base of a stack. The velocity at the base of a 100-story stack is only slightly and insignificantly greater than the velocity at the base of a three-story stack. The concern is the weight of the stack, which must be supported by clamps at each floor level.

Flow in Building Drains

When the sheet of water reaches the bend at the base of the stack, it turns at approximately right angles into the building drain. Flow enters the horizontal drain at a relatively high velocity compared to the velocity of flow in a horizontal drain under uniform flow conditions. The slope of the building drain is not adequate to maintain the velocity that existed in the vertical sheet when it reached the base of the stack and must flow horizontally. The velocity of the water flowing along the building drain and sewer decreases slowly then increases suddenly as the depth of flow increases and completely fills the cross section of the drain. This phenomenon is called a "hydraulic jump."

The critical distance at which the hydraulic jump may occur varies from immediately at the stack fitting to 10 times the diameter of the stack downstream. Less hydraulic jump occurs if the horizontal drain is larger than the stack. After the hydraulic jump occurs and water fills the drain, the pipe tends to flow full until the friction resistance of the pipe retards the flow to that of uniform flow conditions.

Flow in Fixture Drains

Determination of the required drain size is a relatively simple matter, since the fixture drain must be adequate only to carry the discharge from the fixture to which it is attached. Because of the problem of self-siphonage, however, it is advisable to select the diameter of the drain so that the drain flows little more than half full under the maximum discharge conditions likely to be imposed by the fixture.
For example, a lavatory drain capable of carrying the flow discharged from a lavatory may still flow full over part or all of its length. There are several reasons for this. The vertical component of the flow out of the trap into the drain tends to make the water attach itself to the upper elements of the drain, and a slug of water is formed, filling the drain at that point. If there is not sufficient air aspirated through the overflow, the pipe will flow full for part of its length, with the average velocity of flow being less than the normal velocity for the rate of flow in the drain at a given slope.

If the fixture considered is a water closet, the surge of water from the closet will continue almost without change even along a very long drain until it reaches the stack. Thus, it can be assumed, for all practical purposes, that the surge caused by the discharge of a water closet through a fixture drain reaches the stack or horizontal branch with practically the same velocity it had when it left the fixture.

PNEUMATIC PRESSURES IN A SANITARY DRAINAGE SYSTEM

Because of the pressure conditions in a stack and a building drain, the wastewater does not fill the cross section anywhere, so the air can flow freely along with the water. The water flowing down the wall of the stack drags air with it by friction and carries it through the building drain to the street sewer. The air is then vented through the main street sewer system so dangerous pressures do not build up. The generally accepted pressure is plus or minus 1 inch of water column.

If air is to enter the top of the stack to replace the air being carried along with the water, there must be a pressure reduction inside the stack. Because of the head loss necessary to accelerate the air and to provide for the energy loss at the entrance, however,

this pressure reduction is negligible; it amounts to only a small fraction of an inch (a millimeter) of water. What causes appreciable pressure reductions is the partial or complete blocking of the stack by water flowing into the stack from a horizontal branch.

A small increase in pneumatic pressure will occur in the building drain even if there is no complete blocking of the airflow by a hydraulic jump or by submergence of the outlet and the building sewer. This is due to the decrease in cross-sectional area available for airflow when the water flowing in the drain has adapted itself to the slope and diameter of the drain.

Table 1-1 Residential Drainage Fixture Unit (dfu) Loads

Fixture Drainage Fixture Units (dfu)	IPC	UPC
Bathtub	2	3
Clothes washer	3	3
Dishwasher	2	2
Floor drain	3	*
Laundry tray	2	2
Lavatory, single	1	1
Lavatory, in sets of 2 or 3	2	2
Shower (each head)	2	2
Sink (including dishwasher and garbage disposer)	3	3
Water closet (1.6-gpf gravity tank)	4	4
Water closet (1.6-gpf flushometer tank)	5	5
Water closet (1.6-gpf flushometer valve)	4	4

* Trap loadings

1¼"	1 dfu
1½"	3 dfu
2"	4 dfu
3"	6 dfu
4"	8 dfu

FIXTURE DISCHARGE CHARACTERISTICS

The discharge characteristic curves—flow rates as a function of time—for most water closet bowls have the same general shape, but some show a much lower peak and a longer period of discharge. The discharge characteristics for various types of water closet bowls, particularly low-flow water closets, have a significant impact on estimating the capacity of a sanitary drainage system. Other plumbing fixtures, such as sinks, lavatories, and bathtubs, may produce similar surging flows in drainage systems, but they do not have as marked of an effect as water closets.

Drainage Loads Single-family dwellings contain certain plumbing fixtures—one or more bathroom groups, each consisting of a water closet, a lavatory, and a bathtub or shower stall; a kitchen sink, dishwasher, and washing machine; and, possibly, a set of laundry trays. Large buildings also have other fixtures, such as slop sinks and drinking water coolers. The important characteristic of these fixtures is that they are not used continuously. Rather, they are used with irregular frequencies that vary greatly during the day. In addition, the various fixtures have quite different discharge characteristics regarding both the average rate of flow per use and the duration of a single discharge. Consequently, the probability of all the fixtures in the building operating simultaneously is small. Assigning drainage fixture unit (dfu) values to fixtures to represent their load-producing effect on the plumbing system was originally proposed in 1923 by Dr. Roy B. Hunter. The fixture unit values were designed for application in conjunction with the probability of simultaneous use of fixtures to establish the maximum permissible drainage loads expressed in fixture units rather than in gallons per minute (gpm, L/s) of drainage flow. Table 1-1 gives the recommended fixture unit values. The plumbing engineer must conform to local code requirements.

A dfu is a quantity of load-producing discharge in relation to that of a lavatory.

Dr. Hunter conceived the idea of assigning a fixture unit value to represent the degree to which a fixture loads a system when used at the maximum assumed flow and frequency. The purpose of the fixture unit concept is to make it possible to calculate the design load of the system directly when the system is a combination of different kinds of fixtures, each having a unique loading characteristic. Current or recently conducted studies of drainage loads on drainage systems may change these values. These include studies of (1) reduced flow from water-saving fixtures; (2) models of stack, branch, and house drain flows; and (3) actual fixture use.

STACK CAPACITIES

The criterion of flow capacities in drainage stacks is based on the limitation of the water-occupied cross section to a specified fraction (r_s) of the cross section of the stack where terminal velocity exists, as suggested by earlier investigations.

Flow capacity can be expressed in terms of the stack diameter and the water cross section:

Equation 1-2

$$Q = 27.8 \times r_s^{5/3} \times D^{8/3}$$

where

Q = Capacity, gpm (L/s)
r_s = Ratio of cross-sectional area of the sheet of water to cross-sectional area of the stack
D = Diameter of the stack, in. (mm)

Values of flow rates based on r = ¼, 7/24, and ⅓ are tabulated in Table 1-2.

Whether or not Equation 1-2 can be used safely to predict stack capacities remains to be confirmed and accepted. However, it provides a definite law of variation of stack capacity with diameter. If this law can be

Table 1-2 Capacities of Stacks

Pipe Size, in. (mm)	Flow, gpm (L/s)		
	r = 1/4	r = 7/24	r = 1/3
2 (50)	17.5 (1.1)	23.0 (1.45)	28 (1.77)
3 (80)	52 (3.28)	70 (4.41)	85 (5.36)
4 (100)	112 (7.07)	145 (9.14)	180 (11.35)
5 (125)	205 (12.93)	261 (16.5)	324 (20.44)
6 (150)	330 (20.82)	424 (26.8)	530 (33.43)
8 (200)	710 (44.8)	913 (57.6)	1,140 (72)
10 (250)	1,300 (82.0)	1,655 (104.4)	2,068 (130.5)
12 (300)	2,082 (131.4)	2,692 (170)	3,365 (212.3)

shown to hold for the lower part of the range of stack diameters, it should be valid for the larger diameters. It should be remembered that both F.M. Dawson and Dr. Hunter, in entirely independent investigations, came to the conclusion that slugs of water, with their accompanying violent pressure fluctuations, did not occur until the stack flowed 1/4 to 1/3 full. Most model codes have based their stack loading tables on a value of r = 1/4 or 7/24.

The recommended maximum permissible flow in a stack is 7/24 of the total cross-sectional area of the stack. By substituting r = 7/24 into Equation 1-2, the corresponding maximum permissible flow for the various sizes of pipe in gpm (L/s) can be determined. Table 1-3 lists the maximum permissible fixture units (fu) to be conveyed by stacks of various sizes. The table was created by taking into account the probability of simultaneous use of fixtures. For example, the 500 fu is the maximum loading for a 4-in. (100-mm) stack, thus 147 gpm (9.3 L/s) is equivalent to 500 fu. This is the total load from all branches.

It should be noted that there is a restriction of the amount of flow permitted to enter a stack from any branch when the stack is more than three branch intervals. If an attempt is made to introduce too large a flow into the stack at any one level, the inflow will fill the stack at that level and will even back up the water above the elevation of inflow, which will cause violent pressure fluctuations in the stack—resulting in the siphoning of trap seals—and may also cause sluggish flow in the horizontal branch. This problem was solved in a study of stack capacities made by Wyly and Eaton at the National Bureau of Standards for the Housing and Home Finance Agency in 1950.

The water flowing out of the branch can enter the stack only by mixing with the stream flowing down the stack or by deflecting it. Such a deflection of the high-velocity stream coming down the stack can be accomplished only if there is a large enough hydrostatic pressure in the branch, since a force of some kind is required to deflect the downward flowing stream and therefore change its momentum. This hydrostatic pressure is built up by the backing up of the water in the branch until the head thus created suffices to change the momentum of the stream already in the stack to allow the flow from the branch to enter the stack.

The magnitude of the maximum hydrostatic pressure that should be permitted in the branch as a result of the backing up of the spent water is based on the consideration that this backup should not be sufficiently great to cause the water to back up into a shower stall or to cause sluggish flow. It is half the diameter of the horizontal branch at its connection to the stack. That is, it is the head measured at the axis of the pipe that will cause the branch to flow full near the exit.

When a long-turn tee-wye is used to connect the branch to the stack, the water has a greater vertical velocity when it enters the stack than it does when a sanitary tee is used, and the back pressures should be smaller in this case for the same flows down the stack and in the branch.

Table 1-3 shows the maximum permissible fu loads for sanitary stacks. The procedure for sizing a multistory stack (greater than three floors) is to first size the horizontal branches connected to the stack. This is done by totaling the fixture units connected to each branch and size in accordance with column 2 in Table 1-3. Next, total all the fixture units connected to the stack and determine the size from the same table, under column 4. Immediately check the next column, "Total at One Branch Interval," and determine if this maximum is exceeded by any of the branches. If it is exceeded, the size of the stack as originally determined must be increased at least one size, or the loading of the branches must be redesigned so maximum conditions are satisfied. Take, for example, a 4-in. (100-mm) stack more than three stories in height. The maximum loading for a 4-in. (100-mm) branch is 160 fu, as shown in column 2 of Table 1-3. This load

Table 1-3 Horizontal Fixture Branches and Stacks

Diameter of pipe, in. (mm)	Maximum Number of Drainage Fixture Units (dfu) that May Be Connected			
	Any Horizontal Fixture Branch[a]	1 Stack of 3 or Fewer Branch Intervals	Stacks with More than 3 Branch Intervals	
			Total for Stack	Total at 1 Branch Interval
1½ (40)	3	4	8	2
2 (50)	6	10	24	6
2½ (65)	12	20	42	9
3 (80)	20[b]	48[b]	72[b]	20[b]
4 (100)	160	240	500	90
5 (125)	360	540	1,100	200
6 (150)	620	960	1,900	350
8 (200)	1,400	2,200	3,600	600
10 (250)	2,500	3,800	5,600	1,000
12 (300)	3,900	6,000	8,400	1,500
15 (380)	7,000			

[a] Does not include branches of the building drain.

[b] No more than two water closets or bathroom groups within each branch interval or more than six water closets or bathroom groups on the stack.

is limited by column 5 of the same table, which permits only 90 fu to be introduced into a 4-in. (100-mm) stack in any one-branch interval. The stack would have to be increased in size to accommodate any branch load exceeding 90 fu.

To illustrate clearly the requirements of a stack with an offset of more than 45° from the vertical, Figure 1-1 shows the sizing of a stack in a 12-story building where there is one offset between the fifth and sixth floors and another offset below the street floor.

Sizing is computed as follows:

Step 1. Compute the fixture units connected to the stack. In this case, assume 1,200 fixture units are connected to the stack from the street floor through the top floor.

Step 2. Size the portion of the stack above the fifth-floor offset. There are 400 fixture units from the top floor down through the sixth floor. According to Table 1-3, column 4, 400 fixture units require a 4-in. (100-mm) stack.

Step 3. Size the offset on the fifth floor. An offset is sized and sloped like a building drain.

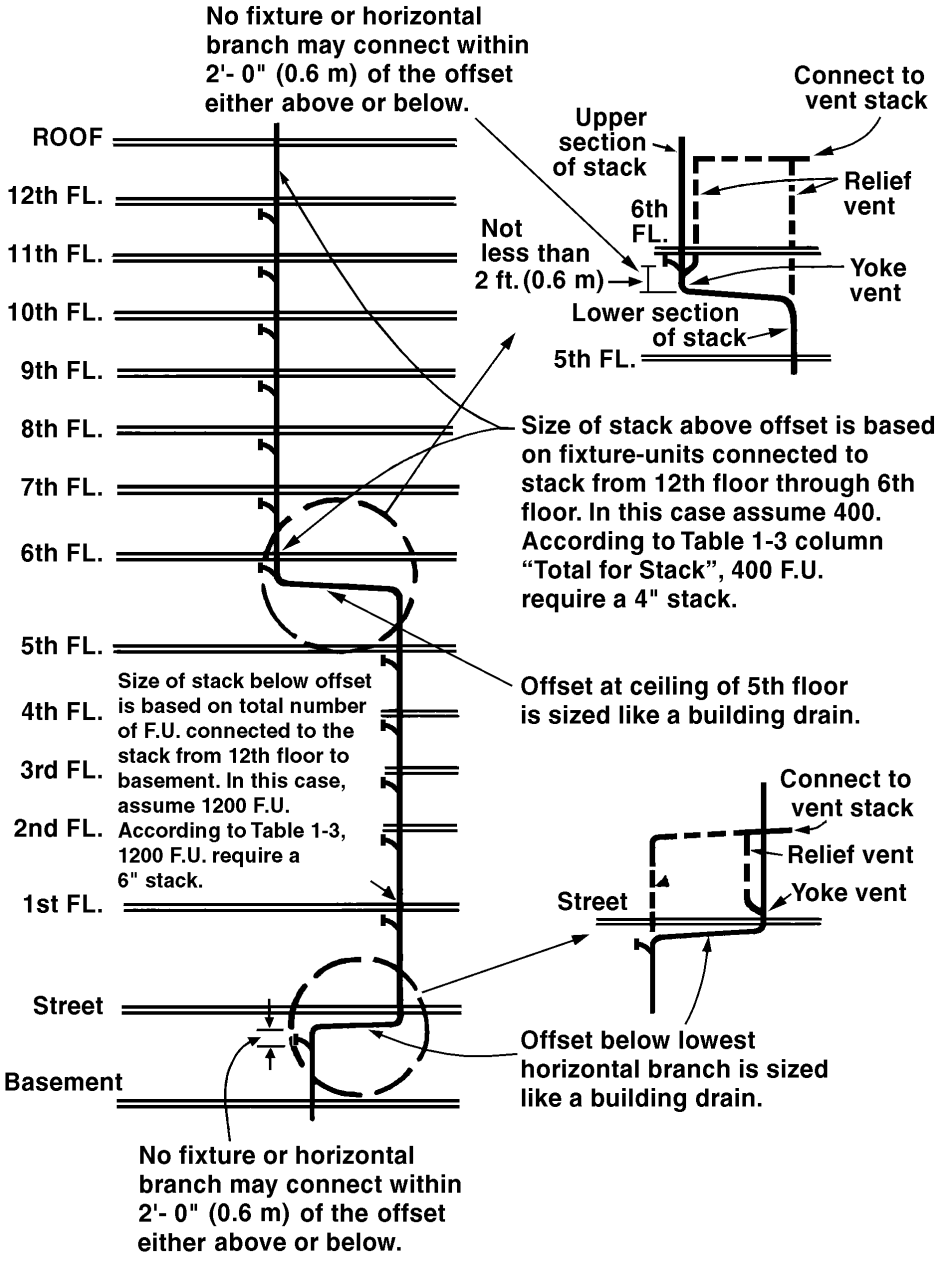


Figure 1-1 Procedure for Sizing an Offset Stack

Step 4. Size the lower portion of the stack from the fifth floor down through the street floor. The lower portion of the stack must be large enough to serve all fixture units connected to it, from the top floor down (in this case 1,200 fixture units). According to Table 1-3, 1,200 fixture units require a 6-in. (150-mm) stack.

Step 5. Size and slope the offset below the street floor the same as a building drain.

The fixture on the sixth floor should be connected to the stack at least 2 ft (0.6 m) above the offset. If this is not possible, then connect them separately to the stack at least 2 ft (0.6 m) below the offset. If this is not possible either, run the fixture drain down to the fifth or fourth floor and connect to the stack at that point.

CAPACITIES OF SLOPING DRAINS

The characteristics of sewage are the same as plain water. Capacities of horizontal or sloping drains are complicated by surging flow.

The determination of drain size is based on highly fluctuating or surging flow conditions in the horizontal branches carrying the discharge of fixtures to the soil or waste stack. After falling down the vertical stack, the water is assumed to enter the building drain with peaks of the surges leveled off somewhat but still in a surging condition.

In a large building covering considerable ground area there are probably several primary branches and certainly at least one secondary branch. After the water enters the building drain, the surge continues to level off, becoming more and more nearly uniform, particularly after the hydraulic jump has occurred. If the secondary branch is long enough, and if the drain serves a large number of fixtures, the flow may become substantially uniform before it reaches the street sewer.

Steady, Uniform Flow Conditions in Sloping Drains

Although the equations of steady, uniform flow in sloping drains should not be used to determine the capacities of sloping drains in which surging flow exists, flow computations based on these formulas afford a rough check on values obtained by the more complicated methods that are applicable to surging flow. Hence, three of the commonly used formulas for flow in pipes will be considered: (1) Hazen and Williams, (2) Darcy-Weisbach, and (3) Manning.

Hazen and Williams formula This formula is usually written as follows:

Equation 1-3

$$V = 1.318 \times C \times R^{0.63} \times S^{0.54}$$

where

V = Mean velocity of flow, fps (m/s)
C = Hazen and Williams coefficient
R = Hydraulic radius of pipe, ft (m)
S = Slope of pressure gradient

The exponents of R and S in Equation 1-3 have been selected to make the coefficient C as nearly constant as possible for different pipe diameters and for different velocities of flow. Thus, C is approximately constant for a given pipe roughness.

Darcy-Weisbach formula In this formula the dimensionless friction coefficient f varies with the diameter of the pipe, the velocity of flow, the kinematic viscosity of the fluid flowing, and the roughness of the walls. It is usually written as follows:

Equation 1-4

$$h_f = \frac{f\,L\,V^2}{D\,2g}$$

where

h_f = Pressure drop or friction loss, ft (m)
f = Friction coefficient
L = Length of pipe, ft (m)
D = Diameter of pipe, ft (m)
V = Mean velocity of flow, fps (m/s)
g = Acceleration of gravity, 32.2 fps^2 (9.8 m/s^2)

Manning formula The Manning formula, which is similar to the Hazen and Williams formula, is meant for open-channel flow and is usually written as follows:

Equation 1-5

$$V = \frac{1.486}{n} \times R^{2/3} \times S^{1/2} = \frac{1.486}{n} \times R^{0.67} \times S^{0.50}$$

In this formula, n is the Manning coefficient and varies with the roughness of the pipe and the pipe diameter.

The quantity of flow is equal to the cross-sectional area of flow times the velocity of flow obtained from the above three equations. This can be expressed as:

Equation 1-5a

$$Q = AV$$

where

Q = Quantity rate of flow, cfs (m^3/s)
A = Cross-sectional area of flow, ft^2 (m^2)
V = Velocity of flow, fps (m/s)

By substituting the value of V from Manning's formula, the quantity of flow in variously sized drains of the same material can be calculated as

Equation 1-5b

$$Q = A \times \left(\frac{1.486}{n}\right) \times R^{2/3} \times S^{1/2}$$

This is the formula used by many plumbing engineers to deal with sloping drain problems. The significant hydraulic parameters used in the above equation are listed in Table 1-4.

It should be noted that the units in the above equations should be converted to the proper units whenever utilizing Equations 1-5a or 1-5b.

Slope of Horizontal Drainage Piping

Horizontal drains are designated to flow at half-full capacity under uniform flow conditions to minimize the generation of pneumatic pressure fluctuations. A minimum slope of ¼ in./ft (6.4 mm/m) should be provided for pipe 3 in. (80 mm) and smaller, ⅛ in./ft (3.2 mm/m) for 4-6-in. (100-150-mm) pipe, and 1/16 in./ft (1.6 mm/m) for pipe 8 in. (200 mm) and larger. These slopes are not a hard and fast rule

Table 1-4 Values of R, R2/3, AF, and AH

Pipe Size, in. (mm)	R = ¾, ft (mm)	$R^{2/3}$, ft (mm)	A_F (Cross-Sectional Area for Full Flow), ft^2 (m^2)	AH (Cross-Sectional Area for Half-full Flow), ft^2 (m^2)
1½ (40)	0.0335 (1.02)	0.1040 (3.17)	0.01412 (0.0013)	0.00706 (0.00065)
2 (50)	0.0417 (1.27)	0.1200 (3.66)	0.02180 (0.0020)	0.01090 (0.0009)
2½ (65)	0.0521 (1.59)	0.1396 (4.24)	0.03408 (0.0031)	0.01704 (0.0015)
3 (80)	0.0625 (1.90)	0.1570 (4.78)	0.04910 (0.0046)	0.02455 (0.0023)
4 (100)	0.0833 (2.54)	0.1910 (5.82)	0.08730 (0.0081)	0.04365 (0.0040)
5 (125)	0.1040 (3.17)	0.2210 (6.74)	0.13640 (0.0127)	0.06820 (0.0063)
6 (150)	0.1250 (3.81)	0.2500 (7.62)	0.19640 (0.0182)	0.09820 (0.0091)
8 (200)	0.1670 (5.09)	0.3030 (9.23)	0.34920 (0.0324)	0.17460 (0.0162)
10 (250)	0.2080 (6.33)	0.3510 (10.70)	0.54540 (0.0506)	0.27270 (0.0253)
12 (300)	0.2500 (7.62)	0.3970 (12.10)	0.78540 (0.0730)	0.39270 (0.0364)
15 (380)	0.3125 (9.53)	0.4610 (14.05)	1.22700 (0.0379)	0.61350 (0.0570)

Table 1-5 Approximate Discharge Rates and Velocities in Sloping Drains, n = 0.015[a]

Actual Inside Diameter of Pipe, in. (mm)	Actual Inside Half-full Flow Discharge Rate and Velocity							
	1/16 in./ft (1.6 mm/m) Slope		1/8 in./ft (3.2 mm/m) Slope		1/4 in./ft (6.4 mm/m) Slope		1/2 in./ft (12.7 mm/m) Slope	
	Disch., gpm (L/s)	Velocity, fps (mm/s)	Disch., gpm (L/s)	Velocity, fps (mm/s)	Disch., gpm (L/s)	Velocity, fps (mm/s)	Disch., gpm (L/s)	Velocity, fps (mm/s)
1¼ (31.8)							3.40 (0.21)	1.78 (45.5)
1⅜ (34.9)					3.13 (0.20)	1.34 (0.41)	4.44 (0.28)	1.90 (48.3)
1½ (38.9)					3.91 (0.247)	1.42 (0.43)	5.53 (0.35)	2.01 (51.1)
1⅝ (41.28)					4.81 (0.30)	1.50 (0.46)	6.80 (0.38)	2.12 (53.9)
2 (50.8)					8.42 (0.53)	1.72 (0.52)	11.9 (0.75)	2.43 (61.8)
2½ (63.5)			10.8 (0.68)	1.41 (0.43)	15.3 (0.97)	1.99 (0.61)	21.6 (1.36)	2.82 (71.7)
3 (76.3)			17.6 (1.11)	1.59 (0.49)	24.8 (1.56)	2.25 (0.69)	35.1 (2.21)	3.19 (81.1)
4 (101.6)	26.70 (1.68)	1.36 (34.6)	37.8 (2.38)	1.93 (0.59)	53.4 (3.37)	2.73 (0.83)	75.5 (4.76)	3.86 (98.2)
5 (127)	48.3 (3.05)	1.58 (40.2)	68.3 (4.30)	2.23 (0.68)	96.6 (6.10)	3.16 (0.96)	137 (8.64)	4.47 (113.7)
6 (152.4)	78.5 (4.83)	1.78 (45.3)	111 (7.00)	2.52 (0.77)	157 (10)	3.57 (1.09)	222 (14.0)	5.04 (128.2)
8 (203.2)	170 (10.73)	2.17 (55.2)	240 (15.14)	3.07 (0.94)	340 (21.5)	4.34 (1.32)	480 (30.3)	6.13 (155.9)
10 (256)	308 (19.43)	2.52 (64.1)	436 (27.50)	3.56 (1.09)	616 (38.9)	5.04 (1.54)	872 (55.0)	7.12 (181.0)
12 (304.8)	500 (31.55)	2.83 (72.0)	707 (44.60)	4.01 (1.22)	999 (63.0)	5.67 (1.73)	1413 (89.15)	8.02 (204.0)

[a] n = Manning coefficient, which varies with the roughness of the pipe.

For full flow: Multiply discharge by 2.00.

For full flow: Multiply velocity by 1.00.

For smoother pipe: Multiply discharge and velocity by 0.015 and divide by n of another pipe.

Table 1-6 Slopes Of Cast Iron Soil Pipe Sanitary Sewers Required To Obtain Self-cleansing Velocities Of 2.0 And 2.5 Ft./sec. (Rased On Mannings Formula With N = .012)

Pipe Size (in.)	Velocity (ft./sec.)	1/4 Full		1/2 Full		3/4 Full		Full	
		Slope (ft./ft.)	Flow (Gal./min.)	Slope (ft./ft.)	Flow (Gal./min.)	Slope (ft./ft.)	Flow (Gal./min.)	Slope (ft./ft.)	Flow (Gal./min.)
2.0	2.0	0.0313	4.67	0.0186	9.34	0.0148	14.09	0.0186	18.76
	2.5	0.0489	5.04	0.0291	11.67	0.0231	17.62	0.0291	23.45
3.0	2.0	0.0178	10.71	0.0107	21.46	0.0085	32.23	0,0107	42.91
	2.5	0.0278	13.47	0.0167	26.62	0.0133	40.29	0.0167	53.64
4.0	2.0	0.0122	19.03	0.0073	38.06	0.0058	57.01	0.0073	76.04
	2.5	0.0191	23.79	0.0114	47.58	0.0091	71.26	0.0114	95.05
5.0	2.0	0.0090	29.89	0.0054	59.79	0.0043	89.59	0.0054	119.49
	2.5	0.0141	37.37	0.0085	74.74	0.0067	111.99	0.0085	149.36
6.0	2.0	0.0071	43.18	0.0042	86.36	0.0034	129.54	0.0042	172.72
	2.5	0.0111	53.98	0.0066	101.95	0.0053	161.93	0.0066	215.90
8.0	2.0	0.0048	77.20	0.0029	154.32	0.0023	231.52	0.0029	308.64
	2.5	0.0075	96.50	0.0045	192.90	0.0036	289.40	0.0045	385.79
10.0	2.0	0.0036	120.92	0.0021	241.85	0.0017	362.77	0.0021	483.69
	2.5	0.0056	151.15	0.0033	302.31	0.0026	453.46	0.0033	604.61
12.0	2.0	0.0028	174.52	0.0017	349.03	0.0013	523.55	0.0017	678.07
	2.5	0.0044	218.15	0.0026	436.29	0.0021	654.44	0.0026	612.58
15.0	2.0	0.0021	275.42	0.0012	550.84	0.0010	826.26	0.0012	1101.68
	2.5	0.0032	344.28	0.0019	688.55	0.0015	1032.83	0.0019	1377.10

and might be less under unusual conditions. The signer must confirm required slopes with the local code authority. These minimum slopes are required to maintain a velocity of flow greater than 2 fps for scouring action. Table 1-5 gives the approximate velocities for given flow, slopes, and diameters of horizontal drains based on the Manning formula for half-full pipe and n = 0.015.

A flow velocity of 2 fps will prevent the solids within a pipe from settling out and forming a system stoppage. Table 1-6 has been prepared to give the size of a pipe in conjunction with flow rate to maintain a self-cleansing velocity of 2 fps.

Load or Drainage Piping

The recommended loads for building drains and sewers are tabulated in Table 1-7. This table shows the maximum number of fixture units that may be

Table 1-7 Building Drains and Sewers[a]

Diameter of Pipe, in. (mm)	Maximum Permissible Fixture Units for Sanitary Building Drains and Runouts From Stacks			
	Slope, in./ft (mm/m)			
	1/16 (1.6)	1/8 (3.2)	1/4 (6.4)	1/2 (12.7)
2 (50)			21	26
2½ (65)			24	31
3 (80)		20	42[b]	50[b]
4 (100)		180	216	250
5 (125)		390	480	575
6 (150)		700	840	1,000
8 (200)	1400	1600	1,920	2,300
10 (250)	2500	2900	3,500	4,200
12 (300)	2900	4600	5,600	6,700
15 (380)	7000	8300	10,000	12,000

[a] On-site sewers that serve more than one building may be sized according to the current standards and specifications of the administrative authority for public sewers.

[b] No more than two water closets or two bathroom groups, except in single-family dwellings, where no more than three water closets or three bathroom groups may be installed. Check the local codes in the area served for exact requirements or restrictions.

connected to any portion of the building drain or building sewer for given slopes and diameters of pipes. For example, an offset below the lowest branch with 1,300 fu at ¼ in./ft (6.4 mm/m) slope requires an 8-in. (200-mm) pipe.

For devices that provide continuous or semi-continuous flow into the drainage system, such as sump pumps, ejectors, and air-conditioning equipment, a value of 2 fu can be assigned for each gpm (L/s) of flow. For example, a sump pump with a discharge rate of 200 gpm (12.6 L/s) is equivalent to 200 × 2 = 400 fu.

COMPONENTS OF SANITARY DRAINAGE SYSTEMS

Sumps and Ejectors

The distinction between sump and ejector pumps is more terminology than actual fact. A sump pump is designed to transport clear, non-sanitary wastewater with some turbidity and suspended solids no larger than sand grains. An ejector pump is designed to transport sanitary waste and larger solids suspended in the effluent. All effluent is a liquid with solids suspended in it but has the same hydraulic characteristics as water.

Building drains that cannot flow directly into a sewer by gravity must be discharged into a covered basin from which fluid is lifted into the building's gravity drainage system by automatic pump equipment or by any equally efficient method approved by the administrative authority.

An ejector basin must be of airtight construction and must be vented. It is airtight to prevent the escape of foul odors generated by sanitary waste from the subdrainage system. Since it is airtight, a vent is required to relieve the air in the basin as wastes discharge into it and also to supply air to the basin while the contents are being discharged to the sanitary gravity drainage system. A duplex pump system shall be used. If one pump breaks down, the control system will alert the second pump to start. The system will remain in operation and no damage will be caused by the cessation of system operation. When a duplex unit is used, each pump should be sized for 100 percent flow, and it is good practice to have the operation of the pumps alternate automatically.

A sump basin need not be airtight or vented because of the lack of objectionable odors. Incoming water is collected in the sump before it is pumped to the gravity drain pipe. Heavy-flow drains require large sumps to retain greater-than-usual amounts of water, thereby creating more head pressure on the pipe inlet. Most manufacturers make their basins with bottom, side, or angle inlets and with inside caulk, no-hub, push-on, spigot, or screwed connections. Outlet connections are made to accept pressure-type pipe joints. No-hub pipe and fittings are not acceptable on pumped discharge piping due to the pressure limitations of the pipe joints.

Sump and ejector systems normally use a wet pit and will have the pumps either above slab or submerged. They are controlled with a float switch or electronic, with control switches mounted inside the basin. Typical ejector installations are illustrated in Figure 1-2. Typical ejector installations are illustrated in Figure 1-3.

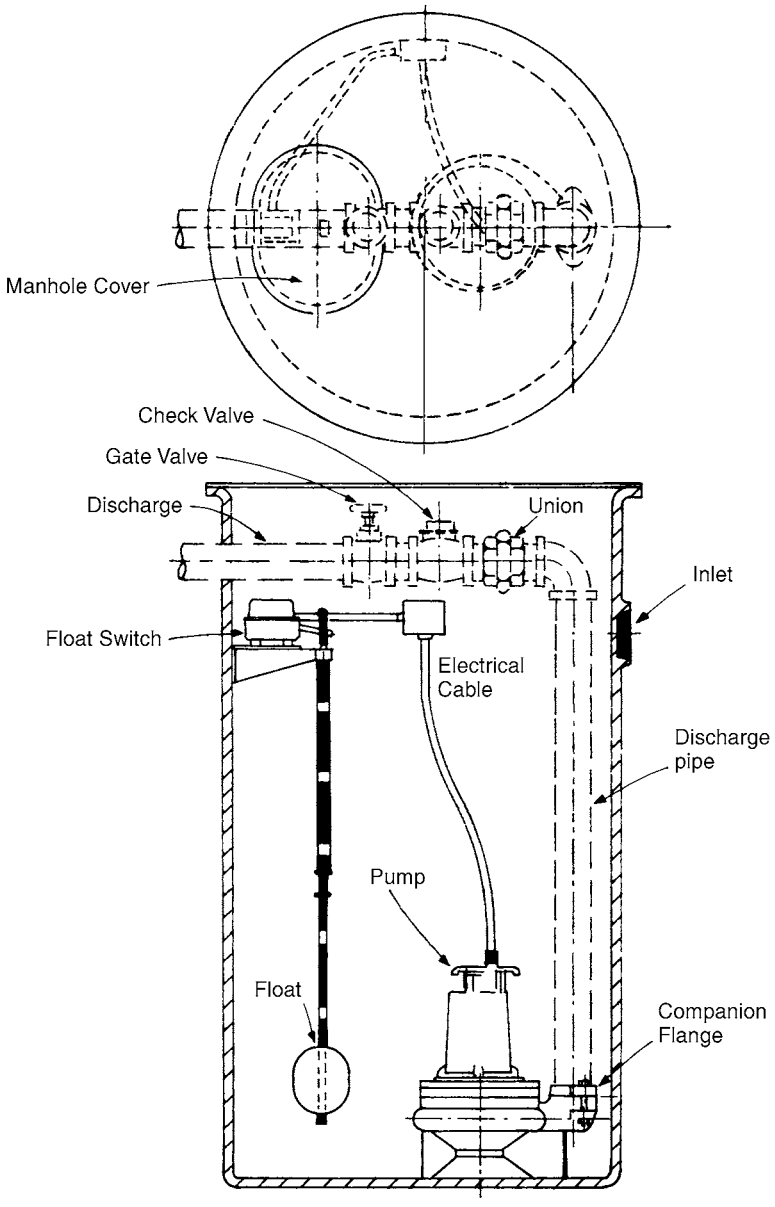


Figure 1-2 Typical Ejector Pump Installation

Cleanouts

The cleanout provides access to horizontal and vertical lines to facilitate inspection and provide a means of removing obstructions such as solid objects, greasy wastes, and hair. Cleanouts, in general, must be gas- and water-tight, provide quick and easy plug removal, allow ample space for the operation of cleaning tools, have a means of adjustment to finished surfaces, be attractive in appearance, and be designed to support whatever traffic is directed over them.

Some cleanouts are designed with a neoprene seal plug, which prevents "freezing" or binding to the ferrule. All plugs are machined with a straight or running thread and a flared shoulder for the neoprene gasket, permitting quick and certain removal when necessary. A maximum opening is provided for tool access. Recessed covers are available to accommodate carpet, tile, terrazzo, and other surfaces finishes and are adjustable to the exact floor level established by the adjustable housing or by the set screws.

Waste lines are normally laid beneath the floor slabs at a distance sufficient to provide adequate backfill over the joints. Cleanouts are then brought up to floor-level grade by pipe extension pieces. Where the sewer line is at some distance below grade and not easily accessible through extensions, small pits or manholes with access covers must be installed. When cleanouts are installed in traffic areas, the traffic load must be considered when the materials of construction are selected.

The size of the cleanout within a building should be the same size as the piping, up to 4 in. (100 mm). For larger size interior piping, 4-in. (100-mm) cleanouts are adequate for their intended purpose; however, 6-in. (150-mm) cleanouts are recommended to allow for a larger variety of access needs such as for sewer video equipment.

Cleanouts should be provided at the following locations:

1. Five ft 0 in. (1.5 m) outside or inside the building at the point of exit.
2. At every change of direction greater than 45°.
3. A maximum distance between cleanouts of 50 ft (15.1 m) should be maintained for piping 4 in. (100 mm) and smaller, and of 75 ft (22.9 m) for larger piping. Underground sanitary sewer piping larger than 10 in. (250 mm) in diameter should be provided with cleanouts at every change of direction and every 150 ft (45.7 m).
4. At the base of all stacks.
5. To comply with applicable codes.

Optional locations include:

1. At the roof stack terminal.
2. At the end of horizontal fixture branches or waste lines.
3. At fixture traps. (Fixture traps can be pre-manufactured with cleanout plugs, although some codes prohibit the installation of this kind of trap.)

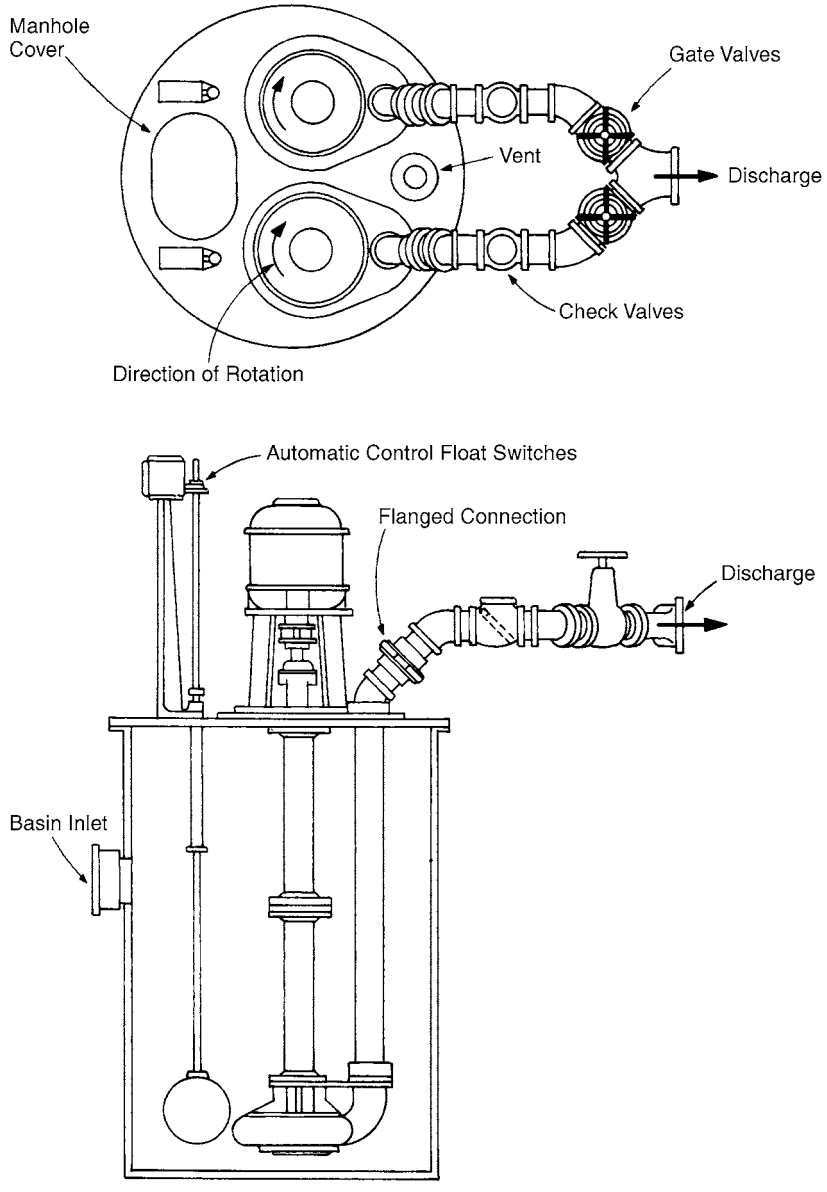


Figure 1-3 Typical Submerged Sump Pump Installation

Floor Drains and Floor Sinks

A large-diameter drain with a deep sump connected to a large-diameter pipe passes more water faster than a smaller drain. However, economics do not allow the designer arbitrarily to select the largest available drain when a smaller, less-expensive unit will do a satisfactory job. High-capacity drains are intended for use primarily in locations where the flow reaches high rates, such as malls, wash-down areas, and certain industrial applications. Table 1-8, which shows minimum ratios of open grate area based on pipe diameter, is offered as a guide for the selection of drains where the drain pipe diameter is known.

Table 1-8 Recommended Grate Open Areas for Various Floor Drains With Outlet Pipe Sizes

Nominal Pipe Size, in. (mm)	Recommended Minimum Grate Open Area for Floor Drains	
	Transverse Area of Pipe, in.[2a] (× 10 mm²)	Minimum Inside Area, in.² (× 10 mm²)
1½ (40)	2.04 (1.3)	2.04 (1.3)
2 (50)	3.14 (2.0)	3.14 (2.0)
3 (80)	7.06 (4.6)	7.06 (4.6)
4 (100)	12.60 (8.1)	12.06 (8.1)
5 (125)	19.60 (12.7)	19.60 (12.7)
6 (150)	28.30 (18.3)	28.30 (18.3)
8 (200)	50.25 (32.4)	50.24 (32.4)

[a] Based on extra-heavy soil pipe, nominal internal diameter.

The only drawback to using the open-area-pipe-diameter-ratio method is that all drain manufacturers do not list the total open areas of grates in their catalogs. This information usually can be obtained upon request, however.

For the sizing of floor drains for most indoor applications, the capacity of a drain is not extremely critical because the drain's primary function is to handle minor spillage or fixture overflow. The exceptions are, of course, cases where equipment discharges to the drain, where automatic fire sprinklers may deluge an area with large amounts of water, and where flushing of the floor is required for sanitation.

Generally located floor drains or drains installed to anticipate a failure may not receive sufficient water flow to keep the protective water seal or plumbing trap from evaporating. If it does evaporate, sewer gases will enter the space. Automatic or manual trap primers should be installed to maintain a proper trap seal. (A small amount of vegetable oil will dramatically reduce the evaporation rate of infrequently used floor drains and floor sinks.)

Figure 1-4 shows the basic components of a floor drain.

Grates/Strainers

The selection of grates is based on use and the amount of flow. Light-traffic areas may have a nickel-bronze-finished grate, while mechanical areas may have a large, heavy-duty, ductile iron grate.

The wearing of spike-heeled shoes prompted the replacement of grates with a heel-proof, ¼-in.-square (6.4-mm) grate design in public toilet rooms, corridors, passageways, promenade decks, patios, stores, theaters, and markets. Though this type of grating has less drainage capacity than the previous one, its safety feature makes it well worth the change.

Grates or strainers should be secured with stainless-steel screws in nickel-bronze tops. Vandal-proof fasteners are available from most manufacturers. Vandal-proofing floor drain grates is advisable. If there is public access to the roof, consideration must be given to protecting the vent openings from vandals.

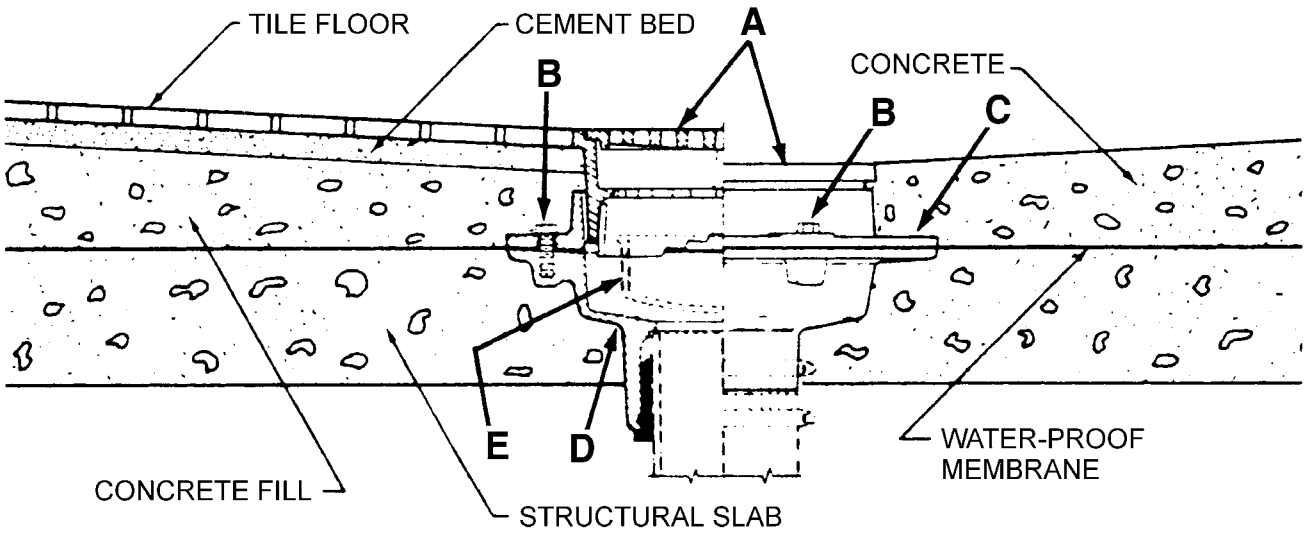


Figure 1-4 Basic Floor-Drain Components: (A) Removable Grate; (B) Rust-Resistant Bolts; (C) Integral, One-Piece, Flashing Ring; (D) Cast Drain Body with Sump; (E) Sediment Bucket (optional).

In school gymnasium shower rooms, where the blocking of flat-top shower drains with paper towels can cause flooding, dome grates in the corners of the room or angle grates against the walls can be specified in addition to the regular shower drains. Shower-room gutters and curbs have become undesirable because of code requirements and the obvious dangers involved. Therefore, the passageways from shower areas into locker areas need extended-length drains to prevent runoff water from entering the locker areas.

Where grates are not secured and are subject to vehicular traffic, it is recommended that non-tilting and/or tractor-type grates be installed. When a grate starts to follow a wheel or is hit on one edge and starts to tilt, the skirt catches the side of the drain body and the grate slides back into its original position. Ramp-drain gratings should be slightly convex because rapidly flowing ramp water has a tendency to flow across the grate. A better solution to this problem is to place flat-top grates on a level surface at the bottom of the ramp, rather than on the ramp slope.

A technique in casting grates is the reversal of pattern draft, which removes the razor-sharp edges created when grates are buffed. See Figure 1-5. The prevalent buffing technique is called scuff-buff because it gives the grate a slightly used appearance. The use of slots in grates is becoming obsolete because of the slicing edges they create, which cause excess wear and tear on the wheels of hand-trucks and other vehicles. Square openings are more desirable because they shorten this edge and provide greater drainage capacity than round holes.

Flashing Ring

This component makes an effective seal, which prevents water from passing around the drain to the area below.

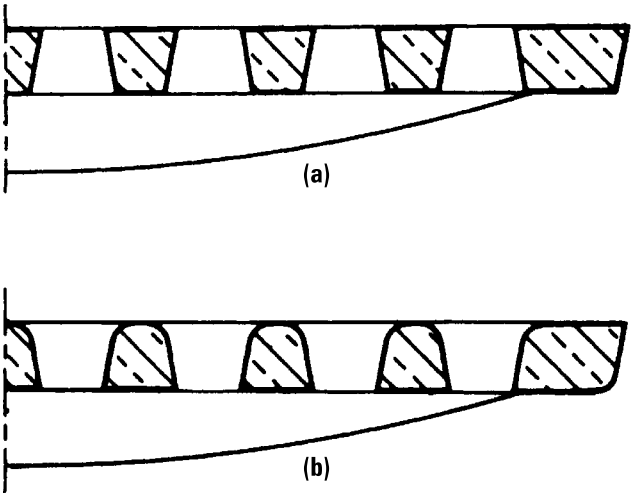


Figure 1-5 Pattern Draft for Floor Gratings: (a) Sharp Edge, (b) Reverse Pattern.

Sediment Bucket

A sediment bucket is an additional internal strainer designed to collect debris that gets by the regular strainer. It is required wherever the drain can receive solids, trash, or grit that could plug piping, such as the following locations:

1. Toilet rooms in commercial buildings should be equipped with floor drains with sediment buckets to facilitate cleaning.
2. Floor drains with sediment buckets must be provided in mechanical equipment rooms, where pumps, boilers, water chillers, heat exchangers, and HVAC equipment regularly discharge and/or must be periodically drained for maintenance and repairs. HVAC equipment requires the drainage of condensate from cooling coils using indirect drains.
3. Boilers require drains with sediment buckets. Strategically located floor drains are also required in buildings with wet fire-protection sprinkler systems to drain water in case sprinkler heads are activated. The maximum temperature of liquids discharged should be 140°F (60°C).

Floor drains shall connect to a trap so constructed that it can be readily cleaned and sized to serve efficiently the purpose for which it is intended. A deep-seal-type trap or an approved automatic priming device should be provided. The trap shall be accessible either from the floor-drain inlet or by a separate cleanout within the drain. Figure 1-6 illustrates several types of drains that meet these conditions.

Accessories

A variety of accessories are available to make the basic drain adaptable to various types of structures. The designer must know the construction of the building, particularly the floor and deck structures, to specify the appropriate drain.

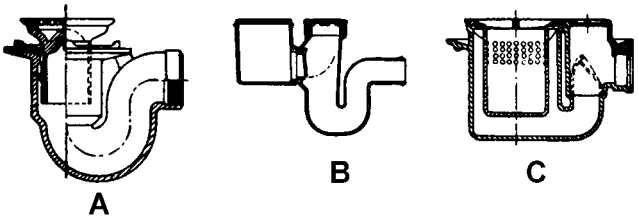


Figure 1-6 Types of Floor Drain: (A) Typical Drain with Integral Trap that May Be Cleaned Through Removable Strainer at Floor Level; (B) Floor Drain with Combination Cleanout and Backwater Valve, for Use Where Possibility of Backflow Exists; (C) Drain with Combined Cleanout, Backwater Valve, and Sediment Bucket.

Backwater Valves

A backwater valve can be installed on a building sewer/house drain when the drain is lower than the sewer line, when unusual sewer surcharges may occur due to combined storm water and sanitary sewer systems, or when old municipal sewers incur high rates of infiltration. A backwater valve reacts similarly to a check valve. The device consists of a mechanical flapper or disc, which requires a certain amount of maintenance; therefore, attention must be given during the placement of these devices to a free area and access for maintenance. Sediment can accumulate on the flapper valve seat, preventing the flapper from closing tightly. Also, many valves employ a spring or mechanical device to exert a positive pressure on the flapper device, which requires occasional lubrication. Most manufacturers of backwater valves provide an access cover plate for maintenance, which may also be used as a building sewer cleanout.

Figure 1-7 illustrates various types of backwater valves that may be installed where there is a possibility of backflow.

Oil Interceptors

In commercial establishments such as service stations, garages, auto repair shops, dry cleaners, laundries, industrial plants, and process industries having machine shops, metal-treating process rooms, chemical process or mixing rooms, etc., there is always the problem of flammable or volatile liquids entering the drainage system, which can contaminate the sewer line and cause a serious fire or explosive condition.

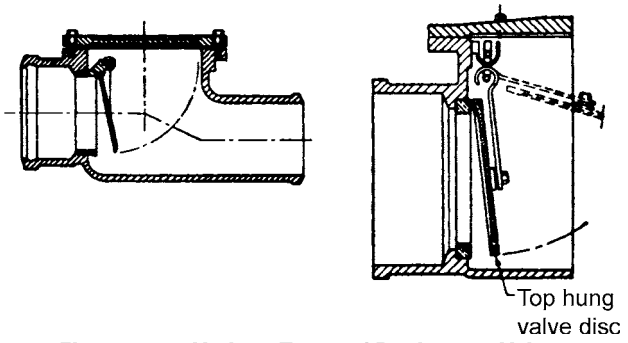


Figure 1-7 Various Types of Backwater Valve

Oil interceptors are designed to separate and collect oils and other light-density, volatile liquids, which would otherwise be discharged into the drainage system. An oil interceptor is required wherever lubricating oil, cutting oil, kerosene, gasoline, diesel fuel, aircraft fuel, naphtha, paraffin, trisodium phosphate, or other light-density and volatile liquids are present in or around the drainage system.

The interceptor is furnished with a sediment bucket, which collects debris, small parts, chips, particles, and other sediment that are frequently present in industrial waste from these types of facilities and could clog the drainage system. A gasketed, removable cover permits access for cleaning the interceptor. To eliminate pressure buildup inside the interceptor, a connection on each side of the body allows venting of the interceptor.

Oil interceptors are sized in accordance with the maximum anticipated gpm (L/s) flow rate of wastewater that could be discharged through a tailpiece and are typically protected from back-siphonage by the vacuum breaker mounted at the tailpiece entrance.

Fixture wastewater type. These devices are mounted on the trap of frequently used fixtures. A tapping at the overflow line will allow small amounts of wastewater to enter an adjacent, infrequently used drain as the trap surges during use.

Automatic trap primers can be obtained as pre-engineered devices, which have widely accepted approval. All direct connections between the sewer system and the potable water system must be protected from potential contamination. The above-referenced primers can be manufactured, or fitted with, devices that are approved to prevent cross-contamination.

Supports

The location of pipe supports is usually specified by code. They are located to maintain a slope that is as uniform as possible and will not change with time. In this regard, the rigidity of pipe and joints and the possibility of creep and bedding settlement are primary considerations. When building settlement may be significant, special hanging arrangements may be necessary. Underground piping should be continuously and firmly supported, but blocking below metal

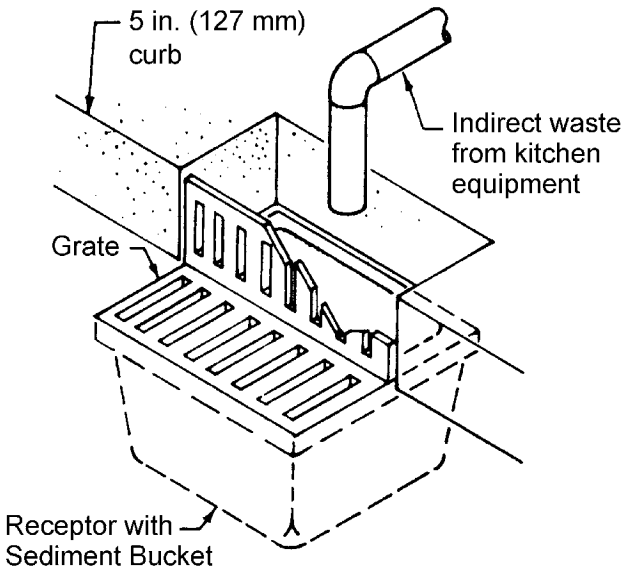


Figure 1-8 Combination Floor Drain and Indirect Waste Receptor

pipe is usually acceptable. Consult the manufacturer for recommendations for piping materials not covered in the code and for special problems.

Hangers should be designed adequately. To protect from damage by building occupants, allow at least a 250-lb (113.4-kg) safety factor when designing hangers. See *Data Book*, Volume 4, Chapter 6 for further information.

Seismic restraint must also be considered.

MATERIALS

Piping

Materials recommended for soil and waste piping, installed aboveground within buildings, are copper alloy, copper, cast iron (hub-and-spigot or hubless), galvanized steel, or PVC plastic pipe. Underground building drains should be cast-iron soil pipe, hard-temper copper tube, ABS or PVC, PVDF, DWV pattern Schedule 40 plastic pipe with compression joints or couplings, installed with a minimum cover of 12 in. (300 mm). Corrosive wastes require suitably acid-resistant materials such as high-silicon cast iron, borosilicate glass, polypropylene, etc. (*Note*: Some blood analyzers discharge sodium azide, which forms a very dangerous, explosive compound with copper pipes. Either other piping must be used or the sodium azide must be kept out of the system.) The materials used for pipe fittings must be compatible with the materials utilized for piping. Fittings should slope in the direction of flow and have smooth interior surfaces without ledges, shoulders, or reductions that may obstruct the flow in piping.

Drains specified with cast-iron or PVC bodies should be suitable for most installations. Where extra corrosion resistance is required, high-silica cast iron, polypropylene, borosilicate glass, stainless steel, galvanized iron, or other acid-resisting material should be selected. Where a sediment bucket is used, it should be bronze or galvanized or stainless steel. Enameled sediment buckets are impractical because they chip when cleaned.

In the selection of materials for top surfaces, such as grates, where floor drains are visible in finished areas, appearance is a prime consideration. As cast iron will rust and galvanizing and chrome plating will eventually be worn off by traffic, the preferred material is solid, cast nickel-bronze, which maintains its attractive appearance. In a swimming pool, however, chlorine necessitates the use of chlorine-resistant materials. For large grates that will be subject to hand-truck or forklift traffic, a ductile iron grate with or without a nickel-bronze veneer is recommended.

Polished brass or bronze for floor service has the disadvantage of discoloring unless there is constant traffic over it. Cast aluminum has also been found inadequate for certain floor-service applications due to excessive oxidation and its inability to withstand abrasion.

JOINING METHODS

Drain and cleanout outlets are manufactured in five basic types:

1. *Inside caulk.* In this arrangement, the pipe extends up into the drain body and oakum is packed around the pipe tightly against the inside of the outlet. Molten lead is then poured into this ring and later stamped or caulked to correct for lead shrinkage. Current installation methods use a flexible gasket for a caulking material. See Figure 1-9.

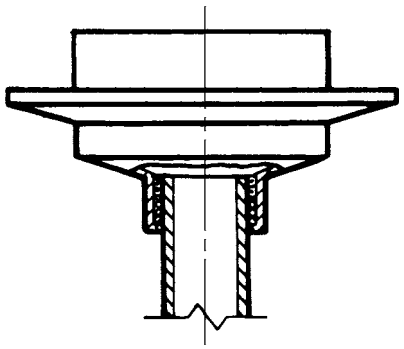


Figure 1-9 Inside-Caulk Drain Body

2. *Spigot outlet.* This type utilizes the caulking method as outlined above, except that the spigot outlet is caulked into the hub or bell of the downstream pipe or fitting. See Figure 1-10.

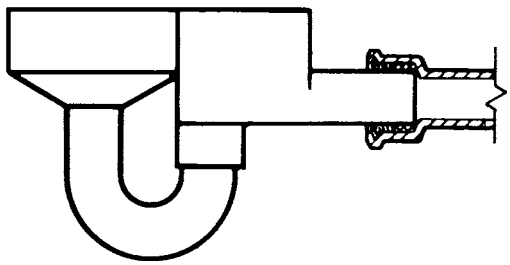


Figure 1-10 Spigot-Outlet Drain Body

3. *Push-seal gasketed outlet.* This type utilizes a neoprene gasket similar to standard ASTM C564 neoprene gaskets approved for hub-and-spigot, cast-iron soil pipe. A ribbed neoprene gasket is applied to the accepting pipe, thus allowing the drain outlet to be pushed onto the pipe.
4. *No-hub.* This type utilizes a spigot (with no bead on the end) that is stubbed into a neoprene coupling with a stainless-steel bolting band (or other type of clamping device), which, in turn, accepts a downstream piece of pipe or headless fitting. See Figure 1-11.
5. *IPS or threaded.* This type is a tapered female thread in the drain outlet designed to accept the

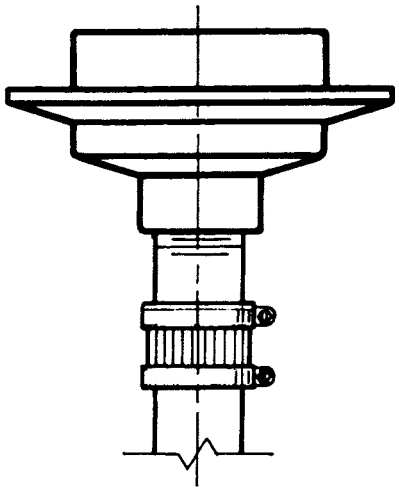


Figure 1-11 No-Hub-Outlet Drain Body

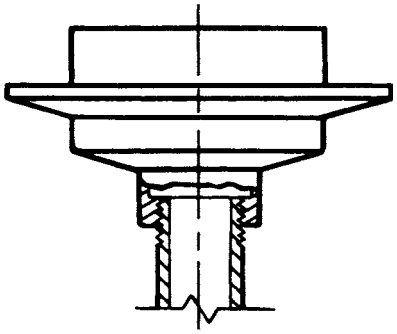


Figure 1-12 IPS or Threaded–Outlet Drain Body

tapered male thread of a downstream piece of pipe or fitting. See Figure 1-12.

Noise Transmission

Avoiding direct metal-to-metal connections may reduce noise transmission along pipes. Using heavier materials generally reduces noise transmission through pipe walls. Isolating piping with resilient materials, such as rugs, belts, plastic, or insulation may reduce noise transmission to the building. See Table 1-9 for relative noise-insulation absorption values.

BUILDING SEWER INSTALLATION

The installation of building sewers is very critical to the operation of the sewer. Inadequate bedding in poor soils may allow the sewer to settle, causing dips and low points in the sewer. The settlement of sewers interrupts flow, diminishes minimum cleansing velocity, reduces capacity, and creates a point where solids can drop out of suspension and collect.

The following are some guidelines for installing building sewers:

1. *Compacted fill.* Where natural soil or compacted fill exists, the trench must be excavated in alignment with the proposed pitch and grade of the sewer. Depressions need to be cut out along the trench line to accept the additional diameter at the piping joint or bell hub. A layer of sand or pea gravel is placed as a bed in the excavated trench because it is easily compacted under the pipe, allowing more accurate alignment of the pipe pitch. The pipe settles into the bed and is firmly supported over its entire length.
2. *Shallow fill.* Where shallow amounts of fill exist, the trench can be over-excavated to accept a bed of sand, crushed stone, or similar material that is easily compacted. Bedding should be installed in lifts (layers), with each lift compacted to ensure optimum compaction of the bedding. The bed must be compacted in alignment with the proposed pitch and grade of the sewer. It is recommended that pipe joints or bell hub depressions be hand-prepared due to the coarse crushed stone. The soil-bearing weight determines trench widths and bedding thickness.
3. *Deep fill.* Where deep amounts of fill exist, the engineer should consult a geotechnical engineer, who will perform soil borings to determine the depths at which soils with proper bearing capacities exist. Solutions include compacting existing fill by physical means or removing existing fill and replacing it with crushed stone structural fill.
4. *Backfilling.* Backfilling of the trench is just as critical as the compaction of the trench bed and the strength of existing soils. Improper backfill placement can dislodge pipe and cause uneven sewer settlement, with physical depressions in the surface. The type of backfill material and compaction requirements need to be reviewed to coordinate with the type of permanent surface. Landscaped areas are more forgiving of improper backfill placement than hard surface areas such as concrete or bituminous paving.

Care must be taken when using mechanical means to compact soils above piping. Mechanical compaction

Table 1-9 Relative Properties of Selected Plumbing Materials for Drainage Systems

Materials	Noise Absorption	Corrosion Resistance[a]
ABS	Fair	Good
Cast iron	Excellent	Good
Clay	[b]	Excellent
Concrete	[c]	Fair[d]
Copper	Fair	Good
Glass borosilicate	[b]	Excellent
Polypropylene	Fair	Excellent
PVC	Fair	Excellent
Silicon iron	[c]	Excellent
Steel, galvanized	Good	Fair

[a] This refers to domestic sewage. Consult manufacturer for resistance to particular chemicals.
[b] Since these materials are used only aboveground for chemical waste systems, this is not applicable.
[c] This material is usually allowed only belowground.
[d] Susceptible to corrosion from hydrogen sulfide gas.

of the first layer above the pipe by vibrating or tamping devices should be done with caution. Compacting the soil in 6-in. (150-mm) layers is recommended for a good backfill.

Proper sewer bedding and trench backfill will result in an installation that can be counted upon for long, trouble-free service.

SANITATION

All drains should be cleaned periodically, particularly those in markets, hospitals, food-processing areas, animal shelters, morgues, and other locations where sanitation is important.

Where sanitation is important, an acid-resisting enameled interior in floor drains is widely accepted. The rough surfaces of either brass or iron castings collect and hold germs, fungus-laden scum, and fine debris that usually accompany drain waste. There is no easy or satisfactory way to clean these rough surfaces. The most practical approach is to enamel them. The improved sanitation compensates for the added expense. However, pipe threads cannot be cut into enameled metals because the enameling will chip off in the area of the machining. Also, pipe threads themselves cannot be enameled; therefore, caulked joints should be specified on enameled drains. Most adjustable floor drains utilize threaded adjustments. The drains cannot be enameled because of this adjusting thread. However, there are other adjustable drains that use sliding lugs on a cast thread and may be enameled.

Another point to remember is that a grate or the top ledge of a drain can be enameled, but the enamel will not tolerate traffic abrasion without showing scratches and, eventually, chipping. The solution to this problem is a stainless-steel or nickel-bronze rim and grate over the enameled drain body, a common practice on indirect waste receptors, sometimes referred to as "floor sinks." Specifiers seem to favor the square, indirect waste receptor, but the round receptor is easier to clean and has better anti-splash characteristics. For cases where the choice of square or round is influenced by the floor pattern, round sinks with square tops are available.

In applications such as hospital morgues, cystoscopic rooms, autopsy laboratories, slaughterhouses, and animal dens, the enameled drain is fitted with a flushing rim. This is most advisable where blood or other objectionable materials might cling to the sidewalls of the drain.

Where the waste being drained can create a stoppage in the trap, a heel inlet on the trap with a flushing connection is recommended in addition to the flushing rim, which merely keeps the drain sides clean. (This option may not be allowed by certain codes.) A 2-in. (50-mm) trap flushes more effectively than a 3-in. (80-mm) trap because it allows the flushing stream to drill through the debris rather than completely flush it out. A valve in the water line to the drain is the best way to operate the flushing-rim drain. Flush valves have been used and save some water; however, they are not as convenient or effective as a shutoff valve. In any flushing water-supply line to a drain, a vacuum breaker installed according to code must be provided.

KITCHEN AREAS

When selecting kitchen drains, the designer must know the quantity of liquid and solid waste the drains will be required to accept, as well as which equipment emits waste on a regular basis and which produces waste only by accidental spillage.

Floor-cleaning procedures should be ascertained to determine the amount of water used. If any amount of solid waste is to be drained, receptors must be specified with removable sediment buckets made of galvanized or stainless steel. Also, there must be enough vertical clearance over these drains to conveniently remove the sediment buckets for cleaning.

Many kitchen planners mount kitchen equipment on a 5-in. (125-mm) curb. Placing the drain on top of the curb and under the equipment makes connection of indirect drain lines difficult and the receptor inaccessible for inspection and cleaning. Mounting the receptor in front of the curb takes up floor space, and the myriad of indirect drains that discharge into it create a potential hazard for employees who may trip over them. The solution requires close coordination between the engineer and the kitchen designer. Figure 1-8 shows an arrangement whereby any spillage in front of the curb can be drained by half of the receptor, while indirect drains are neatly tucked away.

Where equipment is on the floor level and an indirect waste receptor must be provided under the equipment, a shallow bucket that can easily be removed is recommended.

WATERPROOFING

Whenever a cast-iron drain is cemented into a slab, separation due to expansion and contraction occurs and creates several problems. One is the constant wet area in the crevice around the drain that promotes mildew odor and the breeding of bacteria. Seepage to the floor below is also a possibility. A seepage or flashing flange can correct this problem. Weep holes in the flashing flange direct moisture into the drain. Also, this flange accepts membrane material and, when used, the flashing ring should lock the membrane to the flange.

One prevalent misconception about the flashing flange is that it can have weep holes when used with cleanouts. In this case, there can be no weep holes

into the cleanout to which the moisture can run. Weep holes should also be eliminated from the flashing flanges of drains, such as reflection-pool drains, where an overflow standpipe to maintain a certain water level shuts off the drain entrance.

The term "non-puncturing," used in reference to membrane-flashing, ring-securing methods, is now obsolete, as securing bolts have been moved inboard on flashing L flanges and the membrane need not be punctured to get a seal. Of the various arrangements, this bolting method allows the greatest squeeze pressure on the membrane.

FLOOR LEVELING

A major problem in setting floor drains and cleanouts occurs when the concrete is poured level with the top of the unit, ignoring the fact that the addition of tile on the floor will cause the drain or cleanout to be lower than the surrounding surface. To solve the problem, cleanouts can be specified with tappings in the cover rim to jack the top part of the cleanout up to the finished floor level. Floor drains can be furnished with adjustable tops to attain an installation that is flush with the finished floor.

THERMAL EXPANSION

When excessive thermal expansion is anticipated, pipe movement should be controlled to avoid harmful changes in slope or damage. Anchoring, using expansion joints, or using expansion loops or bends may do this. When anchoring, avoid excessive stress on the structure and the pipe. Piping or mechanical engineering handbooks should be consulted if stress analysis is to be performed due to excessive stresses or to the differing expansion characteristics of materials.

PROTECTION FROM DAMAGE

Following are some common types of damage to anticipate and some methods of protection:

Hazard	Protection
Abrasion	Plastic or rubber sleeves. Insulation where copper pipe leaves slab.
Condensation	Insulation on piping.
Corrosion	See *Plumbing Engineering Design Handbook,* Vol. 1, Ch. 8: Corrosion.
Earth loads	Stronger pipe or pipe sleeves.
Expansion and contraction	Flexible joints, loops, swing joints, or offsets.
Fire	Building construction around pipe. Some jurisdictions require metal piping within 2 ft (0.6 m) of an entry into a firewall. Must maintain fire ratings.
Heat	Keeping thermoplastic pipe away from sources of heat or using insulation.
Nails	Using ferrous pipe, steel sleeves, steel plates, or space pipe away from possible nail penetration zone.
Seismic	Bracing pipe and providing flexible joints at the connection between piping braced to walls or structure and piping braced to the ceiling and between stories (where there will be differential movements).
Settlement	Sleeves or flexible joints. When embedded in concrete, covering with three layers of 15-lb (6.8-kg) felt.
Sunlight	Protecting thermoplastic pipe by insulation and jacket or shading to avoid warping.
Vandals	Installing pipe above reach or in areas protected by building construction. Piping needs to be supported well enough to withstand 250 lb (113.4 kg) hanging on the moving pipe.
Wood Shrinkage	Providing slip joints and shrinkage clearance for pipe when wood shrinks. Approximately ⅝ in. (16 mm)/floor is adequate for usual frame construction, based on 4% shrinkage perpendicular to wood grain. Shrinkage along the grain does not usually exceed 0.2%.

ALTERNATE SANITARY SYSTEMS

The design and installation of alternative engineered plumbing systems is permitted in all codes. A licensed professional engineer who is responsible for the proper operation of the system must design them. The most important consideration is that if an alternative system is contemplated, submission to, and approval by, the authorities having jurisdiction must be obtained. In order to expedite approval, the following is suggested:

1. Indicate on the design documents that the plumbing system, or parts thereof, is an alternative design.
2. Submit enough technical data to support the proposed alternative design and prove the system conforms to the intent of the code. This shall include suitability for the intended purpose, strength, equivalent level of performance compared to traditional installations, safety, and quality of materials.
3. The design documents shall include floor plans, riser diagrams, and an indication of the proposed flow.
4. Assurance that manufacturers' installation instructions will be adhered to.
5. If approval is given, the permit and all construction applications shall indicate an alternative engineered design is part of the approved installation.

The alternative systems are characterized by, but not limited to, using a single stack for both sanitary and vent or no vent at all. One exception is a con-

ventional drainage, reduced vent system. All of the following described systems have been successfully used in the United States and in other parts of the world for many years and have proven effective in actual use.

All of the alternative systems to be discussed have combined sanitary and vent. Because it is considered appropriate, they have been included in the sanitary drainage system chapter.

SOVENT SYSTEM

The Sovent system was developed in 1959 in Switzerland. It is a patented, single-stack, combination drainage and vent system that uses a single stack instead of a conventional two-pipe drainage and vent stack. The Sovent system uses copper pipe and is suitable only for multistory buildings because it will allow substantial economy in piping installation. Although installed in many countries throughout the world, it remains an alternative, unconventional system with only limited usage in the United States. It shall conform to ANSI B-16.45 and CISMA Standard 177. It is not the intent of this chapter to provide specific design criteria for a Sovent system, but rather to discuss the individual component characteristics that will enable a plumbing engineer to obtain a working knowledge of how the Sovent system works. A typical Sovent-Stack system is illustrated in Figure 1-13.

The entire Sovent system consists of three principal parts: copper DWV piping for all branch wastes and stacks, an aerator fitting at each floor level where the branch waste line connects to the stack, and a deaerator fitting at the base of a stack where a stack enters the house drain.

The starting point is the horizontal soil and waste branches. The fixture units and branch sizes are similar to those figures found in conventional systems.

The maximum fixture units that may be connected to a branch or stack are also similar to that of conventional systems. Branch sizes must be increased one size where the following exists:

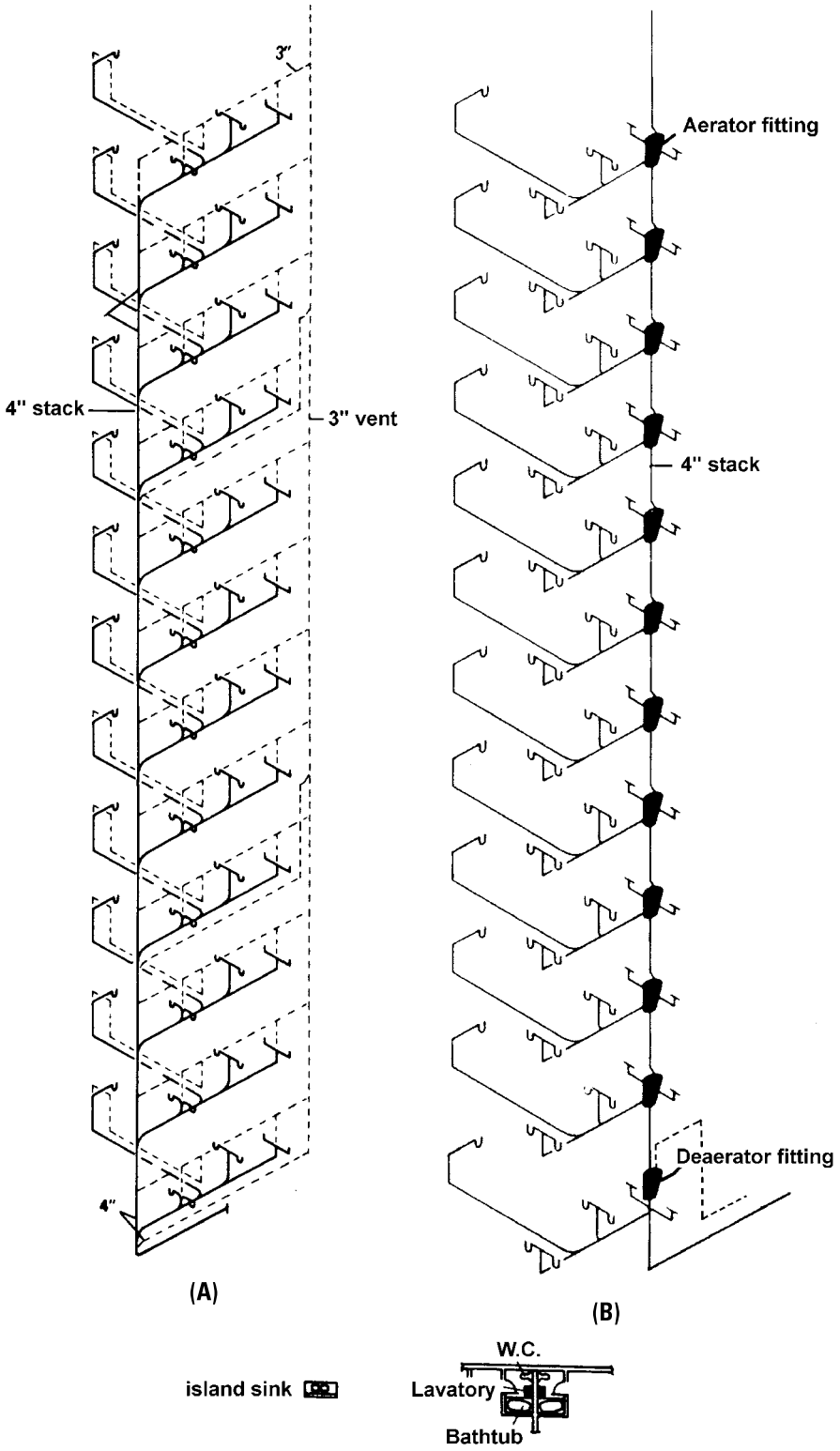


Figure 1-13 (A) Traditional Two-Pipe System, (B) Typical Sovent Single-Stack Plumbing System.

1. A second vertical drop or a vertical drop of more than 3 ft (0.9 m) requires an increase in the downstream side of the connection.
2. When three 90-degree changes in direction occur in a horizontal branch, the horizontal branch shall be increased in size at the upstream side of the third change.
3. When a branch serves two water closets and one or more additional fixtures, the soil line shall be increased to 4 in. (100 mm) at the point where one water closet and one additional fixture are connected.
4. When a soil branch exceeds 12 ft (3.7 m) in horizontal length.
5. When a waste line exceeds 15 ft (4.6 m) in horizontal length.

Stacks must be carried full size through the roof. Two stacks can be connected at the top above the highest fixture. Two stacks may also be combined at the bottom prior to entering the building drain. The size is based on the total fixture units. Fixtures may be connected into a horizontal offset in a stack below the deaerator fitting.

An aerator fitting is required at each level where a soil branch, a waste line the same size as the stack, or a waste branch one size smaller than the stack is connected. It consists of an upper stack inlet, a mixing chamber, and a baffle in the center of the fitting. This provides a chamber where the flow from the branches may gradually mix smoothly with the air and liquid already flowing in the stack. It also limits the turbulence and velocity of the entering water. A 2-in. (50-mm) horizontal branch may enter the stack with no fitting. There are two basic styles of aerator fitting that meets the needs of most design conditions: the double-side entry fitting and the single-entry fitting. Face entry and top entry are used in special cases.

A deaerator fitting is required at the bottom of a stack and is designed to overcome the tendency of the falling waste to build up excessive back pressure at the bottom of the stack when the flow is decelerated by the bend into the horizontal drain. It consists of an air separation chamber, a nose piece, a pressure relief outlet at the top connected to the building drain, and a stack outlet at the bottom. The purpose of the deaerator is to separate the air flow from the stack and ensure the smooth flow of liquid into the building drain and to relieve the positive pressure generated at the stack's base. The configuration of the fitting causes part of the air falling with the liquid to flow through the pressure relief line, and the remainder of the air goes directly into the building drain.

There is great importance in explaining the special requirements of the Sovent system to the installing contractor. It is probable the contractor is unfamiliar with this system and a complete explanation will be necessary. The engineer should make regular inspections of the project to assure the design conditions are met. A complete set of contract documents shall be provided to the owner to allow proper alteration or expansion of the project in the future.

For additional information and specific sizing contact the Copper Development Association.

SINGLE-STACK SYSTEM

The single-stack system is a combination drainage and vent system consisting of a single stack instead of conventional separate drainage and vent stacks. This drainage system is one where the drainage stack shall serve as both a single-stack drainage and vent system when properly sized. The relief of internal air pressure depends on making the one-pipe system larger than that required for drainage purposes alone. The drainage stack and branch piping shall be considered as vents for the drainage system as a whole. Although the pipe sizing is larger in a single-stack system than in a conventional one, installation savings are achieved by reducing the amount of vent piping required.

The major components of the one pipe system are oversize, unvented S traps instead of the conventionally sized and vented P traps and fixtures that allow water to run off after the tap is closed to fill the traps with water to maintain the trap seal. The trap arm length is limited to reduce any suction buildup, and the stack is oversized to limit the internal air pressure and vacuum buildup.

Often referred to as the "Philadelphia" code, this unconventional system has successfully operated for more than 100 years with no problems. Consideration has been made by code bodies to include this system as an engineered design, which allows this to be used providing an engineer has designed it in accordance with code. For further information, contact the Philadelphia building department. A riser diagram of a typical Philadelphia System is illustrated in Figure 1-13.

REDUCED-SIZE VENTING

In 1974, the National Bureau of Standards (NBS) conducted a laboratory study of one-story and split-level experimental drainage systems where the vents varied from one to six pipes smaller than those for conventional systems. They showed satisfactory hydraulic and pneumatic performance under various loading conditions. At the same time, the 10-story wet vent system at the Stevens Building Technology Research Laboratory had been modified by reducing the vents one to three pipe sizes in accordance with the plans and specifications of the NBS and reducing the size of the vents. The results also indicated that

the vents in a two-story housing unit can safely be made smaller than presently allowed without jeopardizing the trap seals.

This system may allow economies of pipe size in the venting design of low-rise residential buildings, although this particular system has not been accepted by authorities. It is limited to special conditions and requires the vent pipes be of a material such as copper or plastic that will resist the buildup of products of corrosion.

VACUUM DRAINAGE SYSTEM

Vacuum drainage operates on the principal of having the majority of the system under a continuous vacuum. The system is proprietary and is made by various manufacturers. The different manufacturers have different names for devices performing similar operations, so generic identification is used. There are various designs capable of sanitary and waste disposal, either separate or in combination, and are used for various projects such as prisons, supermarkets, and ships. There is no direct connection from the sanitary waste to the vacuum system. The one big advantage is that piping is installed overhead and no pipe is required to be placed underground.

The system consists of three basic components: a vacuum network of piping and other devices that collects and transports waste from its origin, vacuum generation pumps, and a vacuum interface device at the point of origin that isolates the vacuum piping from atmospheric pressure. When the system is to serve water closets, the water closets must be purpose made, designed to rinse and refill with ½ gallon (2.2 L) of water.

The piping network for a vacuum waste system is held under a constant vacuum between 12 and 18 in. of mercury (in Hg) (40–65 kPa) and is generally fabricated from PVC, copper, or other nonporous, smooth-bore material. Horizontal piping shall slope at a rate of 1/8 in. per foot (1.18 mm) toward the vacuum center. This piping slope is just as it is in conventional systems. If this slope cannot be maintained, the traps created in the piping runs when routed around obstacles would be cleared because of the differential pressure that exists between the vacuum center and the point of origin. The discharge of the piping system is into the waste storage tanks.

The vacuum generation system includes the vacuum pumps that create a vacuum in the piping and storage tanks that collect and discharge the waste into the sewer system. The vacuum pumps run only on demand and redundancy is provided. They also have sewage pumps that pump the drainage from the storage tank(s) into the sewer.

The vacuum interface is different for sanitary drainage than for clear waste similar to that of supermarkets. Water closet and gray water waste are separate. The vacuum toilets operate instantly upon flushing. When a vacuum toilet is cycled, a discharge control panel assembly is activated sending the discharge to the tank. A valve acts as an interface between the vacuum and the atmosphere controls gray water. It is designed to collect a given amount of the water and then activate, sending the drainage into the tank. The tank will discharge into the sewer when a predetermined level is reached.

When clear water is discharged from a project like a supermarket, the water from cases, etc. goes into an accumulator. When a controller senses sufficient waste is present, it opens the normally closed extraction valve, which separates the atmospheric pressure from the vacuum, and removes the waste from the accumulator.

Because the vacuum toilets use 0.5 gallon/flush as compared to 3.5 gallons/flush (1.9 L to 13 L) from a conventional system, the holding tanks could be smaller. There is also a flush control panel designed to provide all the control functions associated with vacuum toilets. The control panel consists of a flush valve, flush controller, water valve, and vacuum breaker. All controls are pneumatically operated. The flush controller controls the opening of the flush valve and the rinse valve as well as the duration of the time the flush valve is open.

REFERENCES

1. Daugherty, Robert L., Joseph B. Franzini, and E. John Finnemore. 1985. Fluid mechanics with engineering applications. 8th ed. New York: McGraw-Hill.
2. Dawson, F.M., and A.A. Kalinske. 1937. *Report on hydraulics and pneumatics of plumbing drainage systems.* State University of Iowa Studies in Engineering, Bulletin no. 10.
3. Wyly and Eaton. 1950. National Bureau of Standards, Housing and Home Finance Agency.

AMERICAN SOCIETY OF PLUMBING ENGINEERS

PHILADELPHIA CHAPTER

Proud of our support of the American Society of Plumbing Engineers, the ASPE Research Foundation and our Chapter efforts toward education within our industry.

Home of the ASPE National Convention in 2010

www.aspephila.org

Adjust AFTER The Pour

Finish Line™

Adjustable Drainage System

A one-of-a-kind drainage system that adjusts after the pour and forever eliminates:

Drains and cleanouts set too low or too high
Tilted drains and cleanouts
Duct taping and boxing out
Damaged strainers and covers

Hangers & Brackets

Preformed Copper

Arresters, Primers & Boxes

Drainage Products

Plumbing Specialties

BROCHURE ONLINE

Sioux Chief

The Eastern Michigan Chapter of the American Society of Plumbing Engineers is widely known as the Education Chapter.

Informative monthly meetings are held jointly with the Michigan Chapter of the American Society of Sanitary Engineering. Local manufacturers and their representatives sponsor monthly dinners.

The Eastern Michigan Chapter of ASPE is 100% supportive of the Code Study & Development Group of Southeastern Michigan, in which their members participate.

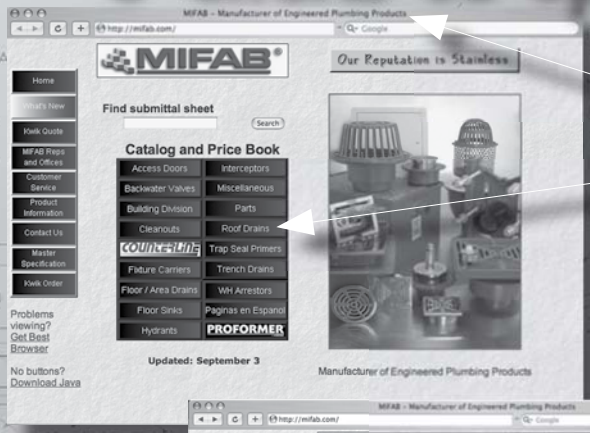
If you are a plumbing design professional, contractor, master or journey plumber, code official, or manufacturer's representative, and do not yet belong to the Society, please contact us for a membership application at www.aspe.org/Eastern_Michigan.

Administrative Office:

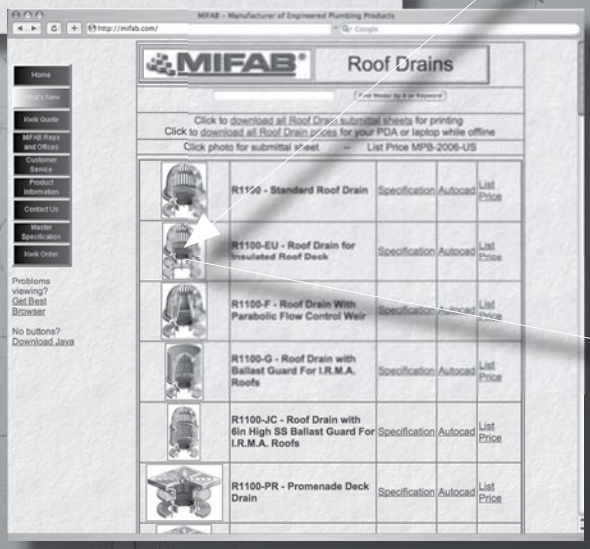
ASPE Eastern Michigan Chapter
14801 West Eight Mile Road
Detroit, Michigan 48235
Ph: (313) 341-7661
Fax: (313) 341-1007

MIFAB®

3 clicks to specification sheet!

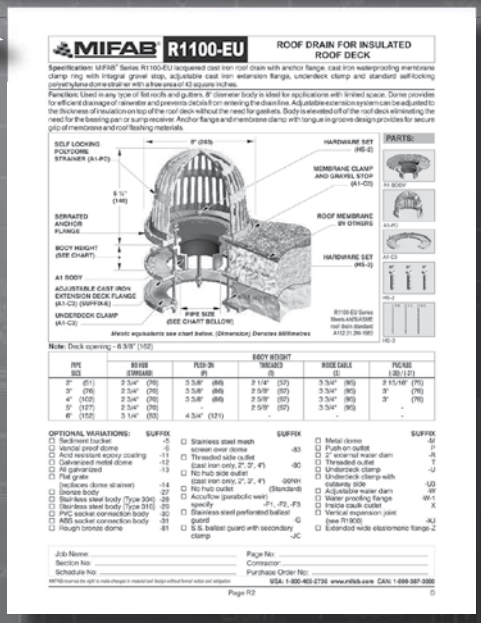


1. Go to www.mifab.com
2. Select product category
3. Click thumbnail for .pdf



Also download:

- Text specifications
- AUTOCAD drawings
- List Prices
- *NEW* Carrier installation videos!



www.mifab.com is where you will find all the latest information about the diverse MIFAB product line. From downloadable product guides to contact information for all MIFAB's offices and sales representatives, it's all here. Designed to streamline the specification process with many user friendly features, it is our mission to provide today's busy engineering office with the best possible resource for specifying our superior commercial drainage products.

Thank you for specifying MIFAB!

It has never been easier to specify MIFAB!

MIFAB is a proud supporter of The American Society of Plumbing Engineers.

MIFAB, Inc.
1321 West 119th Street
Chicago, IL 60643
Tel: (773) 341-3030 Fax: (773) 341-3047
Customer Service Fax: (773)-341-3049
Toll Free: 1-800-465-2736

2 Grey Water (Water Reuse) Systems

INTRODUCTION

One of the means of conserving water is to recycle it. Nonpotable water systems that use non-sanitary recycled water are commonly referred to as gray water systems. When approved, recovered, and filtered sanitary water is used, the system is called a black water system.

There is no single definition of gray water. The definitions of a variety of recycled waters are interchangeable. In general, the term *gray water* is intended to include appropriately treated water that has been recovered from typical fixtures such as lavatories, bathtubs, showers, and clothes washers. Waste potentially containing grease, such as that from kitchens and dishwashers, as well as waste from food disposals in kitchens is excluded due to the possibility of solid articles. Recycled water is intended to include clean water additionally treated to remove bacteria, heavy metals, and organic material. Black water, on the other hand, is water recovered from plumbing fixtures discharging human excrement, such as water closets and urinals, and cooling-tower water (because of the chemicals involved in its treatment). This chapter is limited to the discussion of gray water only.

Note: This chapter is written primarily to familiarize the reader with the general subject area. It is not intended for system design without reference and adherence to other technical data and local code requirements.

Gray water systems have been used in various areas of the world. In many regions, water is a critical resource and extreme measures to optimize the use of water are sometimes necessary. Water reuse offers considerable savings of water resources, which is appealing in localities where underground aquifers are in danger of depletion or where adequate supplies of water are not available. Wastewater management is also a significant reason for the use of gray water systems.

On-site reclamation and recycling of relatively clean, nonpotable water is considered for the following reasons:

1. in areas where the code mandates gray water be used where the availability of potable water is in short supply or restricted;
2. for projects where public liquid sewage disposal capacity is either limited or inadequate;
3. for economic reasons because obtaining potable water or disposing of liquid waste is very costly; and
4. for economic reasons where payback will occur in less than two years and where recycling will reduce sewer and water usage fees, resulting in substantial savings in operating costs.

Appropriately treated gray water is commonly used for the following proposes:

1. flushing water for water closets and urinals;
2. landscape irrigation;
3. cooling-tower makeup;
4. decorative pool and fountain fill water;
5. floor and general hard surface wash down; and
6. laundry prerinse water.

The most common purpose is to provide water for the flushing of urinals and water closets, especially in high-rises, hotels, and large dwellings.

CODES AND STANDARDS

There are no nationally or regionally established model codes that mandate the use of gray water. The Uniform Plumbing Code discusses gray water but limits the discussion to single-family dwellings. Many specific local areas have established standards and guidelines for the use of gray water in facilities and homes. Where gray water use is permitted, local health departments have established minimum treatment standards. In these localities, the engineer must

check for regulations applicable to gray water as is done for plumbing and building codes.

The National Sanitation Foundation's Standard 41, which regulates the minimum water quality for recycled wastewater, is shown in Table 2-1. The gray water quality must be verified against Table 2-1 and existing local regulations, if any, before use.

Table 2-1 The National Sanitation Foundation's Standard 41

Component	Maximum Limits
Biological oxygen demand	5 ppm (5 mg/L)
Suspended solids	5 ppm (5 mg/L)
Total coliform	2.2 counts/26.4 gal (2.2 counts/100 mL)
Nitrogen removal	85–95%

SYSTEM DESCRIPTION

Gray water systems collect diluted wastewater discharged from lavatories, service sinks, baths, laundry tubs, showers, and other similar types of fixtures. This water is then filtered and/or treated until it reaches a level of quality consistent with its intended reuse. The piping network distributes it to sources not used for human consumption in a safe and distinctive manner.

Figure 2-1 shows flow charts for a conventional plumbing system and a recycled water system. In the recycled water flow system, the gray water and black water sources are clearly defined. The use of the gray water system is also defined, namely, for all nonpotable water systems, cooling-tower water requirements, and the irrigation system.

Figure 2-2(A) shows single-line diagrams of a gray water plumbing system to bathtubs and lavatories and a recycled, gray water system with a gray water treatment plant from bathtubs, lavatories, and water closets. The reused water (gray water) from the fixtures is pumped for reuse in the water closets. This figure shows the isometric piping of a gray water system with the supply and drainage piping arrangement. The basic plumbing supply with hot water system feeds the lavatories and the bathtubs, which, in turn, act as a source for the gray water system. In

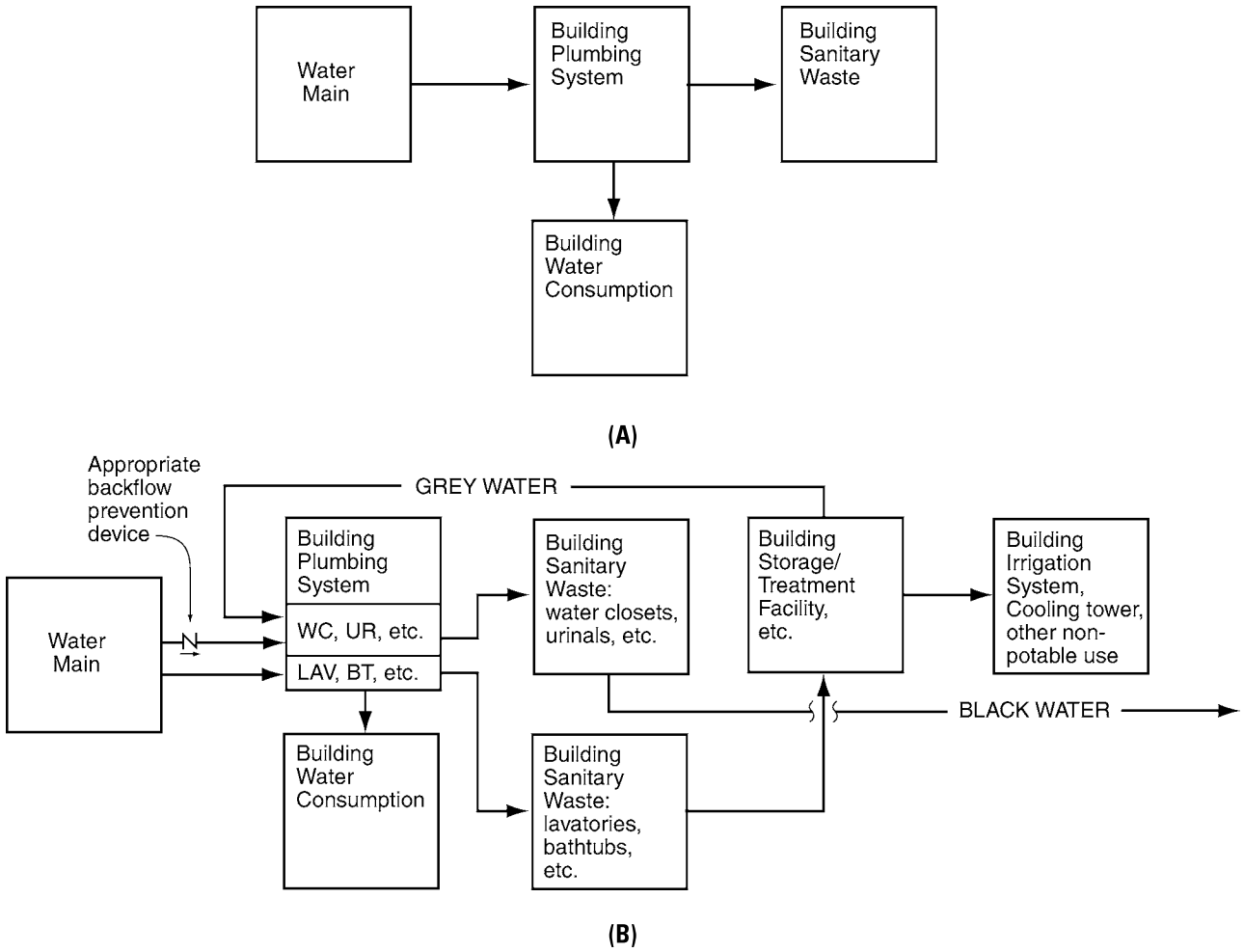
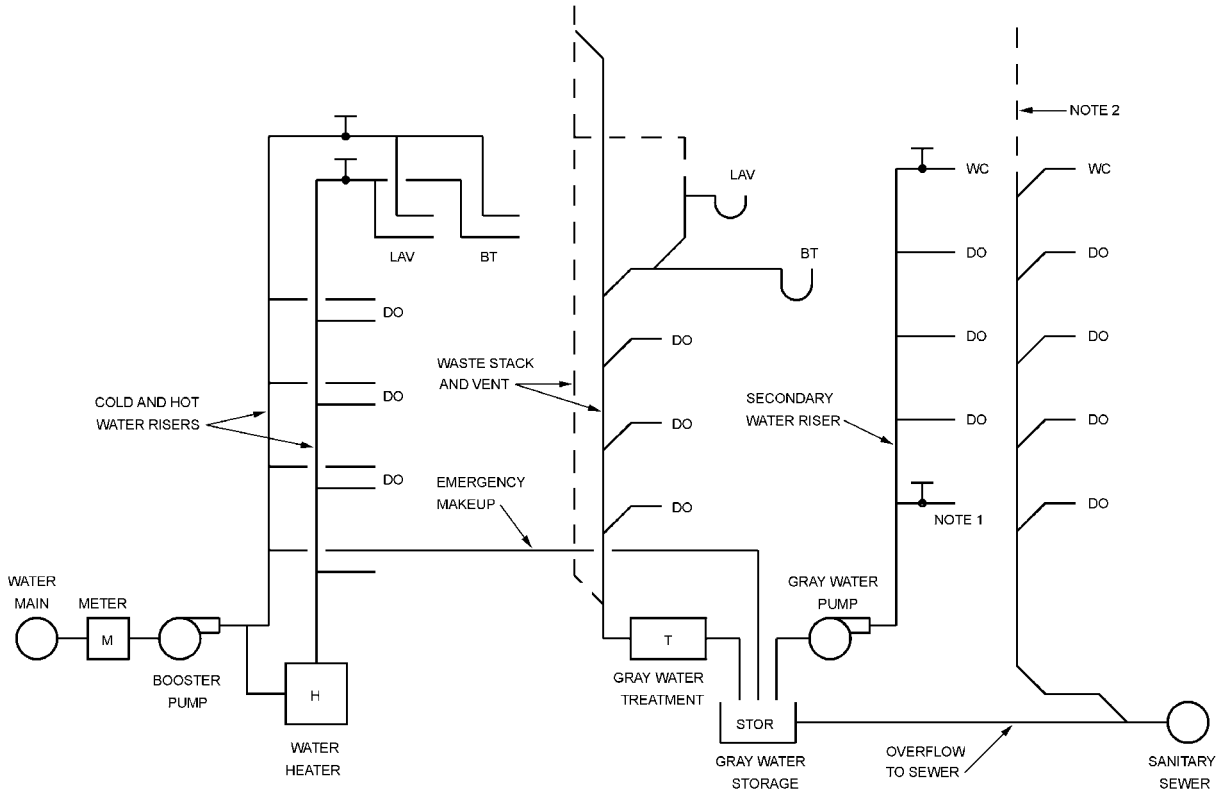
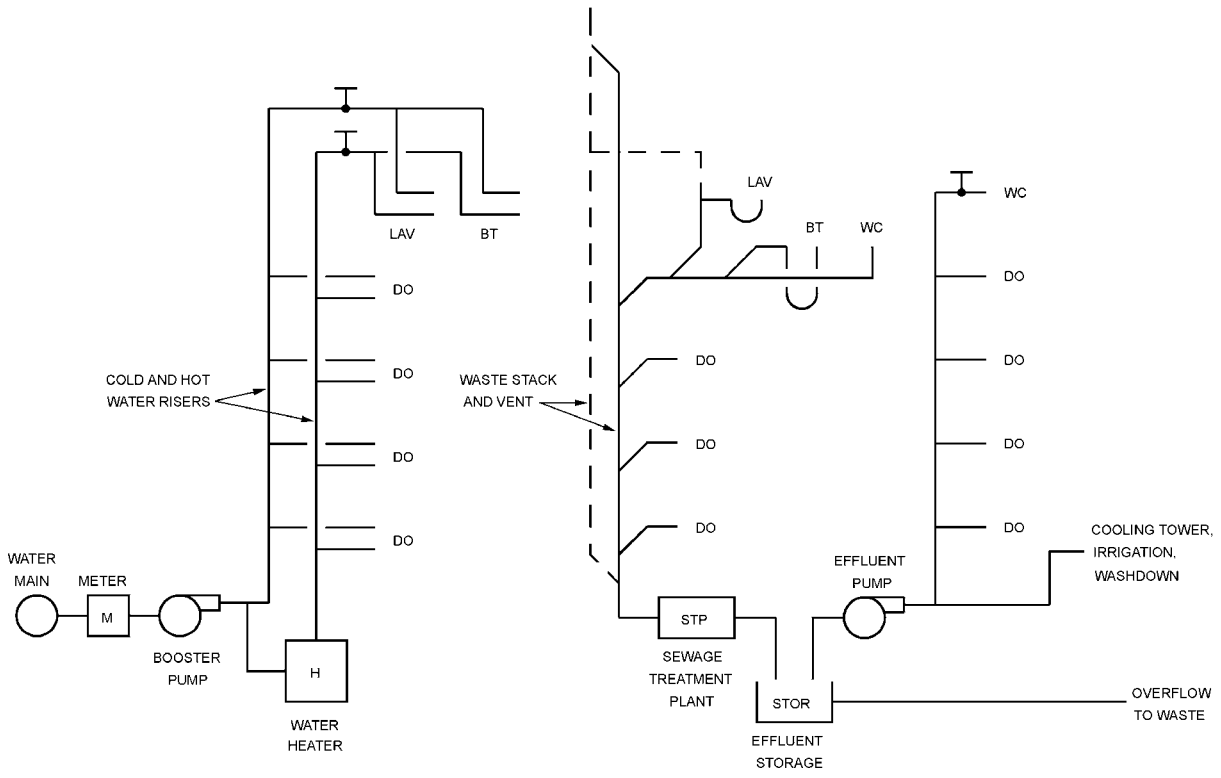


Figure 2-1 Plumbing System Flow Charts: (A) Conventional Plumbing System; (B) Recycled-Water System.



(A)



(B)

Figure 2-2 Riser Diagrams:
(A) Gray-Water Plumbing System; (B) Recycled-Water-Waste System with System Treatment Plant (STP).

*Notes, Figure 2-2(A):*1. Gray water can also be utilized for other uses, such as irrigation, cooling tower makeup, etc., provided treatment is adequate. 2. Common vent for both drainage stacks.

Figure 2-2(B), the effluent storage as well as the sewage treatment plant (STP) utilizes the gray water to route to the cooling tower, irrigation, and wash-down systems and the water closet fixtures.

A gray water system requires modifications to the standard plumbing systems throughout a facility. There will be duplicate drainage systems. Instead of all liquid discharged from all plumbing fixtures going to the sanitary sewer, selected fixtures will have their effluent routed for recovery by the gray water treatment system. The remainder will go to the sanitary sewer. There also will be duplicate water supplies. Potable water will go to lavatories, sinks, showers, etc., and gray water will go to water closets, urinals, and other fixtures, depending on the quality of the gray water treatment.

Special care must be taken during the installation of a gray water system. Clear identification and labeling of the gray water system is mandatory. This will minimize the risk of cross-connection during installation or repair of the system.

Many newly formed, planned communities have adopted gray water systems for their irrigation systems. Warning "nonpotable water" signs or colored PVC piping is now visible across city landscapes. Blue dye has become a clear identification of the use of gray water.

System Components

The following components are generally used for most systems. Their arrangement and type depend on the specific treatment system selected.

1. A separate gray water collection piping system.
2. A primary waste treatment system consisting of turbidity removal, storage, biological treatment, and filtering.
3. Disinfecting systems consisting of ozone, ultraviolet irradiation, chlorine, or iodine.
4. Treated water storage and system distribution pressure pumps and piping.

DESIGN CRITERIA FOR GRAY WATER SUPPLY AND CONSUMPTION

It is estimated that 2/3 of the wastewater discharged from a typical household in one day is gray water. The remaining wastewater (that is, 1/3 of the discharge) is black water from water closets. The discharge from the separate piping systems supplying the gray water system should be sized based on the applicable plumbing code.

The following issues should be considered in the design of any gray water system:

1. The design flow is based on the number of people in a facility.
2. Lavatory use is estimated at 0.25 gal/use (0.95 L/use).
3. Men use urinals 75% of the time and water closets 25% of the time.
4. The average person uses a toilet three times a day.

Design Estimates for Commercial Buildings

Gray water supply

Estimates of gray water supply sources vary in commercial buildings. In an office building, fixtures such as lavatories, water coolers, mop sinks, and coffee sinks are estimated to generate 1 gal/day/person (3.79 L/day/person). For an office building with 500 employees, we would expect to be able to recover 500 gal/day (1,893 L/day) for gray water reuse. Based on five working days/week and 50 weeks/year annual use, 125,000 gal/yr (473,177 L/yr) could be available for gray water reuse.

Gray water demand

The gray water demand for an office building is estimated based on three toilet or urinal uses/day/person. For calculation purposes, assume the population is 50% male and 50% female and that men use urinals 75% of the time and water closets 25% of the time. For an office building with 500 employees, we would estimate the gray water demand as follows:

250 males × 3 flushes/day × 0.5 gal/flush (urinals) × 75% usage = 281 gal/day

250 males × 3 flushes/day × 1.6 gal/flush (water closets) × 25% usage = 300 gal/day

250 women × 3 flushes/day × 1.6 gal/flush (water closets) = 1,200 gal/day

TOTAL gray water demand = 1,781 gal/day = approx. 445,250 gal/yr

[250 males × 3 flushes/day × 1.89 L/flush (urinals) × 75% usage = 1,063 L/day

250 males × 3 flushes/day × 6.06 L/flush (water closets) × 25% usage = 1,136 L/day

250 women × 3 flushes/day × 6.06 L/flush (water closets) = 4,545 L/day

TOTAL gray water demand = 6,744 L/day = approx. 1,686,000 L/yr]

This example shows that approximately 3.6 gal/person/day (13.5 L/person/day) are needed to supply gray water to toilets and urinals for a 500-employee office. This demand could be supplied in part by the 1 gal/person/day available from the fixtures identified in the gray water supply section above.

In shopping centers, flow rates are based on square feet (m^2) of space, not the number of persons. The

flow demand is gallons per day per square foot (0.06 gpd/ft² [0.23 L/day/0.1 m²]).

The calculations in food service resemble those for grease interceptor sizing. The number of seats, the hours of operation, single-serving utensils, and other, similar factors change the equations for gray water calculations.

Design Estimates for Residential Buildings

(a) The number of occupants of each dwelling unit shall be calculated as follows:

Occupants, first bedroom: 2

Occupants, each additional bedroom: 1

(b) The estimated gray water flows for each occupant shall be calculated as follows:

Showers, bathtubs, and wash basins: 25 gpd (95 L/day)/occupant

Laundry: 15 gpd (57 L/day)/occupant

(c) The total number of occupants shall be multiplied by the applicable estimated gray water discharge as provided above and the type of fixtures connected to the gray water system.

Example 2-1 Single-family dwelling, three bedrooms with showers, bathtubs, wash basins, and laundry facilities all connected to the gray water system:

$$\text{Total number of occupants} = 2 + 1 + 1 = 4$$

$$\text{Estimated gray water flow} = 4 \times (25 + 15) = 160 \text{ gpd}$$

$$[4 \times (95 + 57) = 608 \text{ L/day}]$$

Example 2-2 Single-family dwelling, 4 bedrooms with only the clothes washer connected to the gray water system:

$$\text{Total number of occupants} = 2 + 1 + 1 + 1 = 5$$

$$\text{Estimated gray water flow} = 5 \times 15 = 75 \text{ gpd}$$

$$(5 \times 57 = 285 \text{ L/day})$$

Design Estimates for Irrigation Systems

Gray water system design and selection depend on a variety of elements: location, soil type, the water supply source, the type of treatment facility, and the application of reuse. Additional requirements are noted for the reuse of gray water systems for irrigation systems. Some of the parameters are groundwater level, geological stability of the region, plot plan, distance of irrigation from adjacent properties, lakes, lot lines, drainage channels, water supply lines, surface slope, wells, and interaction of gray water systems with private sewage disposals. Inspection and testing are an inherent part of the design.

System components must be securely installed, and the manufacturer must be properly identified. The holding tanks must be installed in dry levels, and, if underground, contamination issues must be accounted for. The authorities having jurisdiction shall review all plans, and qualified and experienced contractors shall install the system in accordance with the contract documents. To design a gray water system, one must estimate the water supply source. Separate design parameters become important for reuse in buildings or in irrigation systems. For irrigation systems, the required area of subsurface must be designed based on soil analysis. The following paragraph clearly defines the design issues for irrigation facilities:

Each valved zone shall have a minimum effective irrigation area in square feet (m^2) as determined by Table 2-2 for the type of soil found in the excavation. Table 2-2 gives the design criteria for the use of gray water systems in various soil types (coarse sand or gravel, fine sand, sandy loam, sandy clay, mixed clay). As the soil weight decreases and the soil becomes less porous, the minimum square feet (m^2) needed for leaching increases. Coarse sand or gravel needs a 20-ft² irrigation area per 100 gal (1.86 m² per 379 L) of estimated gray water discharge per day. Clay with a small amount of sand or gravel requires 120 ft² per 100 gal (11.15 m² per 379 L) of estimated gray water

Table 2-2 Design Criteria of Six Typical Soils

Type of Soil	Minimum Irrigation Area (ft^2/100 gal of estimated gray water discharge/day)	Minimum Absorption Capacity (in.of irrigation area/day)
Coarse sand or gravel	20	5.0
Fine sand	25	4.0
Sandy loam	40	2.5
Sandy clay	60	1.7
Clay with considerable sand or gravel	90	1.1
Clay with small amount of sand or gravel	120	0.8

Source: Uniform Plumbing Code, Appendix G, IAPMO, 2000

Table 2-2(M) Design Criteria of Six Typical Soils

Type of Soil	Minimum Irrigation Area (m^2/L of estimated gray water discharge/day)	Minimum Absorption Capacity (min/m^2 of irrigation area/day)
Coarse sand or gravel	0.005	5.0
Fine sand	0.006	4.0
Sandy loam	0.010	2.5
Sandy clay	0.015	1.7
Clay with considerable sand or gravel	0.022	1.1
Clay with small amount of sand or gravel	0.030	0.8

Source: Uniform Plumbing Code, Appendix G, IAPMO, 2000

per day. The area of the irrigation/disposal field shall be equal to the aggregate length of the perforated pipe sections within the valved zone times the width of the proposed irrigation/disposal field. Each proposed gray water system shall include at least three valved zones, and each zone shall be in compliance with the provisions of the section. No excavation for an irrigation/disposal field shall extend within 5 vertical ft (1.5 m) of the highest known seasonal groundwater, nor shall it extend to a depth where gray water may contaminate the groundwater or ocean water. The applicant shall supply evidence of groundwater depth to the satisfaction of the administrative authority.

Table 2-3 Location of the Gray Water System

Element	Minimum Horizontal Distance From	
	Holding Tank, ft (mm)	Irrigation Disposal Field, ft (mm)
Buildings or structures	5.2 (1,524)	2.3 (610)
Property line adjoining private property	5 (1,524)	5 (1,524)
Water supply wells	50 (15,240)	100 (30,480)
Streams and lakes	50 (15,240)	50.5 (15,240)
Seepage pits or cesspools	5 (1,524)	5 (1,524)
Disposal field and 100% expansion area	5 (1,524)	4.6 (1,219)
Septic tank	0 (0)	5 (1,524)
On-site domestic water service line	5 (1,524)	5 (1,524)
Pressurized public water main	10 (3,048)	10.7 (3,048)

Table 2-4 Subsurface Drip Design Criteria of Six Typical Soils

Type of Soil	Minimum Emitter Discharge, gal/day (L/day)	Minimum Number of Emitters per gal/day (L/day) of Gray Water Production
Sand	1.8 (6.8)	0.6
Sandy loam	1.4 (5.3)	0.7
Loam	1.2 (4.5)	0.9
Clay loam	0.9 (3.4)	1.1
Silty clay	0.6 (2.3)	1.6
Clay	0.5 (1.9)	2.0

Table 2-3 identifies the location and separation distances from a variety of structures and environments. For example, any building or structure shall be a minimum of 5 ft (1.5 m) from a gray water surge tank. The minimum distance from any property lines to a gray water surge tank is 5 ft (1.5 m). Critical areas such as streams, lakes, seepage pits, or cesspools shall be a minimum of 50 ft (15.2 m) from surge tanks and 100 ft (30.5 m) from irrigation fields. Similarly, the distance from the public water main to a surge tank shall be a minimum of 10 ft (3.1 m). The table also identifies additional restrictions.

See Table 2-4 for the design of the gray water distribution in subsurface drip systems for various types of soil. This table gives the minimum discharge, in gallons/day, for effective irrigation distribution. Emitters are defined as orifices with a minimum flow path of 120 microns (μ) and shall have a tolerance of manufacturing variation equal to no more than 7%.

TREATMENT SYSTEMS

Treatment systems vary widely. The treatment system conditions the recovered water to a degree consistent with both the intended use of the conditioned water and the design requirements of the design engineer, the applicable code, or the responsible code official—whichever is the most stringent. Typical wastewater (gray water and black water) treatments used for various types of projects are depicted in Figure 2-3. The size of the treatment systems available vary from those installed for individual private dwellings to those serving multiple facilities. As the treatment facility becomes more complex, the number of treatment activities increases, and the quality of the water improves. Some of the treatment activities are basic screening, flow equalization, biological treatment, filtration, coagulation, sedimentation, disinfections, reclaimed water tank, membrane filtration, and activated carbon filtration.

The selection of a treatment system also depends on the quality and type of the influent water. To decide which is the most appropriate treatment, the kinds of fixture discharge to be used for reclaiming and the treatment requirements of the authorities must be determined.

Table 2-5 Gray Water Treatment Processes for Normal Process Efficiency

Process	Suspended Solids	Biological Oxygen Demand	Chemical Oxygen Demand	Phosphates, P0-4	Nitrogen	Total Dissolved Solids
Filtration	80	40	35	0	0	0
Coagulation/filtration	90	50	40	85	0	15
Chlorination	0	20[a]	20[a]	0	0	0
Tertiary treatment	95	95	910	15–60	50–70	80
Absorption (carbon filtration)	0	60–80	70	0	10	5

[a] Nominal, additional removals possible with super chlorination and extended contact time.

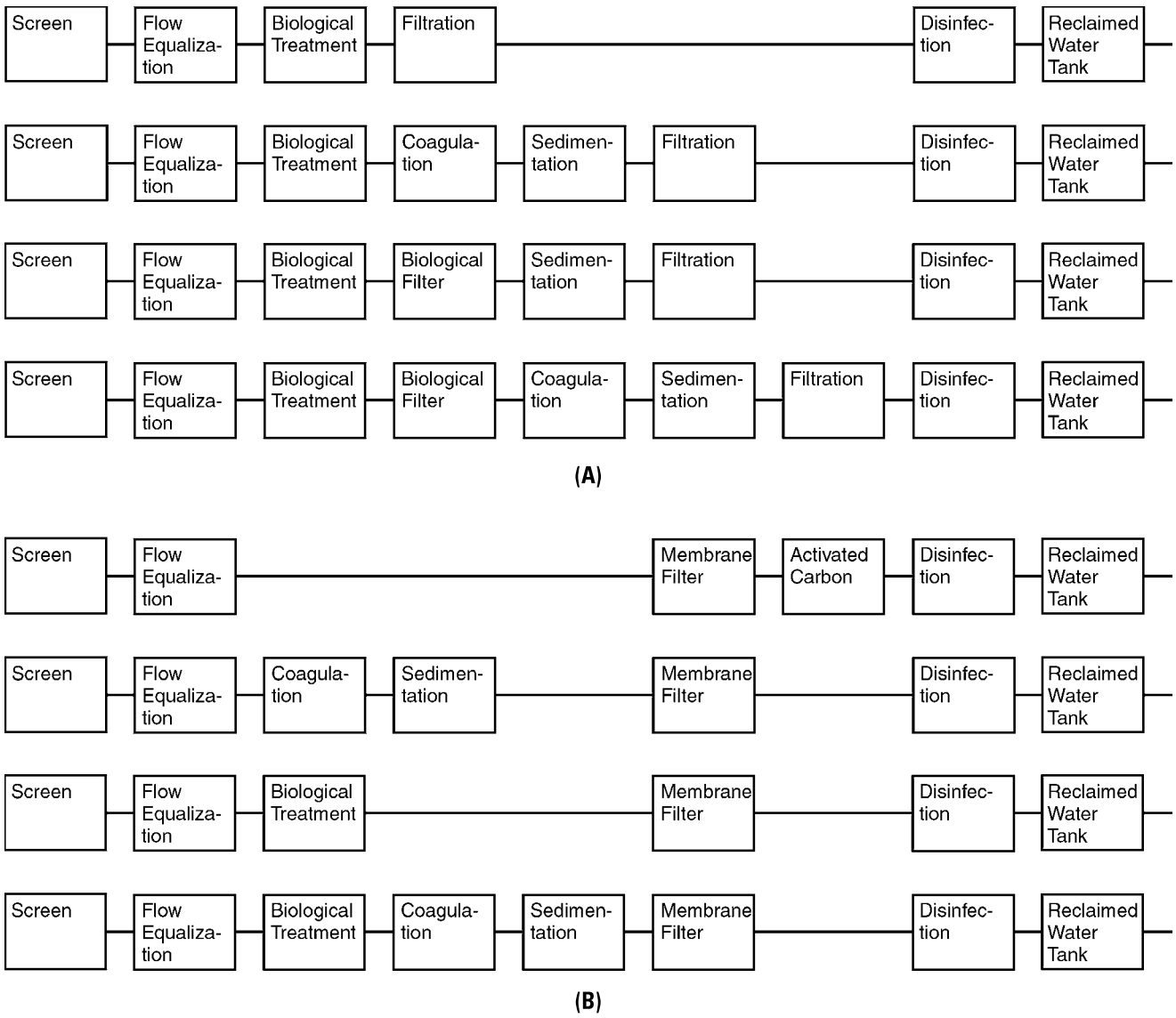


Figure 2-3 Water Treatment Systems: (A) Types of Gray-Water Treatment System; (B) Types of Black-Water Treatment System

Table 2-5 describes the types of filtration and water treatment processes most commonly used in the gray water treatment process. Depending on the type of filtration, the degree and types of components filtered vary. Basic filtration concentrates on reducing suspended solids and does not absorb nitrogen or phosphates. Coagulation assists in building up the solid filtration and adds phosphates to the list.

Table 2-6 Comparison of Gray Water System Applications

System	Piping	Treatment	Potential Gray Water Uses	Water Savings[a]	Savings[a]
Conventional	Base	None	N/A	0	0
Type A (minimal treatment)	Separate gray-water riser/separate WC stack	Filtration, chlorination, color	Water closets	20,000 gal/day (75,708 L/day) 17% (inc. irrigation), 22% (without irrigation)	20,000 gal/day (75,708 L/day) 26%
Type A (enhanced treatment)	Separate gray-water riser/separate WC stack	Chemical filtration, chlorination, color	Water closets cooling towers, irrigation (pos.)	35,000 gal/day, (132,489 L/day) 30% (incl. irrigation), 38% (without irrigation)	35,000 gal/day, (132,489 L/day) 46%
Type B	Separate gray-water riser	Tertiary sewage treatment	All nonpotable uses	61,000 gal/day, (230,909 L/day) 52% (incl. irrigation)	

[a] Values for savings noted are based on the 250-room resort hotel example. Percentages are based on normal usage of 117,850 gal/day, including irrigation, and 91,150 gal/day, without irrigation.

Chlorination is significant only in oxygen demand issues. Tertiary treatment includes filtration of all categories. Absorption, or carbon filtration, concentrates primarily on biological and chemical oxygen demands.

Table 2-6 shows the design elements of gray water system treatments. In the type A treatment, separate gray water riser piping and water closet piping is required. This type of treatment consists of filtration, chlorination, and color modifications. The system re-feeds the water closets. The enhanced version of the type A treatment adds color as well as chemical treatments. If the water source contains high percentages of soaps or foaming agents, the addition of defoaming agents is highly recommended. Increased conditioning of the water increases the use of the water for other applications, such as cooling towers. Type B treatments give the complete tertiary treatment of the water and permit the use of water for a wide variety of reuse applications. The biological and chemical oxygen treatments are mandatory for the high concentrations of fecal matter. The addition of chemical treatment, filtration, and/or carbon absorption conditions the water for a wide variety of applications. Treatment quality also must take into account the chemical compound of the water required for use in piping, cooling towers, industrial applications, and plant life to prevent scaling of pipes and fouling of valves or equipment.

ECONOMIC ANALYSIS—AN EXAMPLE

Table 2-7 gives the life-cycle economic comparison of a gray water system for a 250-room resort hotel. The cost of the conventional system is based on water and sewer annual consumption. The minimum gray water system, Type A treatment facility, has an initial fixed estimated cost of $87,500. This cost amortized over 15 years with 12% interest results in an annual cost for payment of the initial capital cost. This annual cost, plus the water and sewer cost, plus the treatment equipment maintenance cost is near the annual cost for the hotel management. With maximum gray water treatment, Type B, the total annual cost does not decrease very much. In fact, statistically they are nearly the same. Given this data, the only reasons to provide gray water in facilities are governmental or institutional incentives. In addition, the cost of sewage and the cost of water consumption may become the decisive factors. Any increase in the cost of sewage or water, caused perhaps by a drought in a region, can alter the life-cycle economics.

Table 2-7 Life-cycle Economic Comparison: Gray Water Systems for 250-room Hotel

	Installed System		
	Conventional System	Type A (Minimal Grey Water)	Type B (Grey Water)
Fixed Cost	0.000	$87,500	$259,000
Life	20 yr	15 yr	15 yr
	(Base system)		
Cost of money	12%	12%	12%
Capital recovery factor	N/A	0.14682	0.14682
Amortized first cost	0	$12,846	$38,026
Utility costs	0	0	0
Water ($1.40/1,000 gal [3,785 L]	$59,395	$49,315	$28,299
Sewage ($0.50/1,000 gal [3,785 L]	$13,706	$10,106	0
Operational cost	0	0	0
Treatment equipment	0	$1,240	$6,305
Total Annual	**$73,101**	**$73,507**	**$72,630**

Cost

The complete water flow chart of the 250-room hotel is shown in Figure 2-4. As depicted in Table 2-6, the water flow rate savings are clearly defined.

Before one considers using a gray water system, it is desirable to be able to evaluate quickly, on a preliminary basis, the potential economic feasibility of the proposed scheme. To facilitate this, a nomograph such as that shown in Figure 2-5 can be used. This analysis shows the variation in interest rates, variation in cost of combined water and sewage, the daily water use, and cost of total systems based on two types of treatments, A and B. Movement through the chart from an interest rate (based on the current economy) to the combined cost of sewage and water (based on municipalities) to the water consumption (based on building occupancy) and to the type of treatment facility (based on the purity required) can provide an approximate cost for a gray water system.

To use the nomograph, proceed as follows:

1. Enter the lower right portion of the nomograph with the anticipated total potable water consumption for all users (based on a conventional system).
2. Move vertically up to the combined utility cost for water purchase and sanitary sewage charges (e.g., $1.25/1,000 gal [3,785 L] for water and $0.75/1,000 gal [3,785 L] for sewage).
3. Move horizontally to the left to form baseline X.
4. Enter the upper right portion of the nomograph with the estimated additional cost of the gray water system (additional piping, storage, and treatment equipment).
5. Move vertically down to the annual interest rate (cost of money) used in the analysis.
6. Move horizontally to the left to form baseline Y.

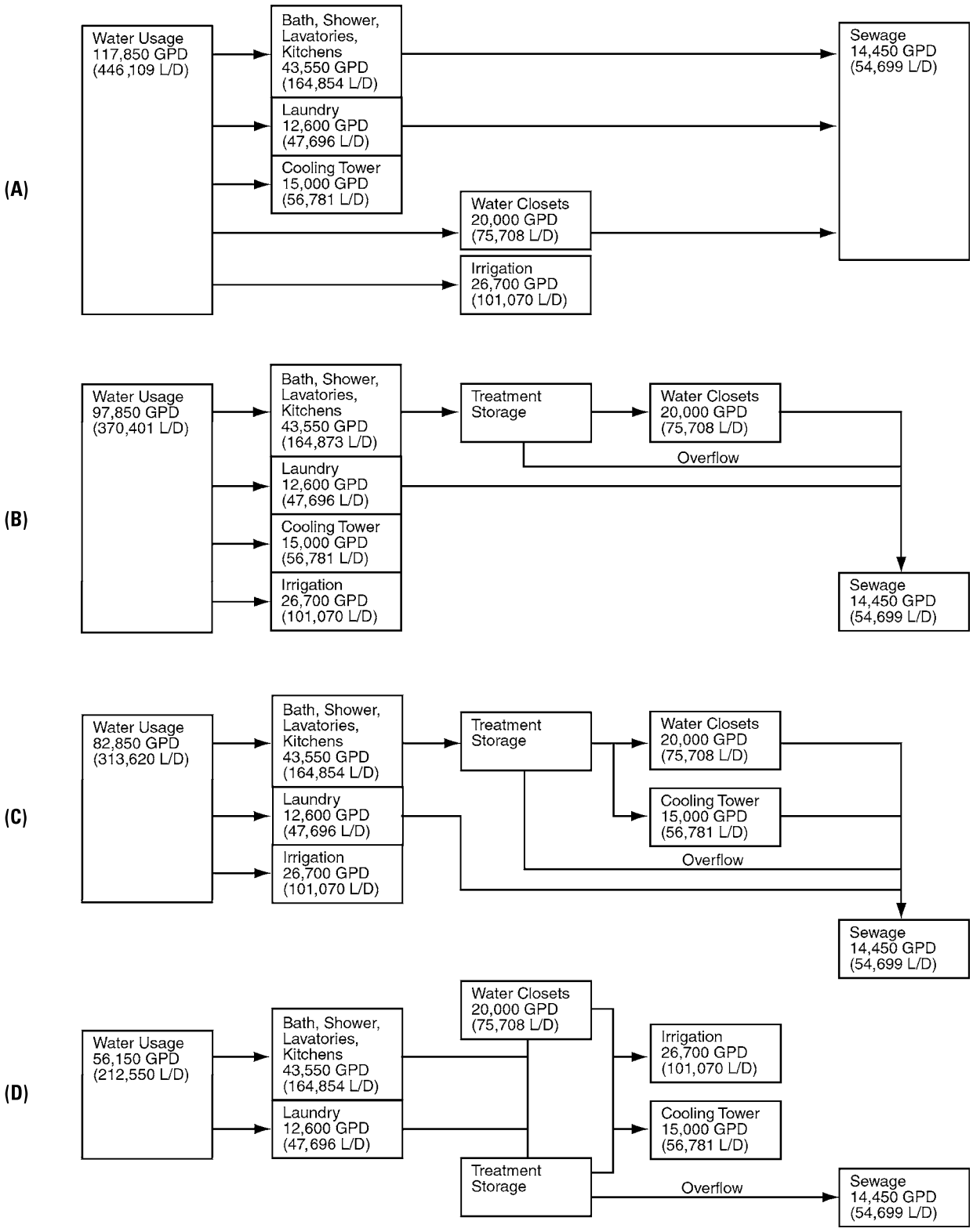


Figure 2-4 System Design Flow Chart Example (250-Room Hotel): (A) Conventional Plumbing System; (B) Recycling for Water Closets; (C) Recycling for Water Closets and Cooling Tower; (D) Recycling for Water Closets, Cooling Tower, and Irrigation

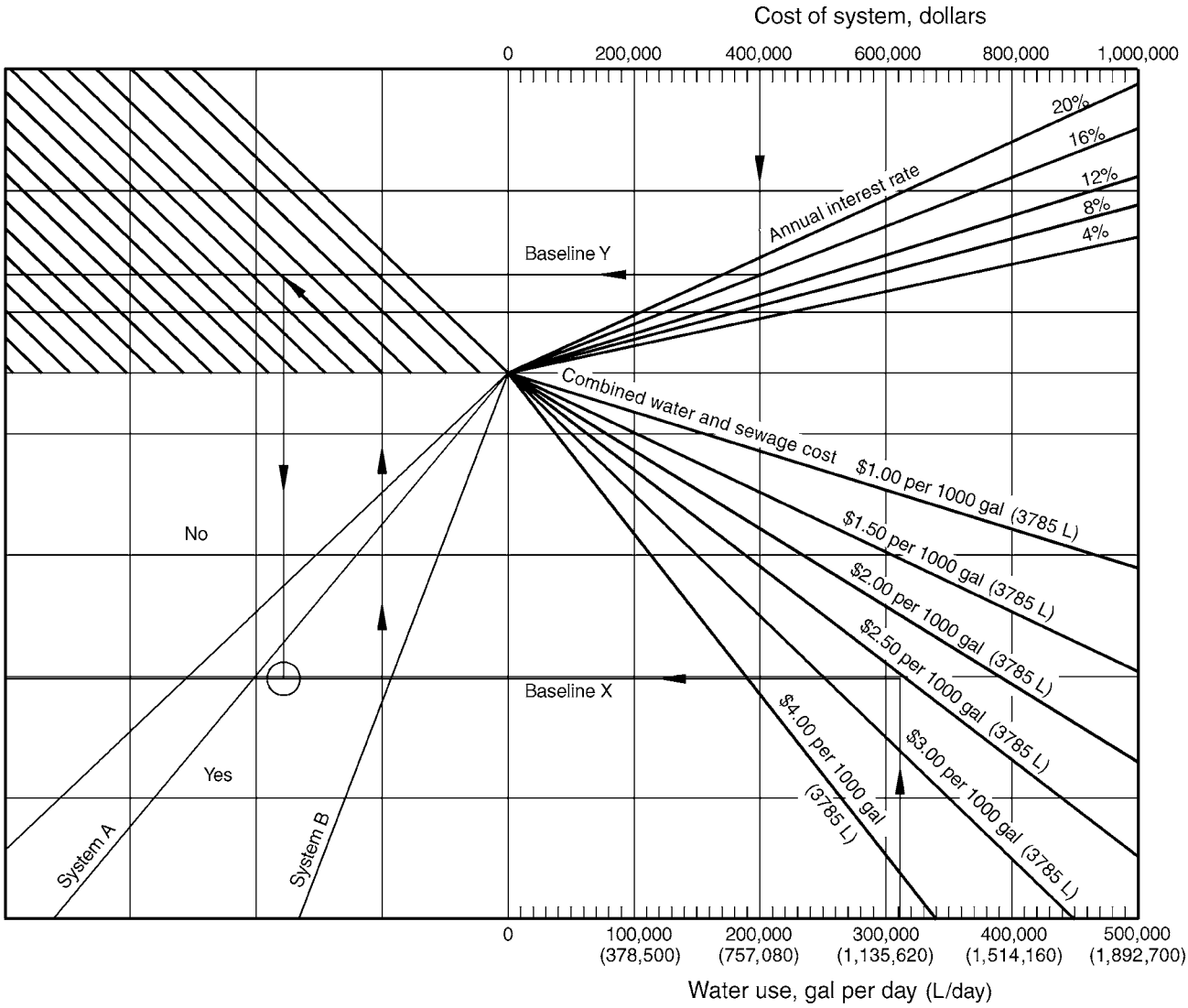


Figure 2-5 Nomograph for Overview of Preliminary Feasibility of Gray-Water Systems

7. If the proposed system is a Type A gray water system, go to the intersection of baseline X and the system A curve (lower left quadrant) of the nomograph. If a Type B gray water system is being studied, go to the intersection of baseline X and the system B curve.
8. From the appropriate intersection, move vertically up to the horizontal separation line and then up and left at the indicated 45° angle to an intersection with baseline Y.
9. From this intersection point, move vertically down once again to the intersection with baseline X.
10. If this final (circled) intersection is in the lower right field, the system appears preliminarily feasible and should be subjected to a more detailed economic analysis.
11. If the final intersection falls to the left and above the sector dividing line, then the economic feasibility of the scheme is strongly suspect.

Note: Obviously, the many variable inputs that must be considered in a detailed economic analysis do not lend themselves to an easy-to-use nomograph. Many of these inputs have been simplified by making normal assumptions about such things as ratios of reuse, relative quantities of water consumption, and sewage discharge. Thus, while the nomograph does give a quick and relatively good indication of feasibility, it does not replace a detailed economic evaluation. This is particularly true if the scheme under consideration has anticipated hydraulic flow patterns that differ markedly from the relative uses outlined in Figure 2-5.

As a region's population grows, the utilization of limited water supplies becomes more critical, and the need for conservation becomes more obvious,

evidenced by regulation, a change in the types of plumbing fixtures, public education and voluntary participation, or an increase in water and sewage system charges. In addition, the economic capabilities of a municipality determine its capability for adding sewage treatment facilities and meeting the demands of the community.

PRECAUTIONS

Since gray water poses a potential health hazard, a great deal of care must be exercised once such a system is installed. One of the greatest dangers is the possibility that the gray water will be inadvertently connected to the potable water system. To avoid this possibility, the water itself and the piping must be made easily distinguishable, anti-cross-connection precautions must be taken, and appropriate alarms must be installed.

Treated water could be colored by food dye that is biodegradable. Fixtures could be bought in the color of the water if the color of the water is found objectionable.

The piping system itself must be clearly identified with labels placed visibly along the run of the pipe. If possible, the piping material should be different so that the possibility of mistaking and interconnecting the two systems is unlikely.

The most important consideration is the education of individuals and the staff of a facility with a gray water system. An explanation of the dangers and proper operating instructions will ensure that an informed staff will operate and maintain the system in a correct manner.

PUBLIC CONCERNS/ACCEPTANCE

Although gray water systems have been approved for general use in different parts of the world and have been designed in a variety of forms, it is still unfamiliar to many city and county governments, plumbing and facility engineers, and the general public. An exception is the Bahamas, where the local code mandates dual or gray water systems in all occupancies.

Although the use of gray water is a proven cost-effective alternative to the use of potable water in various systems, there is reluctance on the part of authorities to approve it. Some reasons include the following:

1. There is no generally accepted standard for the quality of recycled water. Several states in the United States, Japan, and the Caribbean have adopted codes and guidelines, but for most of the world there is no standard. This has resulted in rejection of the systems or long delays during the approval process of projects while the quality of the water is in question.
2. Many regulatory and plumbing codes do not have any specific restrictions against using gray water or have ambiguous language that could be interpreted for its use but whose officials impose special standards due to their lack of experience.

Although the use of gray water is ideal in certain circumstances, the success of gray water systems depends solely on public acceptance, and that requires an adequate educational effort. The use of colored water in water closets may not be attractive to the occupants of a newly occupied high-rise. Educating the users of gray water is imperative. An understanding of the source and the associated dangers and limitations of gray water is essential to acceptance by the general public. To draw a parallel, the general public is now fully aware of the dangers of electricity, yet life without electricity is considered to be abnormal.

An economic analysis of gray water systems in health care facilities may favor dual plumbing systems. However, the presence of viruses, bacteria, and biological contamination in health care gray water systems (through lavatories, bathtubs, showers, and sinks) may increase the cost of water treatment. Also there is a legitimate concern regarding the spread of disease through gray water systems that must not be overlooked. Therefore, the application of gray water systems in health care facilities may be a less attractive option because of the possibility of biological contamination.

CONCLUSION

This *Plumbing Engineering Design Handbook* chapter began with the definition of gray water and ended with a discussion of its public acceptance. It touched briefly on the design elements of the plumbing system and identified the variations among different facilities. The economic analysis of the gray water system can become the decisive issue that determines whether a gray water system is even considered for a project. This analysis can be extrapolated for any other projects and variations.

For the full design of gray water systems, the reader should refer to other technical *Plumbing Engineering Design Handbook* volumes. Water treatment is one of the backbones of the gray water system. Finally, water shortages, government subsidies, tax incentives, the facility limitations of local governments, and population growth will be the primary motivators for designers and project engineers to consider gray water system selections in their designs.

REFERENCES

Atienze, J. and J. Craytor. 1995. "Plumbing efficiency through gray water recycling." *Consulting Specifying Engineer*. (March): 58.

Baltimore, MD, Dept. of Public Works. June 1966. *Commercial water use research project,* by J. B. Wolf, F. P. Linaweaver, and J.C. Center.

Dumfries Triangle and Occoquan-Woodbridge Sanitary District, Woodbridge, VA. *Water uses study*, by G. D. Gray and J. J. Woodcock.

International Association of Plumbing and Mechanical Officials (IAPMO). 1998. California Plumbing Code. Walnut, CA.

IAPMO. 2000. Uniform Plumbing Code.

Konen, Thomas P. 1986. "Water use in office buildings." *Plumbing Engineer* Magazine. July/August.

Lehr, Valentine A. 1987. "Gray water systems." *Heating/Piping/Air Conditioning*. January.

n.a. 1997. "Water: Use of treated sewage on rise in state." *Los Angeles Times*, August 17: A36.

Siegrist, R., and W. C. Boyle. 1976. Characteristics of rural household waste water. *Journal of the Environmental Engineering Division*, (June): 533.

U.S. Dept. of Commerce, National Information Services. 1978. *Management of small waste flows*, by Wisconsin University, PB-286-560.

U.S. General Services Administration. 1995. *Water management: A comprehensive approach for facility managers.*

3 Vents and Venting

INTRODUCTION

Venting the sanitary drainage system goes back to the mid-1800s when there were severe problems of smell and explosions in the sewer lines, both in the street and inside buildings. The plumbers, not plumbing engineers, discovered a vent pipe added to the sanitary piping let air into the sanitary system and mostly solved the problem. After some years of discovery and trial and error, an elemental solution was found. In modern times, the venting of the sanitary system has been refined and codified. The sanitary vent is closely integrated with sanitary drainage. This chapter will provide the necessary principals governing the design and sizing of a modern vent system. The principals of design are as follows.

1. When any individual fixture or stack exceeds the design flow, a slug of water completely fills the sanitary pipe. This slug of water compresses air in front of it and creates a partial vacuum behind the water. The compressed air or vacuum must be relieved.
2. Air moving in the vent pipe has velocity and friction losses similar in theory to flowing water. For this reason, the longer the pipe, the larger the size.
3. The amount of air required is proportional to the amount of water flowing in the drainage pipe. The faster the waste moves, the faster the air flows. The flow of wastewater is found using the table of Drainage Fixture Units (DFU) in the code appropriate for the project location.
4. The vent stack size should be a minimum of one-half the size of the drainage branch it serves but no less than 1¼ inches.
5. In the applicable plumbing code, where the table heading refers to a size for the soil or waste stack, it should also be used for the horizontal branch soil or waste stack. Since venting requirements of a stack are more severe than a horizontal drainage line, there will be a small safety factor.
6. All fixture vents must rise above the flood level of a fixture or piece of equipment served to avoid the vent being used as an alternate waste line if the true waste line is obstructed or blocked.

Vent piping is a gravity circulation system intended to limit the pneumatic fluctuations within the sanitary drainage-piping network to plus or minus one inch of water column. The main reasons the vent system is integral and necessary to any drainage network are:

1. It prevents the loss of fixture trap seals.
2. It allows for the smooth flow of water in the drainage system.
3. It limits movement of water levels in water closet bowls.
4. It eliminates the possibility of foul gas escaping from traps into living spaces and prevents the growth of slime and fungi.
5. It eliminates the "gurgling" of water in the drainage system.

Many types of venting schemes and methods are used in modern codes. Authorities having jurisdiction (AHJ) throughout the country do not recognize some schemes and methods. The vent system to be discussed is a "conventional" two-pipe system with a separate waste or soil stack and a vent stack. There are other total systems, such as the Sovent and "Philadelphia" one-pipe networks that have been successfully installed and operate satisfactorily in parts of the United States and various other countries. They are considered alternative systems because they are not fully recognized. These are discussed in Chapter 1, Sanitary Drainage Systems.

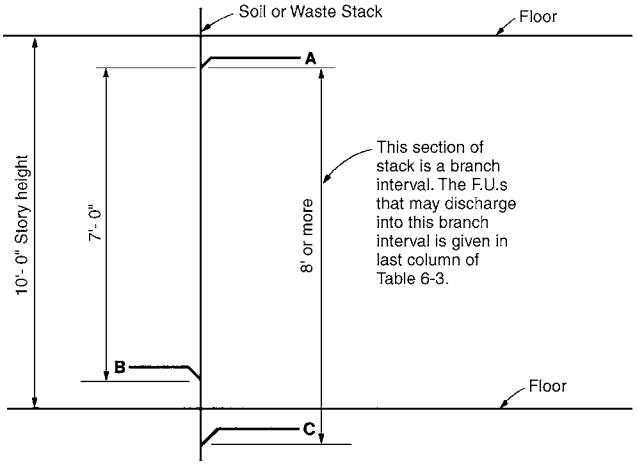
DEFINITIONS

The following definitions and illustrations will be used to avoid any confusion resulting from differences among the various codes. In addition, these definitions will be necessary for a full understanding and

interpretation if an engineer is required to alter an existing project constructed under a previous code.

1. BRANCH INTERVAL

A branch interval is the distance, measured vertically along a stack, within which the horizontal drainage branches from one floor or story are connected to a drain or soil stack. This distance is usually one story, but never less than 8 feet (2.4 m). A branch interval is illustrated in Figure 3-1.



The distance of 7'- 0" between branches A & B is not considered a branch interval. The definition states "at least 8 feet in length."

Figure 3-1 Branch Interval

2. BRANCH VENT

A branch vent connects one or more individual or common vents to a vent stack or a stack vent. A branch vent is illustrated in Figure 3-2.

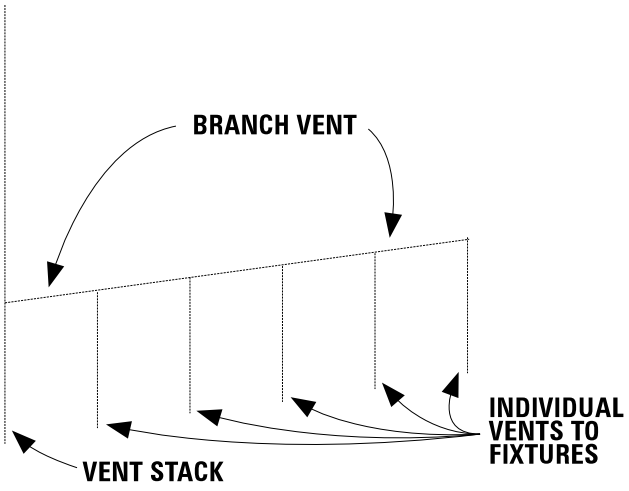


Figure 3-2 Branch Vent

3. BUILDING (HOUSE) TRAP

A building trap, or house trap, is a fitting or assembly in the form of a trap installed in a building house sewer on the outlet of the building drain inside the building, which prevents the circulation of air between the house sewer and the public sewer. A fresh air inlet, based upon code requirements, is often provided on the inlet side of the house trap and opens to the atmosphere at the nearest floor above the house trap. There is no requirement to have it terminate at the roof. A building (house) trap is illustrated in Figure 3-3.

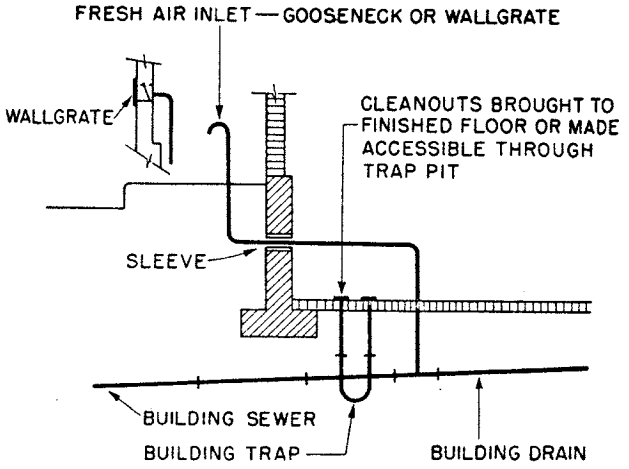


Figure 3-3 Building Trap

4. COMMON VENT

A common vent connects two fixtures with a single vent line to serve both fixtures. It may be used for two fixtures set on the same floor level but connecting at different levels in the stack, provided the vertical drain is one pipe diameter larger than the upper fixture drain but in no case smaller than the lower fixture drain, or whichever is larger, and both drains conform to the distances from trap to vent for various size drains. When fixtures are connected to one horizontal branch through a double wye or a sanitary tee in a vertical position, a common vent for each two fixtures back-to-back with a double connection shall be provided. The common vent shall be installed in a vertical position as a continuation of the double connection. A common vent is illustrated in Figure 3-4.

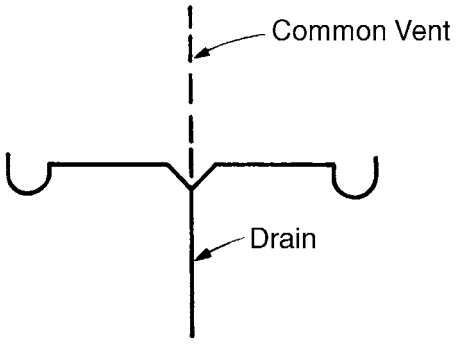
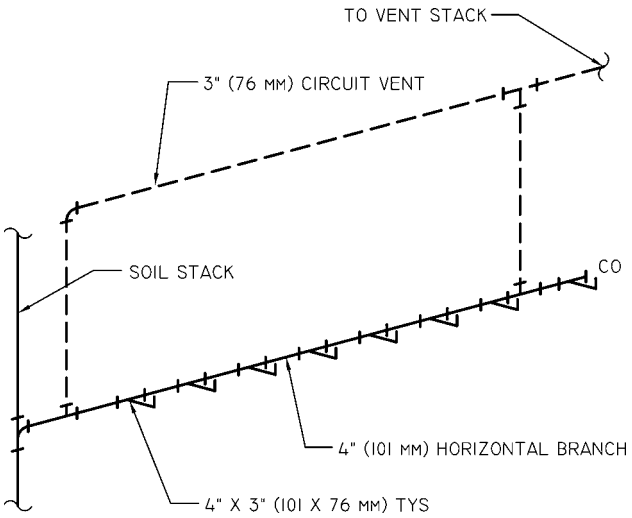


Figure 3-4 Common Vent

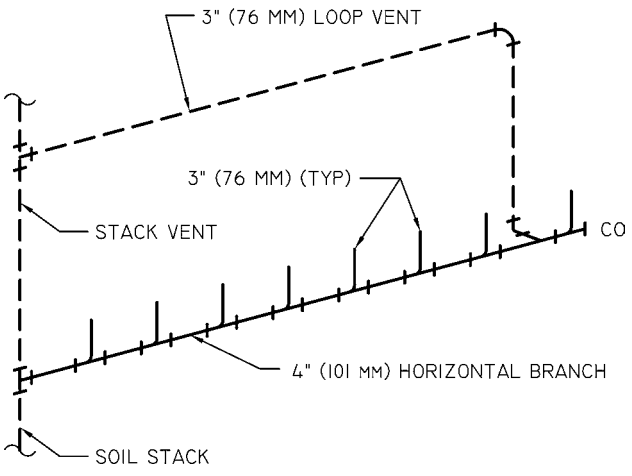
5. CIRCUIT AND LOOP VENT

A circuit vent is a branch vent that serves at least two but not more than eight traps. The vent extends from in front of the last fixture on a drainage line serving multiple fixtures and connects to a vent stack. Fixtures that may be vented by this means are water closets (except blowout type), pedestal urinals, shower stalls, or floor drains connected in a battery. A loop vent is a branch vent serving two or more traps and extends from in front of the last fixture to its connection with a stack vent. The basic principal of this type of vent is that the flow of drainage does not exceed a one-half flow condition.

Additionally, lower-floor branches serving more than three water closets shall be provided with a relief vent taken off in front of the first fixture connection. When lavatories or similar fixtures discharge above such branches, each vertical branch shall be provided with a continuous vent. When the circuit, loop, or relief vent connections are taken off the horizontal branch, the vent branch connection shall be taken off at a vertical angle or from the top of the horizontal branch. Figure 3-5 illustrates typical loop-vented and circuit vented arrangements. A circuit vent is similar to a loop vent except a circuit vent connects into the vent stack.



Circuit Vent



Loop Vent

Figure 3-5 Circuit and Loop Vent

6. CONTINUOUS VENT

A continuous vent is a vertical vent that is a continuation of the drainage pipe to which it is connected. A continuous vent is illustrated in Figure 3-6.

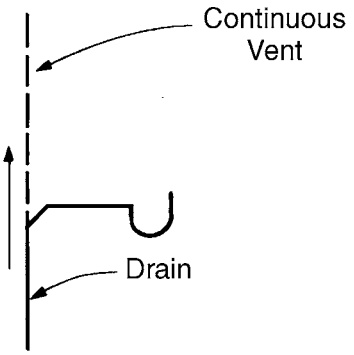


Figure 3-6 Common Vent

7. END VENTING

End venting is a method of venting a series of floor drains with a vent connected to the drainage pipe at the beginning of the run before the first drain. The entire drain line, from the first floor drain to the connection with a main drain, shall be pitched at 1/8 inch per foot (1 percent) and be sized two pipe sizes larger than called for in the code. The theory is that the system is oversized allowing the sewer to flow partially full, thus permitting air to circulate above the water in the pipe. This configuration is similar to a combination waste-and-vent system.

8. FIXTURE BATTERY

A fixture battery is any group of two or more similar, adjacent fixtures discharging into a common, horizontal waste or soil branch. A fixture battery is illustrated in Figure 3-7.

9. FIXTURE UNIT.

A fixture unit is a dimensionless measure of the probable discharge from any fixture into the drainage system compared to that of a lavatory. There are different fixture units assigned to both the water system (WSFU) and the sanitary drainage system (DFU) that would appear in the project location code. The actual flow of waste from the sanitary drainage is obtained from a conversion table found in Chapter 1, Sanitary Drainage Systems.

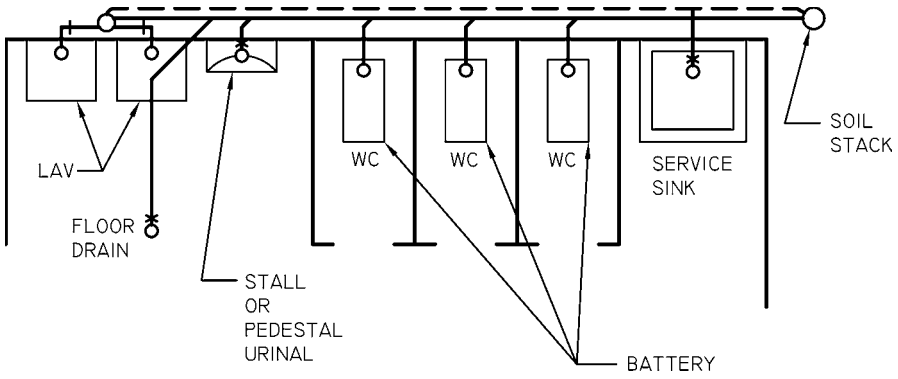


Figure 3-7 Fixture Battery

The selection of the size and length of vent piping requires design or installation information about the size of the soil and/or waste stack and the fixture unit (derived from the supply system design) loads connected to the stack. Total fixture units connected to the stack can be computed in accordance with Table 1-4 in Chapter 1, Sanitary Drainage Systems. Fixture units are really weighting factors that effectively convert the various types of fixtures, having different probabilities of use, to equivalent numbers of an arbitrarily chosen type of fixture with a single probability of use. In other words, the fixture unit assigned to each kind of fixture represents the degree to which it loads the system. The designer should confirm or adjust this data based on the local code.

10 . INDIVIDUAL VENT

An individual vent connects directly to only one fixture and extends to either a branch vent or vent stack. Another name for the individual vent is a revent. An individual vent is illustrated in Figure 3-8.

11. OFFSETS

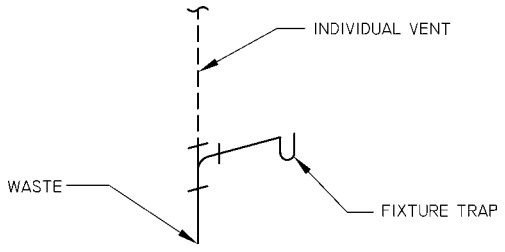


Figure 3-8 Individual Vent

An offset is a run of piping consisting of a combination of elbows or bends that brings one section of the pipe out of line but into a line approximately parallel with the other section. Offsets less than 45 degrees from the horizontal in a soil or waste stack shall comply with the following:

1. Offsets may be vented as two separate soil or waste stacks, namely, the stack section below the offset and the stack section above the offset.
2. Offsets may be vented by installing a relief vent as a vertical continuation of the lower section of the stack or as a side vent connected to the lower section between the offset and the next lower fixture or horizontal branch. The upper section of the offset shall be provided with a yoke vent. The diameter of the vents shall be not less than the diameter of the main vent or of the soil and waste stack, whichever is smaller. Figure 3-9 illustrates typical offsets.

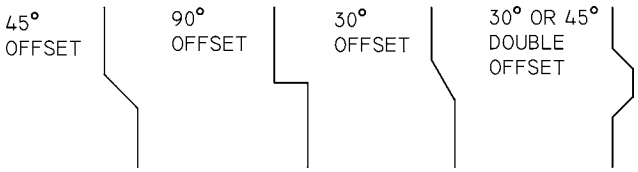


Figure 3-9 Typical Offsets

12. RELIEF VENT

In order to balance the pressures that are constantly changing within the plumbing system, it is necessary to provide an auxiliary vent at various intervals, particularly in multistory buildings. Soil and waste stacks in buildings having more than 10 branch intervals shall be provided with a relief vent at each tenth interval installed, beginning with the top floor.

The size of the relief vent shall be equal to the size of the vent stack to which it connects. The lower end of each relief vent shall connect to the soil or waste stack through a wye below the horizontal branch serving the floor, and the upper end shall connect to the vent stack through a wye not less than 3 ft (0.9 m) above the floor level. Figure 3-10 illustrates important requirements for the installation of a relief vent.

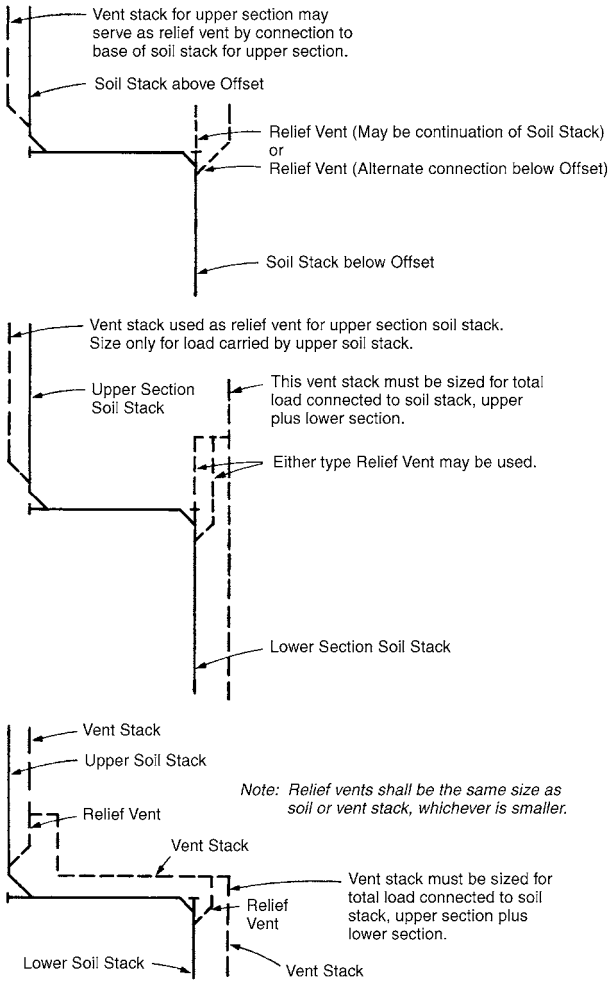


Figure 3-10 Venting at Stack Offsets

12. STACK VENT

A stack vent is the extension of a soil or waste stack above the highest horizontal connection to that stack and terminates through the roof. Fixtures may be installed without individual fixture vents in a one-story building or on the top floor of a building, provided each fixture drain connects independently to the stack, and the water closet and bathtub or shower-stall drain enters the stack at the same level and in accordance with trap-arm requirements.

It is also the name of a method of venting using the stack vent for a branch vent connection. A stack vent is illustrated in Figure 3-11.

13. SUDS VENTING

Suds venting is a method of relieving suds being forced from a stack through the trap and into the facility. This is further covered later in this chapter.

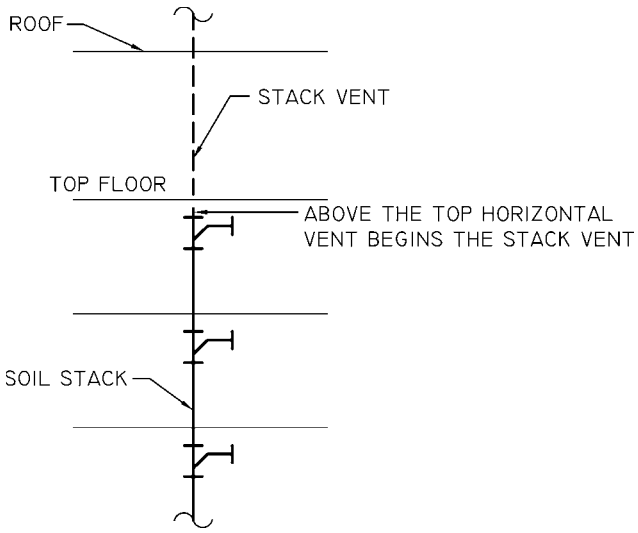


Figure 3-11 Stack Vent

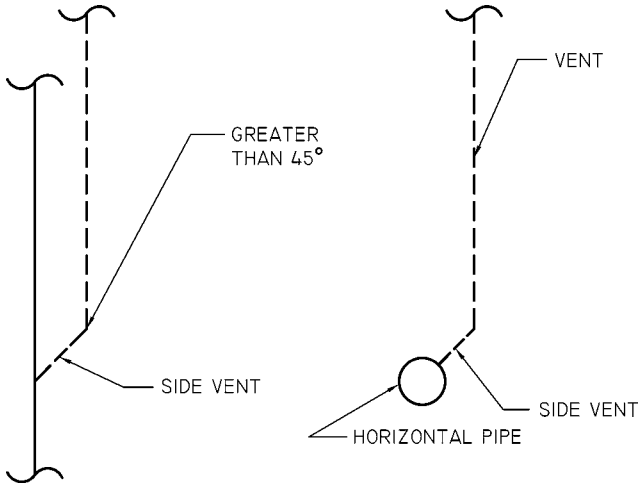


Figure 3-12 Side Vent

14. SIDE VENT

A side vent connects to a drainpipe through a fitting with an angle not greater than 45 degrees to the vertical. A side vent is illustrated in Figure 3-12.

15. TRAP ARM

The trap arm is that portion of the drainage pipe between the trap and the vent.

16. VENT HEADERS

Stack vents and vent stacks may be connected into a common vent header at the highest level of a structure above the connected stacks and then extended to the open air at a single point. This header shall be sized in accordance with the requirements of Table 3-1, the number of fixture units being the sum of all fixture units on all stacks connected thereto, and the developed length being the longest vent length from the intersection at the base of the most distant stack

Table 3-1 Size and Length of Vents

Size of Soil or Waste Stack, in (mm)	Fixture Units Connected	Diameter of Vent Required, in. (mm)								
		1¼ (32)	1½ (38)	2 (51)	2½ (63)	3 (76)	4 (101)	5 (127)	6 (152)	8 (203)
		Maximum Length of Vent, ft (m)								
1½ (38)	8	50 (15.2)	150 (45.7)							
2 (51)	12	30 (9.1)	75 (22.8)	200 (61)						
2 (51)	20	26 (7.9)	50 (15.2)	150 (45.7)						
2½ (63)	42		30 (9.1)	100 (30.5)	300 (91.4)					
3 (76)	10		30 (9.1)	100 (30.5)	100 (30.5)	600 (182.9)				
3 (76)	30			60 (18.3)	200 (61)	500 (152.4)				
3 (76)	60			50 (15.2)	80 (27.8)	400 (122)				
4 (101)	100			35 (10.7)	100 (30.5)	260 (79.2)	1000 (304.8)			
4 (101)	200			30 (9.1)	90 (27.4)	250 (76.2)	900 (274.3)			
4 (101)	500			20 (6.1)	70 (21.3)	180 (54.9)	700 (213.4)			
5 (127)	200				35 (10.7)	80 (27.8)	350 (106.7)	1000 (304.8)		
5 (127)	500				30 (9.1)	70 (21.3)	300 (91.4)	900 (274.3)		
5 (127)	1100				20 (6.1)	50 (15.2)	200 (61)	700 (213.4)		
6 (152)	350				25 (7.6)	50 (15.2)	200 (61)	400 (122)	1300 (396.6)	
6 (152)	620				15 (4.6)	30 (9.1)	125 (38)	300 (91.4)	1100 (335.3)	
6 (152)	960					24 (7.3)	100 (30.5)	250 (76.2)	1000 (304.8)	
6 (152)	1900					20 (6.1)	70 (21.3)	200 (61)	700 (213.0)	
8 (203)	600						50 (15.2)	150 (43.7)	500 (152.4)	1300 (396.6)
8 (203)	1400						40 (12.2)	100 (30.5)	400 (122)	1200 (365.8)
8 (203)	2200						30 (9.1)	80 (27.8)	350 (106.7)	1100 (335.3)
8 (203)	3600						25 (7.6)	60 (18.3)	250 (76.2)	800 (243.8)
10 (254)	1000							75 (22.9)	125 (38)	1000 (304.8)
10 (254)	2500							50 (15.2)	100 (30.5)	500 (152.4)
10 (254)	3800							30 (9.1)	80 (27.8)	350 (106.7)
10 (254)	5600							25 (7.6)	60 (18.3)	250 (76.2)

to the vent terminal in the open air as a direct extension of one stack.

17. VENT STACK

    A vent stack is a vertical pipe extending one or more stories in height and terminating above the highest point of a structure, allowing circulation of air into and out of the drainage system.

18. VENT STACK TERMINAL

    A vent stack terminal is the part of the venting system that extends through the roof, thus keeping the drainage system open to atmospheric pressure.

19. WET VENT

    A wet vent is a continuous vent, other than from a water closet, which also receives and conveys drainage from additional fixtures. The principal of design is to use oversized piping to allow for the flow of water above the flow of the drainage water. Consult the local code for requirements. These fixtures can discharge without being vented. If allowed by local codes, a single-bathroom group of fixtures may be installed with a drain from a back-vented lavatory, kitchen sink, or combination fixture serving as a wet vent for a bathtub or shower stall and for the water closet, provided that:

    1. Not more than one fixture unit is drained into a 1½-in (38-mm) diameter wet vent or not more than four fixture units drain into a 2-in (51-mm) diameter wet vent.
    2. The horizontal branch connects to the stack at the same level as the water-closet drain or below the water-closet drain when installed on the top floor.

    On the lower floors of a multistory building, the waste pipe from one or two lavatories may be used as a wet vent for one or two bathtubs or showers, provided that:

    1. The wet vent and its extension to the vent stack is 2 in (51 mm) in diameter.
    2. Each water closet below the top floor is individually back-vented.

Bathroom groups consisting of two lavatories and two bathtubs or shower stalls back-to-back on a top floor may be installed on the same horizontal branch with a common vent for the lavatories and with no back vent for the bathtubs or shower stalls and for the water closets, provided the wet vent is 2 in (51 mm) in diameter and the length of the fixture trap arm conforms to Table 3-2. A wet vent is illustrated in Figure 3-13.

Table 3-2 Maximum Length of Trap Arm

Diameter of Trap Arm, in. (mm)	Distance – Trap to Vent, ft (m)
1¼ (32)	2½ (0.76)
1½ (38)	3½ (1.1)
2 (51)	5 (1.5)
3 (76)	6 (1.8)
4 (101)	10 (3.0)

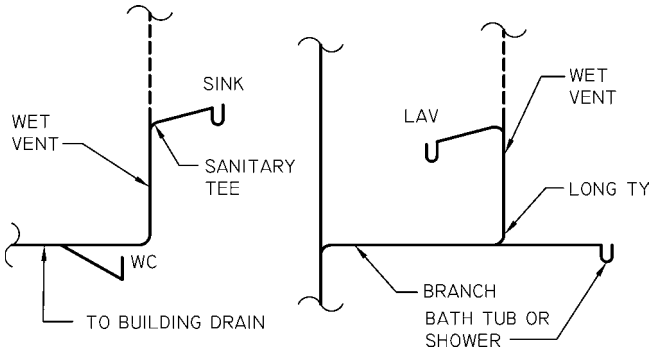


Figure 3-13 Wet Vent

20. YOKE VENT

A yoke vent is a vent connected to a soil or waste stack that continues upward to a connection with a vent stack. A yoke vent is illustrated in Figure 3-14.

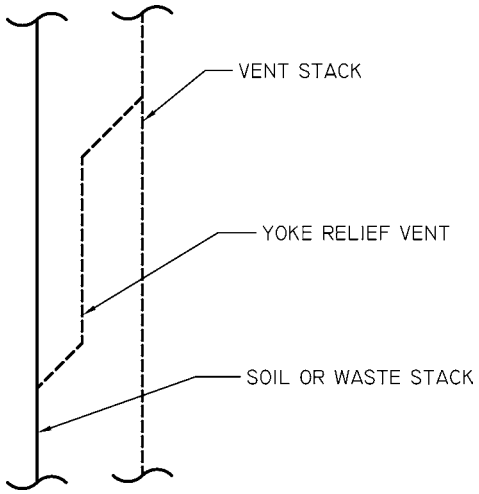


Figure 3-14 Yoke Vent

SIZING THE VENT SYSTEM

DEVELOPED LENGTH

The developed length of an individual or common vent is calculated from its connection with the fixture trap arm to the connection with the branch vent or vent stack. A branch vent developed length is taken from the furthest connection with a waste branch to the point being sized. The developed length of a vent stack is taken from its connection with the soil or waste stack to the highest point outside the structure. The developed length must include an allowance for fittings, similar to water lines. The developed length is one of the items necessary to size a vent.

FIXTURE UNITS

One of the other items, the Sanitary Fixture Units, is associated with the drainage line or stack for the vent being sized. The actual total of sanitary fixture units is obtained from a conversion table found in Chapter 1, Sanitary Drainage Systems.

SIZE OF THE SOIL OR WASTE BRANCH OR STACK

The size of the drainage line for which the vent is provided shall be calculated for each design point.

CALCULATING THE VENT SIZE

Using Table 3-1, each of the above three items will be used to size both the main vent stack and the branch vent associated with the specific drainage stack. Enter the table with the largest soil, waste stack pipe size, or the greatest number of sanitary fixture units for the whole stack. Read horizontally until you come to a figure equal to or exceeding the developed length previously calculated. Read up to find the correct vent size. Please be advised the table presented is to illustrate the procedure involved. The information in the plumbing code for the project location must be used.

The following shall be used as an additional guide when calculating the vent size:

1. For vent stacks, use the total DFU (DFU values found in Table 3-2) for the drainage stack and the full-developed length of the vent to find the size. Vent stacks must be undiminished in size for their entire length. For branch vents, the longest developed length is calculated from the design point to the furthest connection to the drainage line and the DFU.
2. For the size of individual vents, use a table found in the code for the project location. It is usually in the "Typical Plumbing Fixture Schedule" that appears in some form in all of the codes.
3. For building (house) trap fresh air inlets, the size should be a minimum of one-half the size of the

building sewer. The need for a fresh air inlet must be confirmed by the local code.

4. Based on the size of the trap, the maximum length of the trap arm shall be as shown in Table 3-2

VENT TERMINALS

Vent pipes passing through the roof must remain open under all circumstances. Two conditions that would cause the exposed pipe to become blocked are frost closure and snow. Field test has shown that a 4-in (100-mm) size pipe at the roof level is capable of remaining open under all but the most severe conditions.

Though it may be small by comparison to the overall sanitary drainage piping, the vent stack terminal is an important portion of the system. Through the terminal vent, air at atmospheric pressure enters the drainage system to hold in balance the water seal contained in each fixture trap. The balance of atmospheric air pressure and gravitational pull on the wastewater mass follows the principles outlined in Chapter 1, Sanitary Drainage Systems. Vent stack terminals need to be sized in accordance with local codes and/or good engineering practices, which includes the following:

1. Increase the terminal pipe by two sizes at 18 in (455 mm) below the roofline. This allows for the interior building space (which is usually warmer) to provide a convective flow of interior building heat, keeping the vent terminal at the roof from freezing closed.
2. Project the vent terminal in accordance with jurisdictional building codes and locate an appropriate distance from air intake louvers, windows, doors, and other roof openings, 10 ft (3 m) minimum. Sewer gases will be forced upward through the terminal stack by the weight of the water in the trap, therefore, the vent pressures versus the air intake volumes need to be considered.
3. Provide minimum 4-in (100-mm) diameter vent stack terminals. Experience has proven a 4-in (100-mm) terminal allows an adequate volume of air to enter the plumbing system, and its effective opening is not as easily constricted by foreign matter, ice, snow, or vermin, as the opening of a smaller diameter pipe would be. (It should be noted most codes require only one 3-in [75-mm] vent to atmosphere be provided for each building drain.). Winds of sufficient force can affect the function of the venting system and in situations of high winds and high moisture (such as at Niagara Falls), the vent size should be increased to 6 in (150 mm). A strong wind blowing across the effective opening of the vent stack terminal can create unbalanced air pressures within the system. Protective devices are available but may be susceptible to frost closure or the accumulation of snow. Care must also be taken when locating the vent terminals with respect to building walls, higher adjacent roofs, parapet walls, etc., as these may affect the proper flow of air into and out of the venting system as well as provide an undesirable smell if drawn into an HVAC intake. If necessary, electrical heat tracing or insulation could maintain a temperature high enough to prevent ice from forming.

   The vent extension shall not be located under or within 10 ft (3 m) of any window, door, or ventilating opening, unless it is 2 ft (0.8 m) above such an opening. If the terminal is through a building wall it shall be located a minimum of 10 ft (3 m) from the property line, and if above grade, a minimum of 10 ft (3 m) above grade and not under an overhang.

RELIEF VENTS

Soil or waste stacks with no offsets, in buildings having more than 10 branch intervals, shall be provided with relief vents every tenth branch vent interval starting with the top floor. Offsets in the waste stacks may also be required to have a relief vent if the code requires it. Several configurations are possible by various codes. In general, the lower end of the relief vent shall be connected to the waste stack below the horizontal branch serving the floor required to have the relief vent. The upper end of the relief vent shall connect to the vent stack no less than 3 ft (1 m) above that same floor level. Its size shall be equal to the vent stack to which it is connected or the drainage stack, whichever is smaller.

The purpose of differentiating between branch intervals and the actual number of horizontal soil or waste branch lines entering the stack is to prevent overloading the stack in a short distance. Many codes limit the number of DFUs allowed in a branch interval.

CIRCUIT AND LOOP VENTS

These venting schemes are intended to provide a more economical means of venting than provided by the individual vent. In the Uniform Plumbing Code (UPC), it is allowed only for venting of floor-mounted fixtures, such as water closets, showers, and floor drains, and may not be acceptable in all jurisdictions. The International Plumbing Code (IPC) does not have the same restrictions. Any fixture, as long as the connection is on the horizontal, may be vented in this manner. The circuit-venting principal is allowed for the venting of branch waste lines serving floor drains and other floor-mounted fixtures in some codes.

Circuit venting requires a uniformly sized drainage line with at least two, but not more than eight,

fixtures connected in a battery arrangement. The circuit vent is connected to the horizontal drain line between the two most remote fixtures and is connected to the vent stack. In addition to the circuit vent, a relief vent is required to be connected to the vent stack. In addition to the circuit vent, a relief vent is required to be connected to the horizontal drain line at the end of the battery, or every eight fixtures. The size of each shall be one-half the size of the horizontal drainage line or the full size of the vent stack, whichever is smaller.

Loop venting is the same as circuit venting except for the connection of the branch vent to the building system. The loop vent "loops" back to the stack vent instead of the vent stack.

SUDS VENTING

High-sudsing detergents are used in kitchen sinks, dishwashers, and clothes washing machines in residential occupancies and commercial laundries. These suds disrupt the venting action and spread through the lower portions of multistory drainage systems. The more turbulence there is, the greater the suds. In some cases, suds back up through the traps and even spill out on the floor. They cause an increase in the pressure and vacuum levels in the systems. They affect both single-stack and conventional systems. Solutions to the problem may involve avoiding suds pressure zones, connecting the suds-producing stack downstream of all other stacks, and increasing the size of the horizontal building drain to achieve less restrictive flow of air and water. Using streamline fittings, such as wyes, tends to reduce suds formation. Check valves in fixture tailpieces have been used to fix problem installations.

Table 3-3 Suds Pressure-Relief Vents

Waste Size, in. (mm)	Relief Vent Size, in. (mm)
1½ (38)	2 (51)
2 (51)	2 (51)
2½ (63)	2 (51)
3 (76)	2 (51)
4 (101)	3 (76)
5 (127)	4 (101)
6 (152)	5 (127)
8 (203)	6 (152)

Extent of Suds Pressure Zones for Various Size Soil and Waste Piping, Extent of Zone (Measured from Fittings)		
Stack Size, in. (mm)	Upstream, U, ft (m)	Downstream, D, ft (m)
1½ (38)	5 (1.5)	1½ (0.45)
2 (51)	7 (2.1)	1½ (0.45)
2½ (63)	8 (2.4)	2 (0.61)
3 (76)	10 (3.0)	2½ (0.76)
4 (101)	13 (4.0)	3½ (1.1)
5 (127)	17 (5.2)	4 (1.2)
6 (152)	20 (6.1)	5 (1.5)

Note: For use with Figure 3-15.

The National Standard Plumbing Code, one of the traditional codes, lists the following special requirements to avoid suds problems:

1. Where required. Where kitchen sinks, laundry trays, laundry washing machines, and similar fixtures in which sudsy detergents are normally used and discharge at an upper level into a soil or waste stack. The drainage and vent piping for such lower fixtures shall be arranged so as to avoid connection to suds pressure zones in the sanitary drainage and vent systems, or provide a suds relief vent, relieving to a no-pressure zone. Relief vents shall be provided at each suds pressure zone where such connections are installed. In multistory buildings, with more than six branch intervals of fixtures described above, separate waste and vent stacks for the lower four branch intervals of fixtures shall be required as indicated in Table 3-3.
2. Suds pressure zones. Suds pressure zones shall be considered to exist at the following locations in sanitary drainage and vent systems as indicated in Figure 3-15.

   Zone 1. In a soil or waste stack that serves fixtures on two or more floors and receives wastes from fixtures wherein sudsy detergents are used, a zone shall be considered to exist in the vertical portion upstream of an offset fitting and the riser to the upper section of the system, in the horizontal portion downstream of this fitting, and in the horizontal

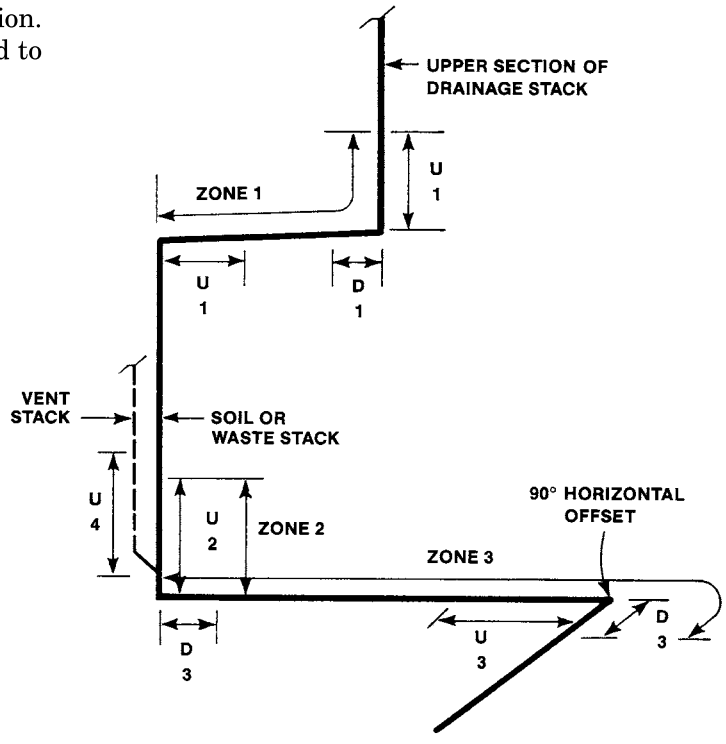
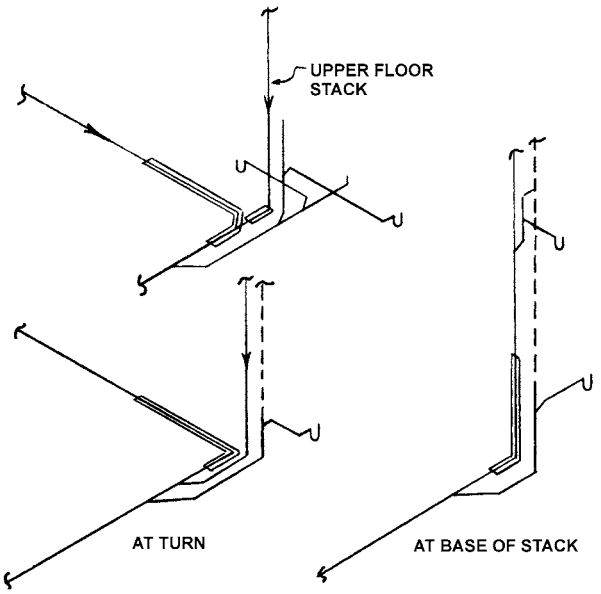


Figure 3-15 Suds Pressure Zones



Note: Double lines represent suds pressure zones.
Shown are connections outside the pressure zones.

Figure 3-16 Illustration of Suds Pressure Connections

portion upstream of the offset immediately preceding the next offset fitting. Refer to Table 3-3 for the size of suds pressure zone relief vents.

Zone 2. In a soil or waste stack, which serves fixtures on two or more floors and receives wastes from fixtures where sudsy detergents are used, a zone shall be considered to exist at the base of the stack and extending upstream as illustrated in Figure 3-16.

Zone 3. In a soil or waste system, which serves fixtures on two or more floors and receives wastes from fixtures wherein sudsy detergents are used, a zone shall be considered to exist downstream in the horizontal drain from the base of the stack and both upstream and downstream of the next offset fitting downstream.

Zone 4. In a soil or waste system, which serves fixtures on two or more floors and receives wastes from fixtures wherein sudsy detergents are used, a zone shall be considered to exist in the vent stack extending upstream from the point of connection to the base of the soil or waste stack as illustrated in Figure 3-16.

AIR ADMITTANCE VALVES

An air admittance valve is a gravity-operated mechanical device that allows air to enter a piping system when a less-than-atmospheric pressure exists but closes upon a positive pressure, not permitting air to exhaust. The best way to think about it is as a vent terminal. It must be located on the outside wall of a building venting to the atmosphere. Its use is controversial and not accepted in some codes but permitted in others. Its use and sizing must be confirmed with the AHJ.

Individual vents, common vents, circuit, and branch vents could terminate locally in the atmosphere with the installation of local air admittance valves at the fixtures, thereby saving the expense of a vent running through the roof. The plumbing system still requires venting in the conventional manner with one vent or vent stack extended to the open air to provide a method of relieving positive pressure in the drainage system. A majority of the venting from fixtures would be eliminated and replaced with the air admittance valve.

There are some general limitations regarding where use is permitted.

1. The valve must be located in a ventilated space, which may include under a sink, in a vanity cabinet, in an attic, and in a ventilated wall space.
2. The valve must be accessible, located above the horizontal drain or fixture drain, a minimum of 4 inches above the trap but could be below the flood level of the fixture.
3. The valve cannot be used where the system is subject to a pneumatic pressure exceeding 1 inch of water column.
4. The valve cannot be used to vent a sump, used in any chemical waste system, or be installed in a plenum.
5. The distance from the fixture trap to the connection must be within the developed length permitted for the vent.
6. When installed above the ceiling, the air admittance valve must be installed a minimum of 6 inches above the insulation material.
7. An air admittance valve may vent an island fixture.

There is alternative venting associated with several other drainage systems. These systems are discussed in Chapter 1, Sanitary Drainage Systems, under Alternative Drainage Systems.

Since traps are a very critical part of the waste and vent network, the following discussion will clarify the role venting plays in the protection of trap seals.

TRAPS AND TRAP SEALS

The primary purpose of the venting system is to protect all of the trap seals in the drainage systems from backpressure and siphonage. This is achieved by providing a venting system designed to permit gases and odors to circulate through the system and

eventually escape into the atmosphere. It also permits the addition of air into the system and the emission of air from all parts of the drainage system. Venting requirements relate to this addition and emanation of air from the drainage system as a whole.

The purpose of traps in any building drainage system is to prevent sewer gas from entering into the building from the building system, including the stacks, branches, and building (house) drain. The water seal in the trap prevents the backflow of sewer gas into the fixture and from there into a room. There are two major ways in which trap seals are reduced. The first is the pneumatic pressure fluctuations in the system. The negative part of the fluctuations caused by the discharge of fixtures in the system (other than the fixture in question to which the trap is attached) may suck water out of the trap. Then the positive part of the fluctuation can force sewer gas past the reduced trap seal. This is called "induced siphonage." The second is where the reduction of the trap seal of the fixture in question is caused by the discharge of the fixture itself. This is referred to as "self-siphonage."

The reduction of trap seals of fixture traps will be the basis for deciding the limitations of drain lengths and slope; therefore, a discussion of what trap seal losses or remaining trap seals are to be considered as necessary. The adequate protection of the building interior against the penetration of sewer air by passage of that air through or past the trap seal depends on the depth of the seal that can be maintained under all conditions and the effects of air fluctuations on induced siphonage and self-siphonage. The important thing to remember is what would be the remaining trap seal if we limited the trap seal losses. It is a code requirement for each fixture trap to have a water seal of not less than 2 inches. This figure of 2 inches allows for the fouling of the fixture drain in time. The remaining trap seal will still protect against the passage of air back into the building as long as the excess pressure in the stack does not exceed twice the depth of water in the seal.

The maximum trap seal loss due to pressure fluctuations considered to be permissible is 1 inch of water. When a "P" trap is used this means the negative pressure of 2 inches of water is required to reduce the trap seal by approximately this amount for a single pressure fluctuation. Experiments have found further trap seal losses will occur if the same pressure reduction is applied to the trap without any refilling occurring in the meantime. On the basis of these considerations, it has arbitrarily been decided to keep the pressure fluctuations in a building drainage system to a maximum of 1 inch of water. It is not necessary for these fluctuations to be exceeded anywhere in the system. The important thing is that they shall not be exceeded when the fixture drains or horizontal branches connect to the building drains or stacks.

When water flows down a stack or when it flows along a sloping drain, for most conditions, the cross section the pipe is only partially filled with water. Since this means it is also partially filled with air, the moving water tends to drag the air along with the flow. This flow might be blocked toward the outlet in many ways, for example by a hydraulic jump in the building drain or a submerged outlet to the public sewer. This creates a considerable positive pneumatic pressure to be built up in the building drain. This pressure may extend up the stack for some distance, decreasing as it travels upwards. If this excessive pressure is to be permitted from occurring, adequate venting must be provided near the bottom of the stack, so air may be carried away without developing a pressure of more than 1-inch water column in the stack to which the vent is connected. This is why all of the codes call for relief vents at various locations in the vent stack.

Water flows down a vertical pipe in what is called sheet flow. This means the water forms a sheet flowing around the perimeter of the pipe with a hollow core. The outer layer of the sheet of falling water down a stack exerts a frictional drag on the core of air inside the sheet of water. If the drain does not flow full in any one section, the stream of air dragged down by the water is more or less allowed to flow out of the outlet end of the drain and into the atmosphere. Some retardation of the air will occur if the hydraulic jump may fill the cross section of the drain. This will create a backpressure, which will be felt part way up the stack. If the drain is completely blocked at some section, the airflow will be blocked also. In the absence of vents, the air pressure in the drain might get to be very high.

REFERENCES

1. American Society of Plumbing Engineers (ASPE) Research Foundation. 1978. Reduced-size venting design, by E. Brownstein. Westlake Village, CA.
2. Copper Development Association, Inc. Copper sovent single-stack plumbing system handbook supplement. New York.
3. Manas, Vincent T. 1957. National plumbing code handbook. New York: McGraw-Hill.
4. National Association of Home Builders Research Foundation. 1971. Performance of reduced-size venting in residential drain, waste and vent system. Report LR 210-17.
5. National Association of Plumbing-Heating-Cooling Contractors and American Society of Plumbing Engineers. 1973. National standard plumbing code.

6. National Bureau of Standards. 1923. Recommended minimum requirements for plumbing in dwellings and similar buildings, by Dr. R. Hunter.
7. National Bureau of Standards. 1974. Laboratory studies of the hydraulic performance of one-story and split-level residential plumbing systems with reduced-size vents, by R. S. Wyly, G. C. Sherlin, and R. W. Beausoliel. Report no. BBS 49.
8. National Bureau of Standards. n.d. Monograph no. 31.
9. Stevens Institute of Technology. 1973. An investigation of the adequacy of performance of reduced-size vents installed on a ten-story drain, waste and vent system, by T. K. Konen and T. Jackson. Report SIT-DL-73-1708.

4 Storm Drainage Systems

GENERAL DESIGN CONSIDERATIONS FOR BUILDINGS AND SITES

Storm-drainage systems convey rainwater from buildings, surface runoff from all types of precipitation, groundwater, and subsurface water to an approved point of disposal. Building sites shall be provided with a means for draining paved areas, areaways, yards, and all other areas where the collection or uncontrolled flow of rainwater could cause damage to a building, overload local streams, or present a hazard to the public.

The drainage may include rainwater from parking lots, roadways, roofs of structures, and undeveloped areas of a site. Depending on the approval of the local administrative authority, some clear-water wastes, such as condensate from HVAC units, untreated cooling-tower water, ice-machine discharge, and pond overflow, also may be discharged into the storm-drainage system. These discharges shall not have any chemicals or sanitary flow.

If any pollutants, including oils, are intended to or might be discharged, storm water management laws require a storm water management device to be provided to separate all pollutants of interest prior to discharge to the environment or a public storm system. Based on the Clean Water Act and the requirements of the local jurisdictions, oil/water separators and pollutant-removal devices are now mandatory for large projects. In addition, storm water mitigation during construction is more stringent than after site build-out. The authority having jurisdiction (AHJ) must approve all drainage plans, including detention and outfall structures, and issue permits.

If the building storm-drainage system is at a lower elevation than the public storm sewer system, thus not allowing for gravity drainage, the effluent must be pumped. Depending on the local code, a redundant (or backup) pump system is mandatory. In climates prone to flash floods and rapid evaporation, the jurisdiction allows holding areas on the site where the storm water is collected in a reservoir for short periods. When a public means of disposal is not available, the discharge should be directed to a safe point of disposal as approved by the authority for storm water control.

The storm sewer should be separate from the sanitary sewer system unless there is an approved combined storm/sanitary sewer system. Such systems are rare because of the additional loads imposed on municipal sewage disposal plants. Also, overflow could cause direct contamination of local streams and waterways. Federal government regulations prohibit the use of combined sewers for any public system that receives federal funding. During major floods, the two systems mix and introduce a major challenge to public works groups as well as the water district.

If the storm-drainage piping connects to the sanitary sewer, the storm drain must be trapped properly prior to its connection. Storm-drainage stacks do not require venting because there is no need to control hydraulic or pneumatic pressures within any fixed limits. Negative pressure occurs at the top of the stack, and positive pressure exists at the bottom of the stack. Because the stack is not vented, pressure can increase, creating turbulence at the base of the stack (known as the hydraulic jump phenomenon). In general, supercritical flow can be changed to subcritical flow only by passing through a hydraulic jump. The extreme turbulence in a hydraulic jump dissipates energy rapidly, causing a sharp drop in the total head between the supercritical and subcritical states of flow. No connections should be made within the area where hydraulic jump may occur.

It may be more advantageous to route the storm and sanitary mains separately to the exterior of the building before they are tied into the combined system, with a trap separating the systems. Traps should be either located inside the building or buried, with access, below the frostline to prevent freezing. Connection of the storm leaders to the sanitary sewer should be a minimum 10 ft (3.05 m) downstream from any sanitary connection to prevent hydraulic jump

from disrupting flow when the storm drains discharge and causing backups in the sanitary system.

Rainwater normally is conveyed from the area being drained to the disposal point at the same rate at which it is collected. There are circumstances where the method of disposal does not have the capacity to receive the instantenous rate. When this occurs, a controlled-flow roof drainage system, which permits water to be retained on the roof or in an on-site retention area to alleviate overtaxation of public storm sewers, is used. The rate of the water flow to be drained is determined by the size, roughness coefficient, and infiltration rate of the area being drained and the rainfall rate. Rainfall intensity charts published by the National Weather Service (NWS) and the administrative AHJ should be consulted when determining the rainfall rate for the area of the country in which a building is being constructed.

Ponding may be allowable on city streets, in parking lots, or in areas such as a paved schoolyard where it would cause few problems because inactivity in a schoolyard is normal during rainy periods. If the structure cannot tolerate the additional weight imposed by the ponding or if the ponding causes a public hazard, more stringent design considerations may be appropriate.

Similar to the requirements for sanitary systems and per the local code authority, all systems must be properly tested upon completion.

CODES AND STANDARDS

Plumbing codes establish a minimum acceptable standard for the design and installation of various systems, including storm water. There are various model codes, but some states and large cities have adopted plumbing codes other than those usually associated with the region. Because of this lack of standardization, the actual plumbing code used for each specific project must be obtained from a responsible code official in the area.

The information pertaining to storm water design appears in the approved local plumbing code, which must be the primary source used for accepted methods and sizing. The tables and charts appearing in this chapter are used only to illustrate and augment discussions of sizing methods and procedures and design methods and should not be used for actual design purposes.

A variety of different codes are used to lay out and size the interior storm water system. Some codes that have been adopted by major cities use a specific figure for sizing roof drains and piping, based on roof areas (in square feet) for that city alone. Others use two tables: one to obtain the maximum rainfall rate for the area where the project is located and another to use that rainfall rate to find the size of the drain and pipe based on the contributing roof area.

MATERIALS

Materials acceptable to the AHJ are written in the the local code. The following discussion provides generally acceptable materials.

Materials for aboveground piping in buildings should be brass, copper pipe or tube, DWV, cast iron, galvanized or black steel, lead, aluminum, ABS, or PVC-DWV. Care should be taken when using plastic piping because of its higher expansion and contraction characteristics, required additional support and hanger spacing, and possible absorption of excessive noise. Exposed leaders or downspouts should be capable of withstanding all anticipated abuses, corrosion, weather, and expected expansion and contraction.

Underground piping should be cast iron (service or extra-heavy weight, depending on the loads exerted on the pipe), ductile iron, hard-temper copper, aluminum, ABS, PVC-DWV, concrete, or extra-strength vitrified clay. If plastic piping is used, a proper class B bedding must be provided for adequate laying and support of the pipe. Plastic piping does not have the scour resistance of metal piping, especially at the base elbow. Aluminum and other metallic pipe must be wrapped or coated when placed in corrosive soils. See other *Plumbing Engineering Design Handbook* chapters on piping and drainage for data on pipe schedules, joining methods, and plumbing drains.

INTERIOR BUILDING DRAINAGE SYSTEM DESIGN

General

The design of storm water drainage systems should be based on code requirements and sound engineering judgment. Special local conditions, building and site characteristics, and code requirements may necessitate a unique design. The designer should keep in mind that the codes are minimum standards only. All designs must meet or exceed the local code requirements. It should be remembered that the design of the interior roof drainage system is covered by code and does not leave much to the engineer's discretion.

General Design Criteria

The following items should be considered when establishing the storm water system:

1. Rainfall rate, snow depth, freezing conditions, snowmelt, frost line, and other conditions usually can be found in NWS or National Oceanic and Atmospheric Administration (NOAA) publications. Also, the local building department can provide the required information for local conditions.
2. The building's construction, including type of roof, pattern of drainage slopes, vertical wall

heights, parapet heights, scupper sizes and locations (if provided), emergency drain requirements and locations, pipe space allocations in the ceiling space, and wall and chase locations, among others, must be determined.

3. Minimum pipe size and slope, overflow requirements, extent of overflow pipe and discharge requirements, and method of connection to the public sewer are all code-related items. The method of disposal into the public sewer is also code mandated and must be followed. If such requirements are not available, use good engineering practices as outlined in this chapter. Methods of retention and detention are usually code- or locally mandated requirements. Several available methods, such as controlled-flow roof drainage, retention and detention basins, recharge basins and dry wells, could be used.
4. Site conditions, including location, size, topography, elevation, soil conditions and types, water table, location and pipe material of public storm sewer, location of existing manholes, and location of other utilities within the site, among others, must be determined.
5. The local code shall be consulted to determine the rainfall rate that is applicable for the design areas. A minimum design should be for a 10-year, five-minute storm for the building roof and site unless other factors are involved that require greater protection from flooding. Rarely is a shorter minimum economically justifiable.
6. Expansion and improper anchoring of the vertical pipe have caused roof drains to be pushed up above the roof deck, destroying the integrity of the roof waterproofing by tearing the flashing and the waterproofing membrane. This problem can be more apparent in high-rise buildings and buildings where the exposed leader is subject to cold rainwater or melting snow and ice that enter piping at the ambient temperature of the building. An expansion joint at the roof drain or a horizontal section of the branch line should be considered to accommodate the movement of the leader without affecting the roof drain. See Figure 4-1.
7. The horizontal section of the pipe and the roof drain body should be insulated, per cold water installations with a vapor barrier, to control condensation. See Figure 4-2. Low-temperature liquid flow in the piping causes condensation to form on the outside of the piping, possibly causing stain damage to the ceilings or, where exposed,

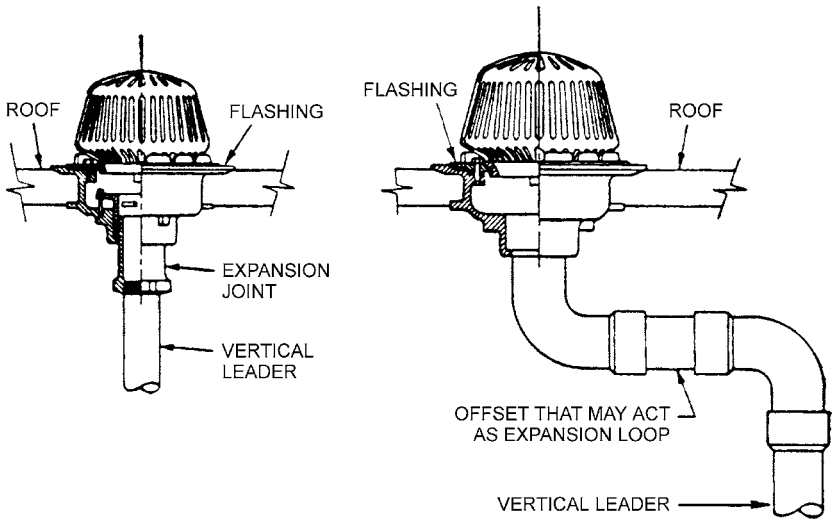


Figure 4-1 Typical Expansion Joint or Horizontal Offset

Source: Reprinted, by permission, from *Plumbing Design and Installation Reference Guide* (Hicks 1986).

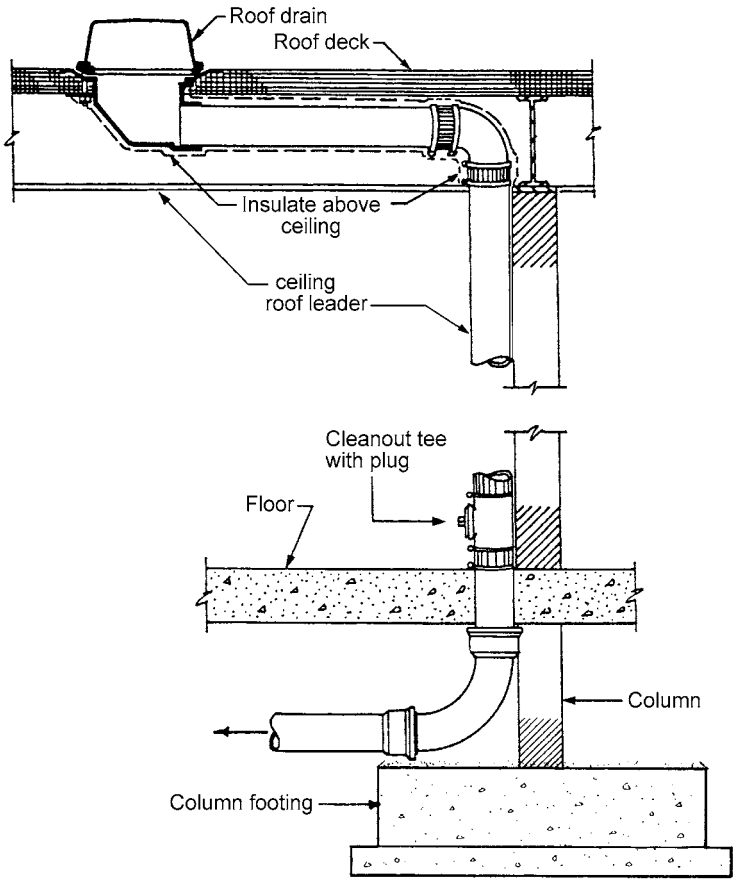


Figure 4-2 Typical Roof Drain and Roof Leader

Source: Reprinted, by permission, from *Cast Iron Soil Pipe and Fittings Engineering Manual* (Cast-Iron Soil Pipe Institute 1976).

drip marks on the flooring. This condensation usually extends 15 feet from the roof drain. Past this distance, the water is no longer cold enough to cause condensation.

8. Locating the vertical leaders within the building has several advantages: convenience, safety, appearance, and freeze protection. However, leaders located on the exterior can be installed at a much lower cost and do not take up valuable floor space.
9. Any piping layout must be coordinated with the other trades that may be affected, such as the architect for furring-in the proper columns for vertical leaders (also known as conductors or downspouts) and the structural engineer for pipe support and footing depths. Other utilities, such as piping, ductwork, and conduit runs, also may be affected.
10. If interior floor/hub drains, drains from lower roofs, clear-water wastes, or areaway drains are connected to the storm system inside the building (if allowed by the AHJ), the drains must connect at least 10 pipe diameters (10 ft [3.05 m] minimum) downstream of the last offset fitting. Clear-water wastes should be properly trapped and vented (see Figure 4-3). Traps must be the same size as the horizontal drain to which they are connected and should be provided with 4-in. (102-mm) minimum, deep-seal P-traps.

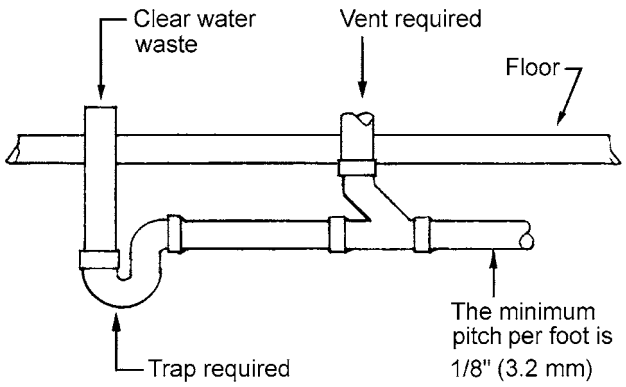


Figure 4-3 Clear-Water Waste Branches for Connection to Storm System

Source: Reprinted, by permission, from *The Illustrated National Plumbing Code Design Manual* (Ballanco & Shumann 1987).

11. Because of the excessive pressure that may exist in the leader, drains sometimes connect to a stack at a lower level. Above an offset, the drain becomes the vent to relieve the pressure, blowing water, and air. These drains are subject to backflow and should be routed separately to tie to the system 10 ft (3.05 m) beyond the elbow or offset. If backwater valves are used, they can cause the areas affected to not drain, and a buildup of water may occur. Horizontal piping of clear-water wastes and vents should be sized as a sanitary drainage branch. When such piping is tied to a leader, an upright wye should be utilized if possible.

To keep the number of leaders to a minimum, combine flows from more than one roof drain, clear-water wastes, or any combination thereof. The engineer must include the additional flows when calculating the leader size. This method is especially beneficial in keeping the costs of high-rise buildings contained.

If leaders are to be located at building columns, the column footings must be dropped correspondingly to accommodate the elbow at the base of the leader (stack). The base elbow should be a long sweep bend to help alleviate any excess pressures in the downstream pipe, and the elbow should be properly supported. The elbow may rest directly on the column footing, which acts as a support (see Figure 4-2).

A riser clamp should be provided at each floor line to support the leader. Also, a cleanout shall be provided at the base of all stacks to allow the base elbow to be rodded out as required by code.

If blockage occurs in the drainage system and backs up in the vertical leader, the piping system may be subject to a head pressure greater than the joining system is designed to withstand. To prevent joint failure, pressure pipe may be considered for the piping system. At the lower floors, all exterior leaders that may be damaged, such as occurs in parking or truck-loading areas, should be protected by metal or concrete guards or recessed in the wall and constructed of a ferrous alloy pipe, such as cast iron, to 5 ft (1.5 m) above the paving or loading platforms.

If an offset is 45 degrees or less, the leader can be sized as a vertical pipe. If the offset is greater than 45 degrees, the pipe must be sized as a horizontal pipe. To avoid stoppages, the leader cannot be reduced in size in the direction of flow throughout its length. For example, an 8-in. (203-mm) horizontal line must tie to an 8-in. (203-mm) vertical leader, even if Table 4-1 requires a smaller size for the vertical leader. Vertical leaders should be tied to the horizontal main with single-wye fittings. Double-wye fittings should be avoided.

Controlled-flow storm-drainage system.

Controlled-flow systems collect rainwater on the roof and release the flow slowly to the drainage system. These systems can provide significant installation savings because they require smaller roof drains, smaller diameter piping, and smaller diameter storm sewers. These systems also help alleviate flooding in overtaxed public storm sewers or drainage canals during heavy rainfalls. The impact on the sewage treatment plant for a combined storm/sanitary sewer (where allowed)

Table 4-1 Sizes of Roof Drains and Vertical Pipes

Diameter of Leader, in. (mm) Dimensions of Leader, in. (mm)	Cross-Sectional Area, in.^{2} (cm^2)	Water Contact Area, in.^{2} (cm^2)	Maximum Discharge Capacity, gpm (L/s)[a]
2 (50.8)	3.14 (20.3)	6.28 (40.5)	30 (1.2)
2×2 (50.8×50.8)	4.00 (25.8)	8.00 (51.6)	30 (1.2)
1½×2½ (38.1×63.5)	3.75 (24.2)	8.00 (51.6)	30 (1.2)
2½ (63.5)	4.91 (31.7)	7.85 (50.6)	54 (3.4)
2½×2½ (63.5×63.5)	6.25 (40.3)	9.00 (58.1)	54 (3.4)
3 (76.2)	7.07 (45.6)	9.42 (60.8)	92 (5.8)
2×4 (50.8×101.6)	8.00 (51.6)	12.00 (77.4)	92 (5.8)
2½×3 (63.5×76.2)	7.50 (48.4)	11.00 (71.0)	92 (5.8)
4 (101.6)	12.57 (81.1)	12.57 (81.1)	192 (12.1)
3×4¼ (76.2×107.6)	12.75 (82.3)	14.50 (93.6)	192 (12.1)
3½×4 (88.9×101.6)	14.00 (90.3)	14.00 (90.3)	192 (12.1)
5 (127)	19.06 (123.0)	15.07 (97.2)	360 (22.7)
4×5 (101.6×127)	20.00 (129.0)	18.00 (116.1)	360 (22.7)
4½×4½ (114.3×114.3)	20.25 (130.6)	18.00 (116.1)	360 (22.7)
6 (152.4)	28.27 (183.4)	18.85 (121.6)	563 (35.5)
5×6 (127×152.4)	30.00 (193.5)	22.00 (141.9)	563 (35.5)
5½×5½ (139.7×139.7)	30.25 (195.2)	22.00 (141.9)	563 (35.5)
8 (203.2)	50.27 (324.3)	25.14 (162.2)	1208 (76.2)
6×8 (152.4×203.2)	48.00 (309.7)	28.00 (180.6)	1208 (76.2)

[a] With approximately 1¾-in. (45-mm) head of water at the drain.

is considerably lessened by the use of controlled-flow roof-drainage systems.

Controlled-flow systems should not be used if the roof is used for functions precluding water storage, such as a sundeck or a parking level, or if not allowed by the AHJ. Holding the water on the roof increases structural costs and may require a different roof-covering material.

The flow-control device should be installed on the drain so the rainwater discharge rate does not exceed the rate calculated to discharge into the site system. This means rainwater will pond on the roof. A typical controlled-flow roof drain is illustrated in Figure 4-4. The roof design for controlled-flow roof drainage should be based on a minimum 30 lb/ft^2 (1.44 kPa) loading to provide a safety factor above the 15.6 lb/ft^2 (0.75 kg/m^2) represented by the 3-in. (76.2-mm) design depth of water. The roof should be level, and 45-degree cants should be installed at any wall or parapet. The flashing should extend at least 6 in. (152.4 mm) above the roof level. Doors opening onto the roof must be provided with a curb at least 4 in. (101.6 mm) high. Flow-control devices should be protected by strainers, and in no case should the roof surface in the vicinity of the drain be recessed to create a reservoir.

Roof drain manufacturers have done much research on engineering criteria and parameters regarding the head of water on the roof for the weir design in controlled-flow roof drains, and they have established suggested design procedures with flow capacities and charts.

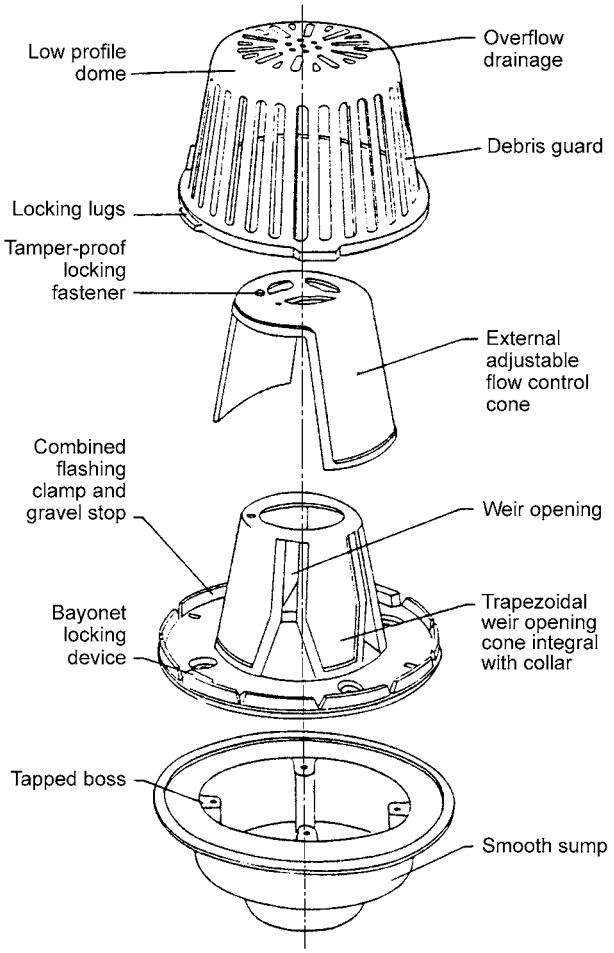


Figure 4-4 Example of a Controlled-Flow Drain

Source: Reprinted, by permission, from the Jay R. Smith catalog.

Roof Drainage

Coordination The building roof transfers the combined weight of live and dead loads (with the proper additional safety factor) to the supporting structure. Live loads include snow, rain, wind, and water on roof. Dead loads include all mechanical and electrical equipment and the roof deck.

Locating the roof drains should be a cooperative effort among the architect, structural engineer, and plumbing engineer. The architect is familiar with the building construction, parapets, walls, chase locations, available headroom for pipe runs, roof construction, and waterproofing membrane. The structural engineer is familiar with the structural support layout, roof slopes, column orientation, footing sizes and depths, and maximum allowable roof loading. The plumbing engineer can provide information concerning the maximum roof areas per drain, wall and column furring-out requirements, headroom requirements, ceiling space requirements, minimum footing depths, and possible benefits of ponding. The plumbing engineer also should ensure the drains are located in the low points of the roof to limit deflec-

tion—which could cause ponding and shifting of the roof low point—and to minimize the horizontal piping runs.

Drain location The following are generally accepted minimum dimensions. It is advisable to locate drains closer than these minimums. The plumbing engineer is under no obligation to follow these guidelines if not possible.

The roof drain should not be farther than 50 ft (15.2 m) from the end of a valley. The maximum distance between drains should be 200 ft (61 m). With a roof slope of ¼ in./ft (21 mm/m) and a distance of 20 ft (6.1 m) from the roof high point to the roof drain, the depth of water at the drain is approximately 3 in. (76.2 mm). The parapet wall scuppers should be set 4 in. (101.6 mm) above the roof low point. A maximum weight at the drain, which is transmitted to the roof structural supports, should be 26 lb/ft^2 (126.9 kg/m^2) live load, which would exceed the capacity of a normal 20 lb/ft^2 (97.7 kg/m^2) roof live load (30 lb/ft^2 (146.5 kg/m^2) live load in snow areas). The designer must closely coordinate the drainage system design with the roof structural design.

The roof drain should be a minimum 12–18 in. (0.30–0.46 m) from any parapet wall or other obstruction to allow for proper flashing. The drains should be located a minimum 10 ft (3.05 m) from any building opening or air intake. The minimum roof drain size should be 2 in. (50.8 mm) for decks and where the accumulation of leaves is possible. In selecting the roof drain size, all horizontal roof area from adjacent high points that slope to the drain must be taken into account, as well as 50% of the vertical wall area that is associated with the drain.

All penetrations through the roof must be sealed watertight. Metal flashing, 18–24 in. (0.46–0.61 m) square or round, often is suggested around the roof drain because of the heavy wear and the likelihood that the drain will present leakage problems. The flashing usually is placed between the roofing plies. This flashing also may be used to form a roof sump to collect storm water prior to its entering the drain. (A square opening is easier to cut into the roof than a round opening.)

Most codes require a minimum two roof drains on roofs with areas less than 10,000 ft^2 (929 m^2), and four drains on roofs exceeding 10,000 ft^2 (929 m^2). Some codes allow a maximum 10,000-ft^2 (929-m^2) roof area per drain, but this may require the drains and associated piping to be excessively large. To control labor costs and avoid potential furring and footing depth problems with the piping, a maximum 5,000-ft^2 (465-m^2) area per drain and a maximum 8-in. (203-mm) drain and leader size should be considered. Good engineering practice is to place at least two roof drains in any roof area except for the smallest.

The roof drain shall be installed a minimum 12–18 in. (0.30–0.46 m) from any parapet wall or other obstruction to allow for the proper flashing. The drains shall be located a minimum 10 ft (3.05 m) from any building opening or air intake.

The designer must be aware of the location of roof expansion joints. These joints may prohibit rainwater flow across the roof, thus dividing the roof into fixed drainage areas.

Adjacent surfaces The roof drain also receives rainwater from other roof areas such as penthouses that discharge onto the roof area being calculated and from the adjacent vertical walls. Some codes require 50% of two adjacent vertical wall areas to be added to the horizontal roof area. Other codes use complex formulas for various wall configurations. These formulas are normally excessive for roof areas that have more than one vertical wall or multiple-story walls with runoff directed to the horizontal roof surface. Rain seldom falls in a totally vertical direction. Depending on wind conditions, the angle of rainfall could be as much as 60 degrees to the vertical or more. Wind, particularly with high-rise buildings, can blow rain off a vertical wall and away from building surfaces.

Typical roof drains Standard roof drains have three basic parts: strainer, flashing ring with gravel stop, and drain body or sump. Strainers may be cast-iron coated or polyethylene dome type (for use where leaves may accumulate) or flat type (for sunroofs, areaways, and parking decks). Standard roof drain construction is shown in Figure 4-2. Typical roof drain types for all common roof types are depicted in Figure 4-5.

When selecting the type of drain to use, the engineer must know the roof construction and thickness. The roof may be flat or pitched, used to retain water for cooling purposes, have a sprinkler system for cooling purposes, used as a terrace, used as a parking deck with heavy traffic, or used to retain rainwater to limit the effluent to the storm sewer system.

Roof drains, other than for flat decks, should have dome strainers that extend a minimum 4 in. (101.6 mm) above the roof surface immediately adjacent to the drain. Strainers for roof drains shall have available inlet areas not less than 1½ times the area of the leader that serves the drain. Dome-type strainers are required to prevent the entrance of leaves, debris, birds, and small animals. Flat-deck strainers, for use on sun decks, promenades, and parking garages where regular maintenance may be expected, shall have available inlet areas not less than two times the area of the leader that serves the drain. Heel-proof strainers may be required if the roof is subject to pedestrian traffic.

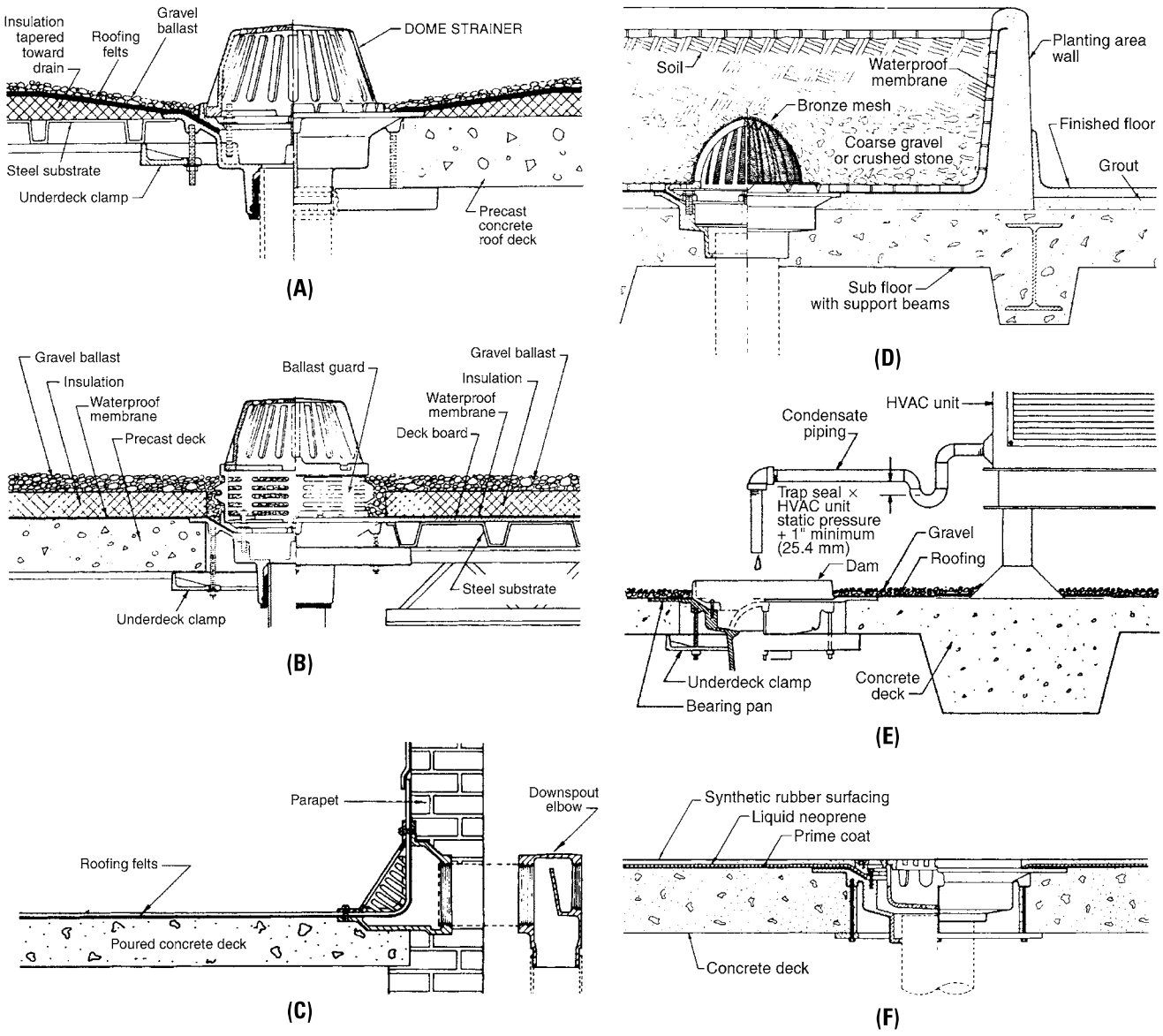


Figure 4-5 Typical Roof-Drain Installations: (A) Steel or Concrete Roof Deck with Insulation Tapered to the Drain; (B) Precast or Steel Substrate with an Inverted-Membrane Type Roof; (C) Parapet Drain in Poured Concrete Deck with Downspout Elbow; (D) Planting Area Drain in Raised Planter Box; (E) Indirect Waste for HVAC Equipment on Concrete Roof Deck; (F) Promenade Drain in Precast Deck with Synthetic Flooring and Underdeck Clamp.

Source: Reprinted by permission of Tyler Pipe/The Wade Division, Tyler, Texas.

The flashing ring is used to attach the roof waterproofing membrane to the drain body to maintain the watertight integrity of the roof. An underdeck clamp should be utilized to secure the drain to the metal or wood decking. Poured concrete roofs do not require these clamps. Drain receivers should be used on drains for concrete decks. Drains that may receive sand and grit should be provided with sediment buckets.

Secondary roof drainage systems

Secondary (emergency) roof drainage is required in case the primary drains are blocked. This drainage consists of either scuppers through the sides of the building or separate roof drains installed at a higher elevation than the primary roof drain. If scuppers are utilized, they should be placed ½ in. (12.7 mm) above the maximum designated head, 4 in. (101.6 mm) above the roof level. One scupper, or secondary drain, should be provided for each roof drain.

Codes require the primary drainage system to be designed for the local code value based on the roof area (in square feet). The secondary drainage system shall handle overflow occurring when the primary drain is clogged. These same codes may require secondary drainage systems to be designed for more stringent values, such as those required when the primary drainage system is clogged. The design,

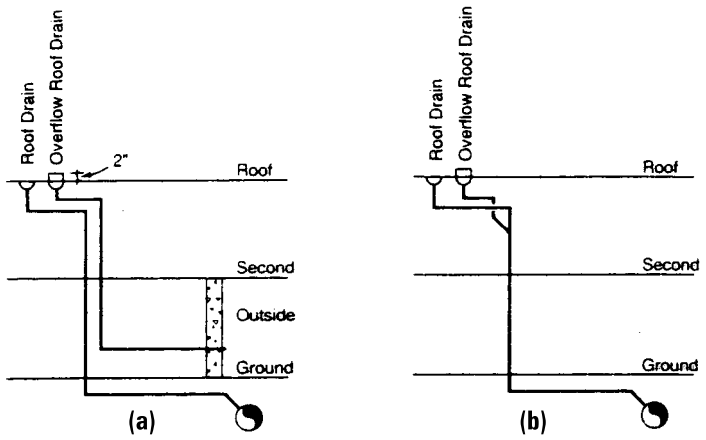


Figure 4-6 Overflow (Secondary) Drainage Piping Discharge Locations, (a) Above Ground, (b) Primary Drain Connection

size, and placement of secondary roof drains are mandated by local code requirements. Additonally, if a rainfall heavier than the design rainfall occurred, the two systems should work together to carry the increased load.

Secondary drainage systems may be either scuppers, which allow the entrapped rainwater to overflow the roof, or a separately piped drainage system. Table 4-2 lists the discharge from scuppers for various dimensions. The secondary piping system shall be designed similarly to the primary drainage system. Some codes and designers prefer the discharge from the secondary drainage system to be readily noticeable to ensure the prompt repair of the primary drainage system.

Overflow (secondary) drains and piping sometimes are mandated by the local code or AHJ. Sizing is based on code requirements, the same as for roof drains. These drains shall be installed separately from the primary system as mandated by code requirements, and installed separately to several possible disposal points. One of them, illustrated in Figure 4-6a, is above grade so building personnel can see that the primary drainage system is blocked. Another, illustrated in Figure 4-6b, discharges directly into the main drainage system adjacent to the primary drain. A third possibility is connecting a separate system to the main house drain before or after leaving the building.

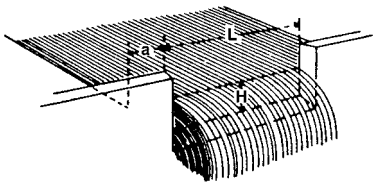


Table 4-2 Discharge from Rectangular Scuppers–Gallons per Minute

Water head (inches)	Width of scupper–inches					
	6	12	18	24	30	36
0.5	6	13	19	25	32	38
1	17	35	53	71	89	107
1.5	31	64	97	130	163	196
2		98	149	200	251	302
2.5		136	207	278	349	420
3		177	271	364	458	551
3.5			339	457	575	693
4			412	556	700	844

Notes: Table 4-2 is based on discharge over a rectangular weir with end contractions
Head is depth of water above bottom of scupper opening
Height of scupper opening should be 2 times the design head.
Coordinate the allowable head of water with the structural design of the roof.

Rainfall Rates

The rainfall rate for roof drain sizing shall be established by the local code or AHJ. Table 4-3 lists the maximum rainfall rates for various U.S. cities. The rates for various rainfall intensities that often are used without calculation—duration, length, and return period—also are listed. Using Table 4-3 a designer can select a precipitation frequency value for a 10- or 100-year return period with durations of five, 15, and 60 minutes. Other return periods and durations can be interpolated between the values listed. (Table 4-3 is included for general reference and is not intended for specific design.)

The selection of the duration and frequency of a storm for the site as a whole is discussed later in this chapter under the site drainage requirements. If the code for roof drains provides this information, first establish the closest city and determine the rainfall intensity in in./hour. Then go to the code chart and use this figure for sizing purposes. If exact figures are not found, either mathematically interpolate between the figures shown or refer to recommendations by the local code officials. It also may be possible to find a rate one-half of the value of the actual rainfall as provided in the code for roof drains.

Interior Pipe Sizing and Layout Criteria

The interior storm-drainage systems required for a building of simple design are shown in Figures 4-7 and 4-8. The following points should be considered:

1. The contributing area of each roof drain shall be calculated and noted.
2. Roof drains and vertical pipe are sized as indicated in code requirements, depending on the square footage of the contributing roof area. Table 4-1 shows sizes based on the rate of discharge. Based on tests conducted by a major manufacturer, flow (gpm) through individual roof drains is depicted in Figure 4-9.
3. Where there is an adjacent vertical wall, the drain size is based on the horizontal collection area

Table 4-3 Maximum Rates of Rainfall for Various US Cities, in./h (mm/h)

	Frequency and Duration of Storm			
	100-Yr., 5 Min.	100-Yr., 15-Min.	100-Yr., 60-Min.	10-Yr., 5-Min.
Alabama				
Birmingham	10.08(256.0)	7.28 (184.9)	3.7 (94.0)	7.50(190.5)
Huntsville	9.96(253.0)	7.08 (179.8)	3.3 (83.8)	7.30(185.4)
Mobile	10.80(274.3)	8.00 (203.2)	4.5 (114.3)	8.18(207.8)
Montgomery	10.26(260.6)	7.60 (193.0)	3.8	7.73(196.4)
Alaska				
Fairbanks	Use NOAA atlas for detailed state precipitation map.		1.00 (25.4)	3.70 (94.0)
Juneau			0.60 (15.2)	1.70 (43.2)
Arizona				
Phoenix	Use NOAA atlas for detailed state precipitation map.		2.2 (55.9)	4.30(109.2)
Arkansas				
Bentonville	10.20(259.1)	7.24 (183.9)	3.62 (91.9)	7.38(187.4)
Ft. Smith	10.20(259.1)	7.28 (184.9)	3.9 (99.1)	7.41(188.1)
Little Rock	9.96(253.0)	7.16 (181.9)	3.7 (94.0)	7.36(186.9)
California				
Eureka	Use NOAA atlas for detailed state precipitation map.		1.5 (38.1)	2.70 (68.6)
Fresno			1.90 (48.3)	3.60 (91.4)
Los Angeles			2.00 (50.8)	3.60 (91.4)
Mt. Tamalpais			1.50 (38.1)	2.50 (63.5)
Pt. Reyes			1.50 (38.1)	2.40 (61.0)
Red Bluff			1.75 (44.5)	3.80 (96.5)
Sacramento			1.30 (33.0)	3.00 (76.2)
San Diego			1.50 (38.1)	3.30 (83.8)
San Francisco			1.50 (38.1)	3.00 (76.2)
San Jose			1.50 (38.1)	2.00 (50.8)
San Luis Obispo			1.5 (38.1)	3.10 (78.7)
Colorado				
Denver	Use NOAA atlas for detailed state precipitation map.		2.2 (55.9)	5.70(144.8)
Grand Junction			1.70 (43.2)	3.00 (76.2)
Pueblo			2.50 (63.5)	5.00(127.0)
Wagon Wheel Gap			1.90 (48.3)	3.60 (91.4)
Connecticut				
Hartford	8.70(221.0)	5.96 (151.4)	2.8 (71.1)	6.23(158.2)
New Haven	9.00(228.6)	6.00 (152.4)	3.0	6.42(163.1)
Delaware				
Dover	9.48(240.8)	7.00 (177.8)	3.5 (88.9)	6.93(176.1)
District of Columbia				
Washington	9.72(246.9)	7.22 (183.4)	4.0 (101.6)	7.10(180.4)
Florida				
Jacksonville	10.08(256.0)	8.08 (205.2)	4.3 (109.2)	7.86(199.6)
Key West	9.12(231.6)	7.24 (183.9)	4.28(108.7)	7.07(179.6)
Miami	9.84(249.9)	8.80 (223.5)	4.5 (114.3)	7.69(195.4)
Orlando	10.80(274.3)	8.40 (213.4)	4.50(114.3)	8.42(213.9)
Pensacola	10.80(274.3)	8.08 (205.2)	4.60(116.8)	8.18(207.8)
Tampa	10.80(274.3)	8.40 (213.4)	4.2 (106.7)	8.33(211.6)
Tallahassee	10.50(266.7)	8.04 (204.2)	4.1	8.05(204.4)
Georgia				
Atlanta	9.90(251.5)	7.12 (180.9)	3.5 (88.9)	7.33(186.2)
Augusta	9.84(249.9)	7.20 (182.9)	4.00(101.6)	7.33(186.2)
Macon	10.08(256.0)	7.40 (188.0)	3.7 (94.0)	7.62(193.6)
Savannah	9.60(243.8)	7.60 (193.0)	4.0 (101.6)	7.44(188.9)
Thomasville	10.44(265.2)	7.88 (200.2)	4.0 (101.6)	7.96(202.2)
Hawaii				
Honolulu	Use NOAA atlas for detailed state precipitation map.		3.00 (76.2)	5.2 (132.1)
Idaho				
Boise	Use NOAA atlas for detailed state precipitation map.		1.0 (25.4)	2.7 (68.6)
Lewiston			1.0 (25.4)	3.1 (78.7)
Pocatello			1.20 (30.5)	3.7 (94.0)
Illinois				
Cairo	9.84(249.9)	6.96 (176.8)	3.40 (86.4)	7.16(181.8)
Chicago	9.30(236.2)	6.60 (167.6)	2.7 (68.6)	6.76(171.8)
Peoria	9.72(246.9)	6.88 (174.8)	2.9	7.04(178.9)
Springfield	9.84(249.9)	7.12 (180.9)	3.0 (76.2)	7.10(180.3)

Table 4-3 Maximum Rates of Rainfall for Various US Cities, in./h (mm/h) Continued

	Frequency and Duration of Storm			
	100-Yr., 5 Min.	100-Yr., 15-Min.	100-Yr., 60-Min.	10-Yr., 5-Min.
Indiana				
Evansville	9.72(246.9)	6.80 (172.7)	3.0 (76.2)	7.04(178.9)
Ft. Wayne	9.24(234.7)	6.48 (164.6)	2.85 (72.4)	6.65(168.9)
Indianapolis	9.42(239.3)	6.60 (167.6)	2.8 (71.1)	6.82(173.2)
Terre Haute	9.66(245.4)	6.72 (170.7)	3.18 (80.8)	7.02(178.2)
Iowa				
Charles City	9.96(253.0)	7.08 (179.8)	3.35 (85.1)	7.06(179.4)
Davenport	9.84(249.9)	7.00 (177.8)	3.0 (76.2)	7.04(178.7)
Des Moines	10.32(262.1)	7.28 (184.9)	3.4 (86.4)	7.31(185.7)
Dubuque	9.84(249.9)	6.94 (176.3)	3.30 (83.8)	7.01(178.0)
Keokuk	9.96(253.0)	7.08 (179.8)	3.30 (83.8)	7.15(181.6)
Sioux City	10.44(265.2)	7.32 (185.9)	3.6 (91.4)	7.34(186.3)
Kansas				
Concordia	10.44(265.2)	7.48 (190.0)	3.75 (95.3)	7.37(187.1)
Dodge City	10.20(259.1)	7.24 (183.9)	3.45 (87.6)	7.20(182.8)
Goodland	9.96(253.0)	6.80 (172.7)	3.5 (88.9)	6.85(174.1)
Iola	10.44(265.2)	7.32 (185.9)	3.62 (91.9)	7.40(187.9)
Topeka	10.50(266.7)	7.40 (188.0)	3.8 (96.5)	7.39(187.8)
Wichita	10.50(266.7)	7.50 (190.5)	3.9 (99.1)	7.51(190.8)
Kentucky				
Lexington	9.36(237.7)	6.56 (166.6)	2.9	6.82(173.3)
Louisville	9.36(237.7)	6.56 (166.6)	2.8 (71.1)	6.88(174.8)
Louisiana				
Alexandria	10.50(266.7)	7.96 (202.2)	4.30(109.2)	7.99(202.9)
New Orleans	10.92(277.4)	8.20 (208.3)	4.5 (114.3)	8.30(210.7)
Shreveport	10.44(265.2)	7.60 (193.0)	4.0 (101.6)	7.81(198.4)
Maine				
Eastport	6.60(167.6)	4.60 (116.8)	2.20 (55.9)	4.63(117.6)
Portland	7.56(192.0)	5.12 (130.1)	2.25 (57.2)	5.36(136.1)
Presque Isle	6.96(176.8)	4.68 (118.9)	2.05 (52.1)	4.91(124.7)
Maryland				
Baltimore	9.72(246.9)	7.24 (183.9)	3.5 (88.9)	7.11(180.7)
Cambridge	9.60(243.8)	7.24 (183.9)	3.25 (82.6)	7.05(179.0)
Cumberland	9.30(236.2)	6.56 (166.6)	2.75 (69.9)	6.76(171.8)
Massachusetts				
Boston	7.20(182.9)	5.20 (132.1)	2.7 (68.6)	5.26(133.5)
Nantucket	7.20(182.9)	5.12 (130.1)	2.50 (63.5)	5.32(135.0)
Springfield	8.64(219.5)	6.00 (152.4)	2.70 (68.6)	6.20(157.5)
Michigan				
Alpena	8.64(219.5)	5.60 (142.2)	2.50 (63.5)	6.02(153.0)
Detroit	8.88(225.6)	5.92 (150.4)	2.5 (63.5)	6.37(161.7)
Escanaba	8.88(225.6)	5.60 (142.2)	2.40 (61.0)	6.22(158.0)
Grand Rapids	9.00(228.6)	6.00 (152.4)	2.6 (66.0)	6.48(164.6)
Houghton	8.40(213.4)	5.20 (132.1)	2.40 (61.0)	6.00(152.5)
Lansing	9.24(234.7)	6.10 (154.9)	2.80 (71.1)	6.62(168.1)
Marquette	8.40(213.4)	5.20 (132.1)	2.40 (61.0)	5.97(151.7)
Port Huron	8.76(222.5)	5.80 (147.3)	2.70 (68.6)	6.31(160.4)
Ste. Marie	7.80(198.1)	5.20 (132.1)	2.25 (57.2)	5.59(141.9)
Minnesota				
Duluth	9.48(240.8)	6.40 (162.6)	2.6 (66.0)	6.70(170.1)
Minneapolis	9.96(253.0)	6.88 (174.8)	3.0 (76.2)	7.00(177.8)
Moorhead	10.02(254.4)	6.88 (174.8)	3.20 (81.3)	6.88(174.7)
Worthington	10.50(266.7)	7.30 (185.4)	3.4 (86.4)	7.29(185.2)
Mississippi				
Biloxi	11.04(280.4)	8.10 (205.7)	4.5 (114.3)	8.35(212.1)
Meridian	10.32(262.1)	7.64 (194.1)	4.05(102.9)	7.82(198.6)
Tupeto	9.96(253.0)	7.20 (182.9)	3.60 (91.4)	7.72(196.0)
Vicksburg	10.44(265.2)	7.68 (195.1)	4.20(106.7)	7.87(199.9)
Missouri				
Columbia	10.08(256.0)	7.20 (182.9)	3.80 (96.5)	7.20(183.0)
Hannibal	10.02(254.5)	7.08 (179.8)	3.75 (95.3)	7.18(182.3)
Kansas City	10.44(265.2)	7.34 (186.4)	3.65 (92.7)	7.37(187.1)
Poplar Bluff	9.96(253.0)	7.08 (179.8)	3.55 (90.2)	7.27(184.6)
St. Joseph	10.44(265.2)	7.36 (186.9)	3.65 (92.7)	7.37(187.1)
St. Louis	9.90(251.5)	7.00 (177.8)	3.2 (81.3)	7.12(180.9)
Springfield	10.14(257.6)	7.20 (182.9)	3.7 (94.0)	7.23(183.7)

Table 4-3 Maximum Rates of Rainfall for Various US Cities, in./h (mm/h) Continued

	Frequency and Duration of Storm			
	100-Yr., 5 Min.	100-Yr., 15-Min.	100-Yr., 60-Min.	10-Yr., 5-Min.
Montana				
Havre	Use NOAA atlas for detailed state precipitation map.		1.60 (40.6)	4.30 (109.2)
Helena			1.50 (38.1)	3.80 (96.5)
Kalispell			1.20 (30.5)	3.30 (83.8)
Miles City			2.15 (54.6)	7.00 (177.8)
Missoula			1.30 (33.0)	2.70 (68.6)
Nebraska				
Lincoln	10.50 (266.1)	7.44 (189.0)	3.80 (96.5)	7.39 (187.8)
North Platte	10.02 (254.5)	6.80 (172.7)	3.35 (85.1)	6.88 (174.7)
Omaha	10.50 (266.1)	7.38 (187.5)	3.6 (91.4)	7.39 (187.8)
Scottsbluff	9.60 (243.8)	6.40 (162.6)	3.15 (80.0)	6.41 (162.7)
Valentine	9.96 (253.0)	6.84 (173.7)	3.25 (82.6)	6.78 (172.2)
Nevada				
Reno	Use NOAA atlas for detailed state precipitation map.		1.2 (30.5)	3.20 (81.3)
Tonopah			1.00 (25.4)	3.00 (76.2)
Winnemucca			1.00 (25.4)	2.70 (68.6)
New Hampshire				
Berlin	7.80 (198.1)	5.36 (136.1)	2.2 (55.9)	5.64 (143.4)
Concord	7.92 (201.2)	5.60 (142.2)	2.50 (63.5)	5.73 (145.5)
New Jersey				
Atlantic City	9.36 (237.7)	6.72 (170.7)	3.4 (86.4)	6.82 (173.3)
Paterson	9.24 (234.7)	6.52 (165.6)	3.00 (76.2)	6.65 (168.9)
Trenton	9.30 (236.2)	6.72 (170.7)	3.2 (81.3)	6.71 (170.3)
New Mexico				
Albuquerque	Use NOAA atlas for detailed state precipitation map.		2.00 (50.8)	3.70 (94.0)
Roswell			2.60 (66.0)	5.40 (137.2)
Santa Fe			2.00 (50.8)	4.40 (111.8)
New York				
Albany	9.12 (231.6)	6.24 (158.5)	2.50 (63.5)	6.48 (164.5)
Binghamton	8.82 (224.0)	5.72 (145.3)	2.4 (61.0)	6.34 (161.1)
Buffalo	8.40 (213.4)	5.34 (135.6)	2.30 (58.4)	5.97 (151.7)
Canton	8.10 (205.7)	5.24 (133.1)	2.25 (57.2)	5.84 (148.3)
Messena	7.86 (199.6)	5.20 (132.1)	2.25 (57.2)	5.61 (142.6)
New York	9.24 (234.7)	6.40 (162.6)	3.1 (78.7)	6.65 (168.9)
Oswego	8.28 (210.3)	5.50 (139.7)	2.20 (55.9)	5.81 (147.6)
Rochester	8.28 (210.3)	5.20 (132.1)	2.20 (55.9)	5.80 (147.3)
Syracuse	8.64 (219.5)	5.32 (135.1)	2.4 (61.0)	6.06 (154.0)
North Carolina				
Asheville	9.60 (243.8)	6.84 (173.7)	3.2 (81.3)	6.99 (177.5)
Charlotte	9.84 (249.9)	6.92 (175.8)	3.4 (86.4)	7.24 (183.9)
Greensboro	9.84 (249.9)	7.00 (177.8)	3.30 (83.8)	7.22 (183.4)
Hatteras	9.36 (237.7)	6.88 (174.8)	4.15 (105.4)	7.07 (179.6)
Raleigh	9.84 (249.9)	7.28 (184.9)	4.0 (101.6)	7.29 (185.1)
Wilmington	9.48 (240.8)	7.36 (186.9)	4.4 (111.8)	7.14 (181.4)
North Dakota				
Bismarck	9.84 (249.9)	6.40 (162.6)	2.7 (68.6)	6.57 (166.9)
Devil's Lake	9.96 (253.0)	6.48 (164.6)	2.82 (71.6)	6.67 (169.5)
Williston	9.00 (228.6)	6.00 (152.4)	2.60 (66.0)	6.00 (152.5)
Ohio				
Cincinnati	9.30 (236.2)	6.52 (165.6)	2.8 (71.1)	6.79 (172.4)
Cleveland	8.76 (222.5)	5.92 (150.4)	2.4 (61.0)	6.31 (160.4)
Columbus	9.00 (228.6)	6.42 (163.1)	2.7 (68.6)	6.57 (166.9)
Steubenville	8.88 (225.6)	6.00 (152.4)	2.70 (68.6)	6.44 (163.7)
Toledo	8.94 (227.1)	6.04 (153.4)	2.6 (66.0)	6.46 (164.1)
Oklahoma				
Hooker	10.08 (256.0)	7.12 (180.8)	3.30 (83.8)	7.08 (180.0)
Oklahoma City	10.50 (266.7)	7.42 (188.5)	4.1	7.58 (192.6)
Tulsa	10.38 (263.7)	7.40 (188.0)	3.80 (96.5)	7.52 (190.9)
Oregon				
Baker	Use NOAA atlas for detailed state precipitation map.		0.90 (22.9)	3.30 (83.8)
Portland			1.3 (33.0)	3.00 (76.2)
Roseburg			1.40 (35.6)	3.60 (91.4)

Table 4-3 Maximum Rates of Rainfall for Various US Cities, in./h (mm/h) Continued

	Frequency and Duration of Storm			
	100-Yr., 5 Min.	100-Yr., 15-Min.	100-Yr., 60-Min.	10-Yr., 5-Min.
Pennsylvania				
Bradford	8.64(219.5)	5.60 (142.4)	2.50 (63.5)	6.11(155.2)
Erie	8.64(219.5)	5.68 (144.3)	2.4 (61.0)	6.14(156.0)
Harrisburg	9.36(237.7)	6.92 (175.8)	2.9	6.76(171.8)
Philadelphia	9.36(237.7)	6.88 (174.8)	3.2 (81.3)	6.76(171.8)
Pittsburg	8.82(224.0)	5.96 (151.4)	2.5 (63.5)	6.40(162.6)
Reading	9.36(237.7)	6.80 (172.7)	3.05 (77.5)	6.81(172.9)
Scranton	9.12(231.6)	6.20 (157.5)	2.8 (71.1)	6.56(166.8)
Puerto Rico				
San Juan	Use NOAA atlas for detailed state precipitation map.		2.50 (63.5)	5.70(144.8)
Rhode Island				
Block Island	8.16(207.3)	5.54 (140.7)	2.75 (69.9)	5.90(149.8)
Providence	7.80(198.1)	5.40 (137.2)	2.9	5.64(143.4)
South Carolina				
Charleston	9.36(237.7)	7.48 (190.0)	4.1	7.24(183.8)
Columbia	9.90(251.5)	6.40 (162.6)	3.5 (88.9)	7.35(186.6)
Greenville	9.84(249.9)	7.36 (186.9)	3.3 (83.8)	7.17(182.1)
South Dakota				
Aberdeen	10.02(254.5)	7.08 (179.8)	3.30 (83.8)	6.82(173.2)
Pierre	9.90(251.5)	6.80 (172.7)	3.10 (78.7)	6.69(169.9)
Rapid City	9.84(249.9)	6.36 (161.5)	2.7 (68.6)	6.51(165.4)
Yankton	10.44(265.2)	7.28 (184.9)	3.62 (91.9)	7.25(184.1)
Tennessee				
Chattanooga	9.84(249.9)	7.00 (177.8)	3.50 (88.9)	7.32(188.9)
Knoxville	9.00(228.6)	6.60 (167.6)	3.1 (78.7)	6.66(169.2)
Memphis	9.96(253.0)	7.14 (181.4)	3.5 (88.9)	7.37(187.3)
Nashville	9.84(249.9)	6.92 (175.8)	3.0 (76.2)	7.10(180.3)
Texas				
Abilene	10.38(263.7)	7.32 (185.9)	3.70 (94.0)	7.43(188.7)
Amarillo	10.20(259.1)	7.24 (183.9)	3.55 (90.2)	7.30(185.4)
Austin	10.50(266.7)	7.68 (195.1)	4.25(108.0)	7.69(195.3)
Brownsville	10.68(271.3)	7.92 (201.2)	4.40(111.8)	7.89(200.4)
Corpus Christi	10.68(271.3)	8.00 (203.2)	4.6 (116.8)	7.92(201.2)
Dallas	10.50(266.7)	7.50 (190.5)	4.2 (106.7)	7.63(193.8)
Del Rio	10.20(259.1)	7.29 (185.1)	4.00(101.6)	7.32(186.0)
El Paso	6.60(167.6)	5.60 (142.2)	2.0 (50.8)	4.57(116.1)
Fort Worth	10.50(266.7)	7.50 (190.5)	3.90 (99.1)	7.60(193.1)
Galveston	10.92(277.4)	8.10 (205.7)	4.70(119.4)	8.30(210.7)
Houston	10.80(274.3)	8.04 (204.2)	4.5 (114.3)	8.18(207.8)
Palestine	10.44(265.2)	7.60 (193.0)	4.00(101.6)	7.79(197.8)
Port Arthur	10.92(277.4)	8.08 (205.2)	4.65(118.1)	8.30(210.7)
San Antonio	10.50(266.7)	7.70 (195.6)	4.4 (111.8)	7.61(193.2)
Tyler	10.38(263.7)	7.52 (191.0)	3.90 (99.1)	7.76(197.0)
Utah				
Modena	Use NOAA atlas for detailed state precipitation map.		1.50 (38.1)	3.80 (96.5)
Salt Lake City			1.30 (33.0)	3.40 (86.4)
Vermont				
Brattleboro	8.40(213.4)	5.88 (149.4)	2.40 (61.0)	6.02(152.9)
Burlington	8.16(207.3)	5.52 (140.2)	2.3	5.75(146.0)
Rutland	8.28(210.3)	5.60 (142.2)	2.4 (61.0)	5.92(150.4)
Virginia				
Lynchburg	9.60(243.8)	6.56 (166.6)	2.75 (69.9)	7.06(179.3)
Norfolk	9.54(242.3)	7.20 (182.9)	4.0 (101.6)	7.11(180.6)
Richmond	9.84(249.9)	7.28 (184.9)	4.0 (101.6)	7.23(183.6)
Winchester	9.48(240.8)	6.68 (169.7)	2.75 (69.9)	6.88(174.6)
Wytheville	9.30(236.2)	6.50 (165.1)	3.25 (82.6)	6.76(171.8)
Washington				
North Head	Use NOAA atlas for detailed state precipitation map.		1.00 (25.4)	2.80 (71.1)
Port Angeles			1.10 (27.9)	2.20 (55.9)
Seattle			1.0 (25.4)	2.20 (55.9)
Spokane			1.00 (25.4)	3.10 (78.7)
Tacoma			1.00 (25.4)	2.80 (71.1)
Tatoosh Island			1.00 (25.4)	3.20 (81.3)
Walla Walla			1.00 (25.4)	2.70 (68.6)
Yakima			1.10 (27.9)	2.60 (66.0)

Table 4-3 Maximum Rates of Rainfall for Various US Cities, in./h (mm/h) Continued

	Frequency and Duration of Storm			
	100-Yr., 5 Min.	100-Yr., 15-Min.	100-Yr., 60-Min.	10-Yr., 5-Min.
West Virginia				
Charleston	9.00(228.6)	6.34 (161.0)	2.9	6.57(166.9)
Elkins	8.94(227.1)	6.32 (160.5)	2.75 (69.9)	6.53(165.8)
Parkersburg	9.06(230.1)	6.34 (161.0)	2.75 (69.9)	6.62(168.0)
Wisconsin				
Green Bay	9.00(228.6)	6.12 (155.4)	2.5 (63.5)	6.42(163.1)
LaCrosse	9.84(249.9)	6.90 (175.3)	2.9	6.98(177.2)
Madison	9.48(240.8)	6.70 (170.2)	3.12 (79.2)	6.79(172.4)
Milwaukee	9.12(231.6)	6.48 (164.6)	2.7 (68.6)	6.60(167.7)
Spooner	9.66(245.4)	6.52 (165.6)	2.85 (72.4)	6.81(172.9)
Wyoming				
Cheyenne	Use NOAA atlas for detailed state precipitation map.		2.5 (63.5)	5.60(142.2)
Lander			1.50 (38.1)	3.70 (94.0)
Sheridan			1.70 (43.2)	5.20(132.1)
Yellowstone Park			1.40 (35.6)	2.50 (63.5)

Sources Table 4-3 is based on the National Oceanic and Atmospheric Administration Technical Memorandum NWS HYDRO-35, except for the 12 western states. NWS Technical Paper no. 25 was used for the following 12 western states Arizona, California, Colorado, Hawaii, Idaho, Montana, Nevada, New Mexico, Oregon, Utah, Washington, and Wyoming. The *NOAA Atlas 2 Precipitation–Frequency Atlas of the Western United States* (11 Volumes, 1973) should also be utilized in the design for the 12 western states.

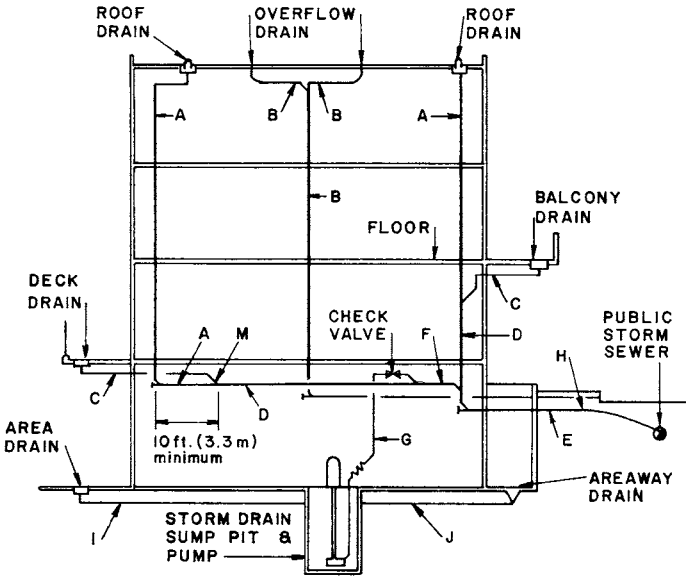


Figure 4-7 Piping Layout for Typical Building Elevation

Note: A = Roof drains and pipe, B = Overflow drains and piping, C = Collection area for deck and balcony drains, D = Storm leaders, E = Building storm drain, F = Main downstream of sump pump, G = Sump pump discharge, H = Building overflow storm drain, I = Area drain piping, J = Area-way/stairwell drain piping, M = Connection of lower deck drain to horizontal storm main.

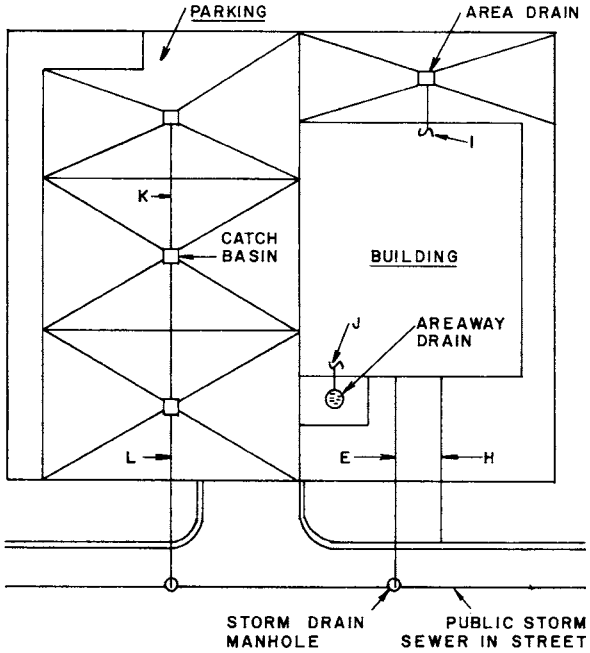


Figure 4-8 Piping Layout for Typical Building Site Plan

Note: E = Building storm drain, H = Building overflow storm drain, I = Area drain piping, J = Area-way/stairwell drain piping, K = Catch basin piping, L = Storm drain from the catch basin.

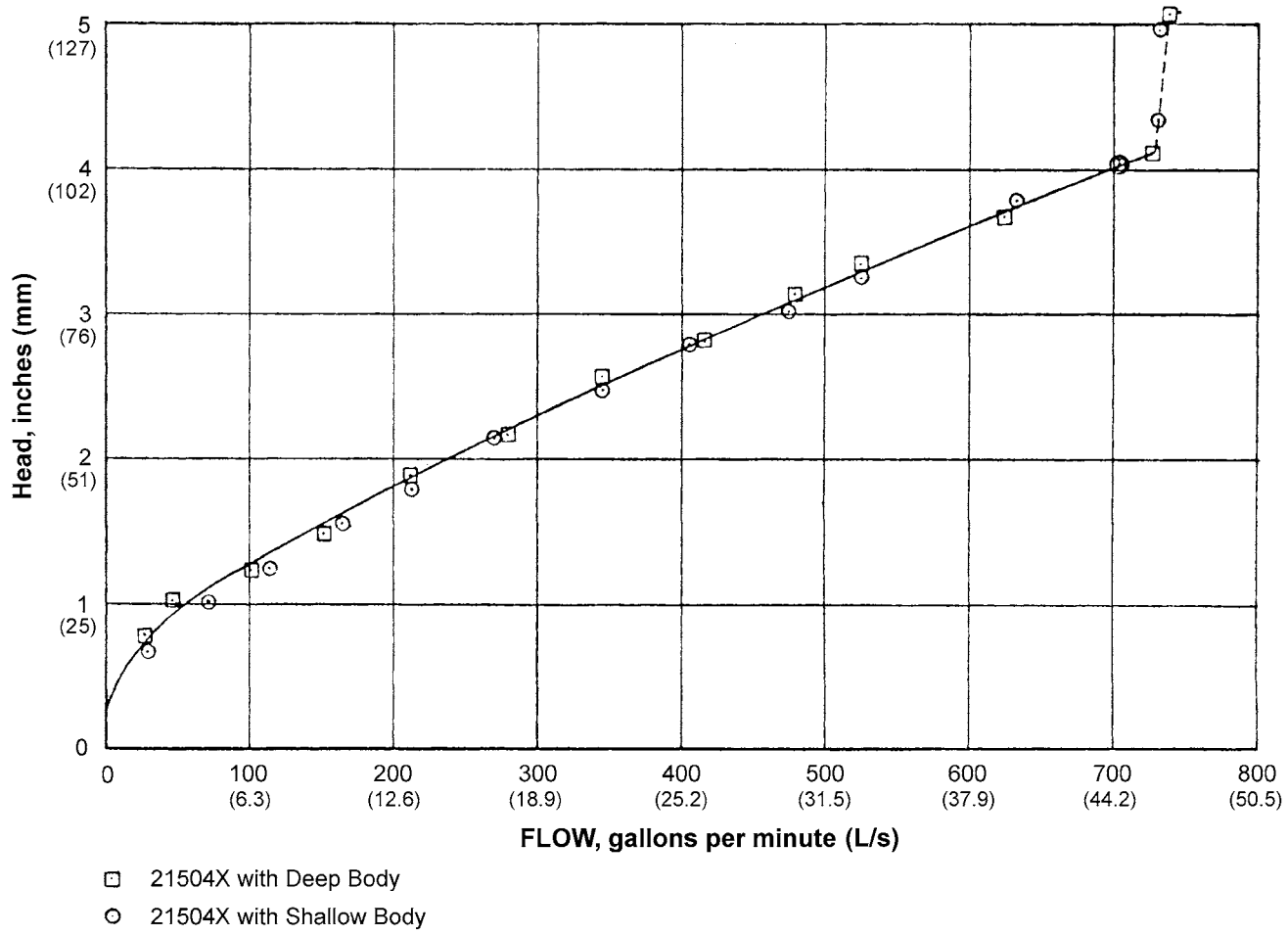


Figure 4-9 4-In. (101-mm) Roof Drain Flow Chart

Source: Reprinted by permission of the Josam Company from the Design Engineering Sheet.

plus a percentage of the two adjacent vertical wall areas. The vertical wall area is referrred to as sidewall flow.

4. The sizes of the horizontal mains are based on the accumulated flow of the drains and leaders upstream as indicated in code r equirements. A minimum 2-ft/s (fps) (0.61-m/s) velocity should be maintained to properly scour the pipe of grit, sand, and debris. (Some authorities recommend a minimum 3-fps [0.91-m/s] velocity to keep the sediment suspended.) The sizes of a typical horizontal storm drain for various slopes are given in Table 4-4.
5. Sizes of mains downstream of sump pumps are based on the accumulated flow of gravity drains upstream plus the discharge capacity of any sump pumps upstream. Often the code assigns a square foot equivelent for each gpm of discharge to be used in sizing mains.
6. The pipe size of the sump pump discharge is based on the capacity of the pump but is normally the same as the discharge pipe size of the pump. The code assignes a square foot equivelent for each gpm for sizing purposes. For duplex pumps operating simultaneously, the combined discharge capacity should be used. The discharge pipe should connect to the horizontal storm main a minimum 10 ft (3.05 m) downstream of the base

Table 4-4 Size of Horizontal Storm Drains

Diameter of Drain (in.)	Maximum Projected Roof Area for Various Slopes of Drains		
	⅛ in. Slope Square Feet	¼ in. Slope Square Feet	½ in. Slope Square Feet
2	250	350	500
2½	357	505	714
3	690	930	1,320
4	1,500	2,120	3,000
5	2,700	3,800	5,320
6	4,300	6,100	8,700
8	9,300	13,000	18,400
10	16,600	23,500	33,000
12	26,700	37,500	53,000
15	47,600	67,000	95,000

of any stack, as high pressure can exist in this zone due to hydraulic jump.

7. When a separate secondary system is required, the size of the building storm drain is based on the accumulated flow from the drain leaders upstream. The method used to dispose of the overflow drain discharge must meet local code requirements. Local codes may not allow open discharge onto the street, especially in northern climates; therefore, it may be necessary to tie the secondary system into the public storm sewer separately from the primary drainage system. Both may be routed to the same manhole but with separate inlets. Local code dictates the size.

8. Because of its four sides and corners, a rectangular gutter experiences greater friction loss than the equivalent round pipe, which diminishes its carrying capacity. To compensate for this increased friction loss, a rectangular leader should be at least 10% larger than a round leader to provide the same capacity. If the 10% increase results in an unavailable rectangular size, the next larger stock size should be used. The ratio of width to depth of rectangular leaders should not exceed 3:1. Use Form 4-1 found in the Appendix at the end of this chapter for roof drain and vertical leader sizing calculations that can be maintained in the project files.

9. For sizing horizontal gutters and downspouts, refer to Table 4-5. This table has been adjusted to include the 10% increase for rectangular leaders. This table depicts semicircular gutters and the equivalent rectangular gutters. The method of selecting sizes is similar to that used for round and rectangular leaders. Gutters should be a minimum 4 in. (101.6 mm) wide. As the roof slope increases, the gutter should be widened to prevent the rainwater from planing over the gutter without entering. The minimum slope the gutter should maintain is ¼ in./ft (1.0 cm/m) where possible.

10. For sizing downspouts from the gutter, the downspout should be sheet metal (which is less susceptible to freezing than nonmetal materials) to 5 ft (1.5 m) above grade and cast iron or ductile iron to the tie-in with the underground piping, as iron is more resistant to damage. Downspouts should be a minimum 1¾–2¼ in. (44.4–57.2 mm) in size and should be a maximum 75 ft (22.8 m) apart (the American Bridge Co. recommends 40 ft [12.2 m]). Outlets that discharge onto grade on splashbacks or are indirectly tied to the underground piping may be provided with screens or strainers for filtering debris and sediment. For residential construction, 5½-in. (139.7-mm) minimum semicircular gutters should be used, and leaders/downspouts should be 3 or 4 in. (76.2 or 101.6 mm) round, or 2–3 in. (50.8–76.2 mm) or 2–4 in. (50.8–101.6 mm) rectangular.

11. Horizontal piping must be supported properly, with bell holes provided for underground bell-and-spigot piping. Use Form 4-2 in the Appendix at the end of this chapter to calculate the storm-drain horizontal main size. Cleanouts should be provided at any change in direction exceeding 45 degrees and at any change in pipe size and to meet any applicable local code requirements for distances between cleanouts. The cleanouts should be extended up to grade or the floor above or out to the wall face with a wall plate. Locating cleanout plugs above ceilings may cause damage to the ceiling when the pipe must be cleaned.

12. Avoid running horizontal piping above the ceilings of computer rooms, kitchens, and food-preparation areas. A pipe rupture above one of these areas

Table 4-5 Sizes of Semicircular and Equivalent Rectangular Gutters

Diameter of Gutter, in. (mm) Dimensions of Gutter, in. (mm)	Cross-Sectional Area, in.^{2} (mm^2)	Water Contact, Area, in.^{2} (cm^2)	Slope,[a] in./ft (mm/m)	Capacity,gpm (L/min)
3 (76.2)	3.53 (22.83)	4.70 (30.32)	1/16 (1.6)	—
3 (76.2)	3.53 (22.83)	4.70 (30.32)	⅛ (3.2)	—
1½×2½ (38.1×63.4)	3.75 (24.25)	5.50 (35.48)	¼ (6.4)	26 (97.5)
1½×2½ (38.1×63.5)	3.75 (24.25)	5.50 (35.48)	½ (12.7)	40 (150)
4 (101.6)	6.28 (40.61)	6.28 (40.52)	1/16 (1.6)	—
4 (101.6)	6.28 (40.61)	6.28 (40.52)	⅛ (3.2)	39 (146.25)
2¼×3 (57.2×76)	6.75 (43.65)	7.50 (48.50)	¼ (6.4)	55 (206.25)
2¼×3 (57.2×76)	6.75 (43.65)	7.50 (48.50)	½ (12.7)	87 (326.25)
5 (127)	9.82 (63.50)	7.85 (50.76)	1/16 (1.6)	—
5 (127)	9.82 (63.50)	7.85 (50.76)	⅛ (3.2)	74 (277.5)
4×2½ (101.6×63.4)	10.00 (64.67)	9.00 (58.20)	¼ (6.4)	106 (397.5)
3×3½ (76×88.9)	10.00 (64.67)	9.00 (58.20)	½ (12.7)	156 (585)
6 (152)	14.14 (91.44)	9.43 (60.9)	1/16 (1.6)	—
6 (152)	14.14 (91.44)	9.43 (60.9)	⅛ (3.2)	110 (412.5)
3×5 (76×127)	15.00 (97.00)	11.00 (71.14)	¼ (6.4)	157 (588.75)
3×5 (76×127)	15.00 (97.00)	11.00 (71.14)	½ (12.7)	225 (843.75)
8 (203.2)	25.27 (163.42)	12.57 (81.29)	1/16 (1.6)	172 (645)
8 (203.2)	25.27 (163.42)	12.57 (81.29)	⅛ (3.2)	247 (926.25)
4½×6 (114.3×152.4)	27.00 (174.6)	15.00 (97.00)	¼ (6.4)	348 (1305)
4½×6 (114.3×152.4)	27.00 (174.6)	15.00 (97.00)	½ (12.7)	494 (1852.5)
10 (254)	39.77 (257.19)	15.70 (101.52)	1/16 (1.6)	331 (1241.25)
10 (254)	39.77 (257.19)	15.70 (101.52)	⅛ (3.2)	472 (1770)
5×8 (127×203.2)	40.00 (258.7)	18.00 (116.40)	¼ (6.4)	651 (2440.25)
4×10 (101.6×254)	40.00 (258.7)	18.00 (116.40)	½ (12.7)	1055 (3956.25)

Note: Figures are based on the Chezy Formula for Discharge of Circular Sewers, n = 0.013, and gutter flowing full.
[a]Minimum velocity of 2 fps (0.6 m/s).

could cause major damage and contamination. Piping under building slabs should be avoided if feasible, as pipe leaks could erode the fill below the slab and cause the slab to crack.

13. If the storm-drainage system receives continuous or intermittent flow from sump pumps, air-conditioning units, or similar devices, the flow should be added to the drainage system, either on the roof if the discharge is onto the roof or in the piping if the discharge ties directly into the drainage system.
14. After layout and sizing, the designer should review the proposed system to determine if revisions to the layout would improve the system from the standpoint of ease of installation, cost of materials, and/or coordination with other trades.

REFERENCES

1. American Concrete Institute. *Concrete Pipe Handbook*. Washington, D.C.
2. American Society of Civil Engineers. n.d. *Manual on the Design and Construction of Sanitary and Storm Sewers.*
3. Ballanco, Julius, and Eugene R. Shumann. 1987. *The Illustrated National Plumbing Code Design Manual*. Ballanco and Shumann—Illustrated Plumbing Codes, Inc.
4. Building Officials and Code Administration (BOCA). 1981. *BOCA Basic Plumbing Code.*
5. Cast-Iron Soil Pipe Institute. 1976. *Cast-iron Soil Pipe and Fittings Engineering Manual*. Vol. 1. Washington, DC.
6. Church, James C. 1979. *Practical Plumbing Design Guide*. New York: McGraw-Hill.
7. Frankel, Michael. 2002. *Facility Piping Systems Handbook*. New York City: McGraw-Hill.
8. Frankel, Michael. "Storm Water Retention Methods." *Plumbing Engineer,* March/April and May/June 1981.
9. Frederick, Ralph H., Vance A. Meyers, and Eugene P. Auciello. *NOAA, National Weather Service 5-60 Minute Precipitation Frequency for the Eastern and Central United States*. NWS tech. memo. HYDRO-35. NTIS Publication PB-272 112. Silver Spring, MD: National Technical Information Service.
10. Hicks, Tyler G., ed. 1986. *Plumbing Design and Installation Reference Guide*. New York: McGraw-Hill.
11. Manas, Vincent T. 1968. *National Plumbing Code, illustrated.* St. Petersburg, FL: Manas Publications.
12. Sansone, John R."Storm Drainage Design and Detention Using the Rational Method." *Plumbing Engineer,* July/August 1978.
13. SBCCI. 1988. *Standard Plumbing Code*. Birmingham, AL.
14. Soil Conservation Service, Engineering Division. 1986. *Urban Hydrology for Small Watersheds.* Technical release no. 55, June. NTIS publication PB87-101580. Silver Spring, MD: National Technical Information Service.
15. Steele, Alfred. 1982. *Engineered Plumbing Design*. Chicago: Delta Communications.
16. Steele, Alfred. "High-rise Plumbing." *Plumbing Engineer*. Chicago: Delta Communications.
17. U.S. War Department. *Engineering Manual of the War Department.* Misc. publication no. 204.
18. U.S. Department of the Army. *Plumbing Design Manual* no. 3.01.
19. Yrjanainen, Glen, and Alan W. Warren. "A Simple Method for Retention Basin Design." *Water and Sewage Works,* December 1973.

APPENDIX

Form 4-1 Storm-Drainage Calculations for Roof Drains and Vertical Leaders

BY _____ DATE _____ SHEET NO. _____ OF _____

CHKD. BY _____ DATE _____ JOB NO. _____

SUBJECT _____

JOB NAME	JOB NO.	DATE
BY	LOCATION	SHEET NO. OF
Rate of Return: Return Period	Year, Duration	Min. = in./hr./s.f. (mm/hr/m^2)

ROOF DRAIN NO.	AREA TO BE CALCULATED ROOF AND VERT. WALL AREAS, ft. × ft. (m^2)	TOTAL AREA TO BE DRAINED S.F. (m^2)	RAINFALL TO BE DRAINED (S.F.) (in./hr./S.F.) = in./hr. [(m^2)(m/hr/m^2) = mm/hr] per DRAIN	CAPACITY (in./hr.) (mm/hr) ×0.0104 = G.P.M. (L/s) per DRAIN	SIZE OF ROOF DRAIN AND VERT. LEADER

Form 4-2 Storm-Drainage System Sizing Sheet

BY _____ SHEET _____ OF _____

JOB _____ JOB NO. _____ DATE _____

STORM DRAINAGE SYSTEM SIZING SHEET

LDR. NO.	LDR. GPM (L/S)	SIZE	PIPE PITCH	MAIN GPM (L/S)	MAIN SIZE	MAIN PITCH	REMARKS

5 Cold Water Systems

INTRODUCTION

The primary task of a building cold water service and distribution system is to provide adequate flow, pressure, and volume suitable for human consumption at every device that uses water, even when the system is at peak demand. The designer's task is to ensure this is done in a reliable, cost-effective, code compliant, and safe manner. This chapter presents the major flow- and pressure-related components of a cold water distribution system, from the utility water meter and containment backflow, to inadequate or excessive pressures, velocity and sizing issues, and final testing and cleaning.

Definitions/Nomenclature

Accuracy (in regards to pressure regulating valves) – The degree of fall-off in the outlet pressure from the set pressure at full-flow capacity. Also, the capability of producing the same results for repetitive operations with identical conditions of flow.

AWWA – American Water Works Association

Backflow – Any reversal of the flow of water from its intended direction

Back-siphonage – Backflow caused by a lowering of normal pressure on the upstream side

Branch length method – Use the uniform pressure loss for the critical circuit piping. Then calculate a new equivalent length for each branch and size the branches (not the critical circuit) based on the new equivalent length pressure drop per 100 ft.

Constant velocity method – Designer bases size on velocity only, then adds the pressure drops not to exceed that total allowable (used for short lengths and/or few connections).

CPVC – Chlorinated polyvinyl chloride

Dead-end service – The type of service in which the pressure regulating valve (PRV) is required to close bottle-tight when there is no demand on the system

Effective pressure – This is the lowest anticipated residual pressure at the connection to the city water main (or the stop valve at a well system) when water is flowing.

Elevation pressure – The pressure change due to a change of elevation (0.433 psi/ft or 2.31 ft/psi—for water)

Fall off – The amount that pressure is decreased from set pressure to meet demand. The amount of fall-off depends on the quantity of flow—the greater the flow, the greater the fall-off. A fall-off of 20 psi (137.9 kPa) is considered to be the maximum allowable fall-off.

Flow pressure – The pressure required at the fixture or appliance

Flow pressure drop – The pressure drop through a device or fitting in a flowing system. For example, in a pressure-reducing valve, this is called fall-off pressure. (Sometimes called dynamic pressure drop as compared to pipe friction pressure drop.)

No-flow pressure – The pressure maintained in the system when the PRV is shut tight so that high pressure at the inlet of the valve is not permitted to enter the system

PRV – Pressure regulating valve

PVC – Polyvinyl chloride

Reduced-flow pressure – The pressure maintained at the PRV outlet when water is flowing. The no-flow (closed), set-point pressure of a PRV is always higher than the reduced-flow (open) pressure. A PRV that is set to open at 45-psi (310.3kPa) pressure (no-flow) would deliver a reduced-flow pressure of 30 psi (206.8 kPa) at peak demand if a 15-psi (103.4-kPa) fall-off had been selected.

Residual pressure – The pressure measured at any point in the system when water is flowing

Response (in regards to PRVs) – The capability of a PRV to respond to change in outlet pressure

RFP–Fiberglass reinforced plastic

RPZ–Reduced pressure zone backflow preventer

Sensitivity–The ability of a PRV to sense a change in pressure. If the valve is too sensitive and quick to respond, the results are over-control and a hunting effect. Not enough sensitivity results in operation that is sluggish and great variations in the outlet pressure.

Set pressure (in regards to PRVs)–That pressure, at the outlet of the PRV, at which the valve will start to open

Static pressure–The pressure measured at any point in the system when no water is flowing

Total pressure loss method–Every circuit uses up all the available pressure from the meter to the end user. It is very difficult to do by hand. Some computer programs can do this. However, the pipe sizes for the branches become very small and the velocity too high.

Uniform pressure loss method–The same pressure drop for *all* piping, including the hydraulically most remote point.

CODES AND STANDARDS

Plumbing codes establish a minimum acceptable standard for the design and installation of various systems, including cold water. There are various model codes, but some states and large cities have adapted plumbing codes other than the ones usually associated with the region. Because of this non-standardization, the actual plumbing code used for each specific project must be obtained from a responsible code official.

The information pertaining to cold water design appears in the approved local plumbing code and must be the primary method used for the accepted methods and sizing. The tables and charts appearing in this chapter are used only to illustrate and augment discussions of sizing methods, sizing procedures, and design methods and should not be used for actual design purposes.

DOMESTIC COLD WATER METERS

Many major municipalities furnish and/or install a particular type of water meter. In such locations, the meter characteristics (type, size, flow, pressure drops, remote readouts, costs, etc.) can be obtained through the local water department. Depending on the type of project being contemplated, a utility may request a particular meter (e.g., compound meter vs. turbine meter).

Whether a utility company's meter or a meter from another source is used, the above-mentioned characteristics must be taken into consideration. The location of the meter is of prime importance. The meter shall not be subjected to freezing or submerged conditions. To discourage tapping of the piping ahead of the meter, it may be required that the meter be located directly inside the building wall. Some jurisdictions want the meter immediately adjacent to the tap to prevent illegal connections between the meter and the tap. Where job conditions mandate such a location, a meter in an outside pit or manhole should be watertight against both surface and groundwater conditions. Electric tape heating may also be required.

A reduced-pressure backflow preventer at the building meter is required by some codes and municipalities.

Water meters for plumbing use are usually classified as the positive-displacement type, which indicates direct flow and record water passage in gal (L) or ft^3 (m^3).

Meter Types

1. *Disc meter.* These meters are normally ½, ¾, 1, 1½, and 2 in. (16, 19.1, 25, 40, and 50 mm) in size; are manufactured to meet the requirements of AWWA Standard C700; have a 150-psi (1034-kPa) maximum working pressure; and measure flow in one direction. This type of meter is common to residential and small commercial installations and is adaptable for remote readout systems.

2. *Compound meter.* These meters are normally 2, 3, 4, and 6 in. (50, 80, 100, and 150 mm) in size; are manufactured to meet the requirements of AWWA Standard C700; have a 150-psi (1034-kPa) maximum working pressure; and measure flow in one direction. This type of meter is used when most of the flow is low but high flows are anticipated. It is capable of recording low flows and has the capacity for high flow rates.

3. *Turbine meter.* The sizes of this meter are 2, 3, 4, 6, and 10 in. (50, 80, 100, 150, and 250 mm). This type of meter has the characteristics of a compound meter but is more suitable for encountering a variety of flows. (A strainer should be installed upstream of the meter.)

4. *Propeller meter.* The sizes of this meter are 2–72 in. (50–1,830 mm). Propeller meters are used where low flows never occur.

5. *Fire-line meters or detector-check meters.* This type of meter may be required by local codes in a water service that feeds a fire-protection sprinkler system or fire-hydrant system. In such a case, the installation must meet the requirements of the local fire official and the appropriate insurance company. The design should include a minimum of 8 pipe diameters of straight pipe upstream of

the meter before any change in direction or connections.

Various types of meter can be equipped with optional accessories. Remote-readout systems, strip-chart recorders, etc. are available for specific applications.

Sizing the Water Meter

The following design criteria may be used as a guide for selecting the proper meter:

1. Building occupancy type.
2. Minimum and maximum demand.
3. Water pressure available at meter.
4. Size of building service.
5. Piping, valve, meter, and elevation losses.
6. Meter costs and tap fees.
7. Maintenance costs and fees.

Tables 5-1 to 5-3 from AWWA Standard M22 are reprinted as additional guidelines for water meters.

Table 5-1 Displacement-Type Meters Meeting AWWA Specifications — Flow-Pressure Loss Averages

Size, in. (mm)	Maximum Capacity—AWWA Flow Criteria				Recommended Design Criteria—80% of Maximum Capacity				Recommended for Continuous Flow—50% of Maximum Capacity				Brands of Meters Avgs.
	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	
⅝ × ¾ (16×19.1)	20	(1.26)	10.4	(71.76)	16	(1.00)	6.1	(42.19)	10	(0.63)	1.0	(6.9)	6
¾ (19.1)	30	(1.89)	10.6	(73.13)	24	(1.51)	6.9	(47.61)	15	(0.95)	1.05	(7.24)	6
1 (25.4)	50	(3.15)	9.3	(64.14)	40	(2.52)	6.3	(43.47)	25	(1.58)	1.0	(6.9)	6
1½ (38.1)	100	(6.30)	11.3	(77.10)	80	(5.05)	8.6	(59.34)	50	(3.15)	0.9	(6.21)	6
2 (50.8)	160	(10.08)	10.4	(71.76)	128	(8.08)	6.5	(44.85)	80	(5.04)	0.5	(3.45)	6
3 (76.2)	300	(18.93)	13.1	(90.39)	240	(15.14)	8.3	(57.27)	150	(9.46)	1.1	(7.59)	3

Source:AWWA Standard M22.

Table 5-2 Compound-Type Meters Meeting AWWA Specifications—Flow-Pressure Loss Averages

Size, in. (mm)	Maximum Capacity—AWWA Flow Criteria				Recommended Design Criteria—80% of Maximum Capacity				Recommended for Continuous Flow— 50% of Maximum Capacity				Brands of Meters Avgs.
	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	
2 (30)	160	(10.08)	9.2	(63.48)	128	(8.07)	6.1	(42.09)	80	(5.04)	2.6	(17.94)	3
3 (80)	320	(20.19)	13.4	(92.46)	250	(15.77)	8.9	(61.36)	160	(10.08)	4.2	(28.98)	5
4 (100)	500	(31.54)	9.6	(66.24)	400	(25.23)	6.3	(43.47)	250	(15.77)	3.5	(24.15)	5
6 (150)	1000	(63.09)	9.4	(64.86)	800	(50.46)	5.8	(40.02)	500	(31.54)	2.5	(17.25)	4
8 (203)	1600	(100.94)	12.0	(82.8)	1280	(80.75)	7.8	(53.82)	800	(50.46)	4.0	(27.60)	3

Source:AWWA Standard M22.

Table 5-3 Turbine-Type Meters Meeting AWWA Specifications—Flow-Pressure Loss Averages

Size, in. (mm)	Maximum Capacity—AWWA Flow Criteria				Recommended Design Criteria—80% of Maximum Capacity				Recommended for Continuous Flow—50% of Maximum Capacity				Brands of Meters Avgs.
	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	gpm	(L/s)	
2 (50)	160	(10.08)	4.5	(31.05)	128	(7.57)	2.8	(19.32)	80	(5.04)	1.0	(6.9)	5
3 (80)	350	(22.37)	4.6	(31.74)	280	(17.66)	3.0	(20.69)	175	(11.04)	1.2	(8.3)	4
4 (100)	600	(37.85)	3.5	(24.15)	480	(30.28)	2.1	(14.5)	300	(18.93)	0.8	(5.5)	4
6 (150)	1250	(78.86)	3.5	(24.15)	1000	(69.09)	2.0	(13.8)	625	(39.43)	0.7	(4.9)	4

Source:AWWA Standard M22.

CROSS CONNECTION CONTROLS

Preventing reverse flows at connection points of a water supply system is referred to as cross connection control. Since the topic is covered in its own chapter, it will only be briefly described here as it relates to cold water systems.

The fundamental principle for selecting a cross connection control is based on the sciences of hydrostatics and hydrodynamics. When water is motionless, hydrostatics applies and the pressure within a given volume is only dependent on elevation. When water is in motion, viscous forces, velocity, and momentum add other factors to consider. Controls to prevent reverse flows recognize the basic static pressure conditions while accommodating the dynamic factors.

In the absence of controls when water supply pressure is lost, low pressures may occur that can draw contaminants into the supply piping. The contaminants then may emerge in other parts of the piping when the pressure is restored. Controls, however, prevent contaminants from being drawn into the piping by devices or piping design. If pressure immediately downstream of the device is less than atmospheric, a situation defined as back-siphonage, a control device may be one of various types of vacuum breakers used. If pressure immediately downstream of the device is greater than atmospheric, a situation defined as back-pressure, a control device may be one of various types of backflow preventers used. If the outlet from a water supply is sufficiently high above its receptor, the piping design is defined as an air gap and is generally applied to faucet spouts.

Thoughtful considerations should be given to the anticipated emergency discharge of backflow preventers, such as the reduced pressure zone and reduced pressure detector assemblies. Conditions

such as a leaking check valve, clogged sensing line, ruptured relief valve diaphragm, or a dislodged relief valve O ring will cause the RPZ to discharge from the atmospheric vent (located on the relief valve). First, the designer should consider how to minimize these potential conditions. In most cases, with the *exception* of fire protection due to the overriding urgency of not compromising water flow to the sprinkler system, the use of the Y-type strainer is strongly encouraged to help prevent debris from entering the valve and fouling the checks. The strainer body material should be consistent with the valve to prevent electrolysis (normally the smaller ½–2 in. are of bronze construction and larger valves 2½–10 in. are made of stainless steel or cast iron with an FDA coating). The strainer screen mesh of the ½–2 in. should be 20 in. and the 2½–10 in.-perforated screen should be no larger than ⅛ in. The designer may wish to include a blow-down valve with the strainer to make maintenance easier. A strainer with only a pipe plug may not be cleaned regularly and needlessly adds to the pressure drop. In some cases, such as industrial facilities and car washes, water hammer can cause a "spitting" type of discharge. This can be avoided with a properly installed and selected mechanical shock arrestor or the use of supplemental checks. It is recommended to use a spring-loaded and soft-seated check design and have it installed directly downstream (outlet side) of the RPZ.

Before an RPZ is located, consideration should be given to both how much water will be discharged as well as to where it will drain. The discharge from a typical RPZ can be found in Figure 5-1. Consideration must be given to the drain system to assure the drainage system can handle the load. The discharge of drains flowing full at different pitches may be found in Table 5-4. If a drain is not capable of accepting the flow, other choices as to the location of the valve, such as outside in a heated enclosure, could be made. At a minimum, the proper air gap fittings should be specified to capture the majority of the discharge and then be connected to the drainage system. There are a wide variety of air gap designs including both funnel and sink styles.

Table 5-4 BFP Flow Rate

Drain Size Flowing Full					
Drain size		Maximum Flow Rate, GPM, l/m			
In	Dn	⅛"/ft	(0.5 cm/m)	¼"/ft	(1.0 cm/m)
2	50	13	100	18	135
3	75	36	275	51	390
4	100	77	585	110	835
6	150	220	1670	314	2385
8	200	494	3755	696	5290
10	250	934	7100	1300	9900

Thermal expansion problems should be anticipated when water utilities require a containment method backflow prevention program. Mainline valve applications such as this will result in a closed piping system. Without properly installing and sizing domestic water expansion tanks, a number of annoying or potentially dangerous problems can result. This can include a buildup of unusually high pressure, causing water heater failures and other plumbing issues.

The pressure losses through often-used RPZs are given in Table 5-5.

BOOSTER PUMP SYSTEMS

When it is determined that city water pressure or well pump pressure is not sufficient to meet the water supply demands of a building, a booster pump system

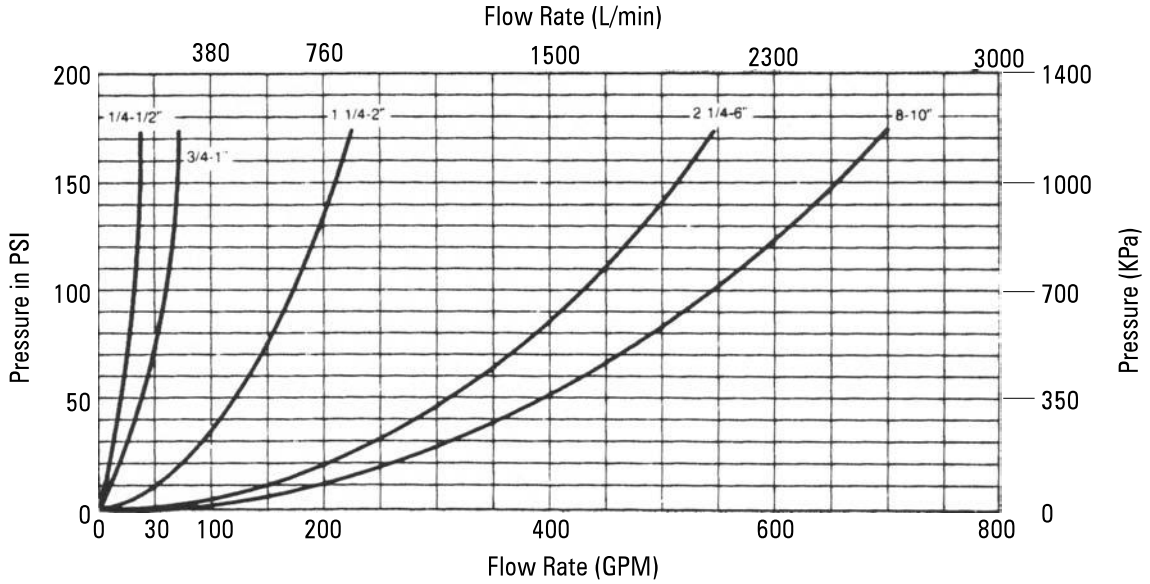


Figure 5-1 RPZ Discharge Flow Rate

Table 5-5 Pressure Losses Through RPZs

3" R.P.Z. – Friction Loss Through Device							
GPM	**WTTS**	**AMES**	**CONB**	**FEBB**	**CLAV**	**HERS**	**WILK**
100	11.5	9.2	12.3	10.9	7.4	11.2	11.0
200	11.9	8.9	12.6	11.1	5.9	11.7	12.6
300	13.1	10.6	13.9	12.6	6.1	12.9	14.8
4" R.P.Z. – Friction Loss Through Device							
GPM	**WTTS**	**AMES**	**CONB**	**FEBB**	**CLAV**	**HERS**	**WILK**
200	8.6	8.5	9.7	10.5	7.4	11.0	10.3
300	9.0	10.0	9.6	8.9	7.0	11.4	10.9
400	10.1	11.3	9.8	8.5	7.5	12.3	11.2
500	11.3	12.2	10.1	8.8	8.0	13.5	12.2
6" R.P.Z. – Friction Loss Through Device							
GPM	**WTTS**	**AMES**	**CONB**	**FEBB**	**CLAV**	**HERS**	**WILK**
300	10.0	6.9	10.7	10.3	7.3	10.4	10.2
400	9.2	7.0	10.7	10.1	7.1	10.6	10.5
500	9.8	7.7	10.8	10.0	7.0	10.7	10.8

Figures denote psi friction losses for specific flows. Do not interpolate between flows; manufacturer's pressure loss curves must be consulted.

Key
WTTS: Watts model #909
AMES: Ames model #4000-ss
CONB: Conbraco model #40-200
FEBB: Febco model #860
CLAV: Cla-Val model #RP-1
HERS: Hersey model #6CM
WILK: Wilkins model #975

is considered. The pump system may be for the entire building, for the upper floors in one or more zones, or for select equipment connections having high-pressure requirements.

The required capacity of the pump system is determined when the building demand is evaluated in terms of peak flow. The peak flow is determined as described for the water service. The pressure requirement is derived from the Bernoulli equation. Recall that between any two points of an ideal flow stream, $h+p/d+v^2/2g$ is a constant. In a more realistic flow, a friction head and pump head are considered. Thus,

Equation 5-1

$$h_1+\frac{p_1}{d}+\frac{v_1^{\,2}}{2g}+h_p=h_2+\frac{p_2}{d}+\frac{v_1^{\,2}}{2g}+h_f$$

where

h = the flow stream's elevation above a datum, ft (m)p as its static pressure, lb/ft^2 (kPa)
d = its density, lb/ft^3 (kg/m^3)
v = its velocity, ft/sec (m/sec)
h_p = the pump head (total dynamic head)
g = acceleration of gravity, 32.2 ft/sec^2 (m/s^2)
h_f = the friction head loss between Points 1 and 2, ft (m)

When Point 1 is considered at a location of a known pressure such as the street main and Point 2 is considered at a fixture, the equation can be rearranged to derive the required pump head to adequately supply that fixture. Various fixtures in the building can be selected to derive various pump heads. The maximum pump head is generally the top fixture of the most remote riser. Additionally, after considering that velocities are similar between Points 1 and 2, we can omit the two velocity terms. Thus,

Equation 5-2

$$h_p=h_2-h_1+\frac{(p_2-p_1)}{d}+h_f$$

The friction head includes various losses such as friction from straight pipe, fittings, valves, meters, tanks, treatment devices, and backflow preventers. In addition, the head loss through the booster pump system piping and its control valves is added. These are typically 4 ft (1.22 m) and up to 18 ft (5.49 m) respectively.

The design of the booster pump system generally consists of one or more electrically driven centrifugal pumps, connecting pipework and various controls such as pressure-reducing valves, motor controls, and a possible hydropneumatic tank. The pump impellers are generally one stage but may be multiple stages if high head is required. Rotational speed choices are generally 1,750 RPM, 3,500 RPM, or other similar synchronous speeds.

Example 5-1

Determine the required total dynamic head of a booster pump system for a building with its most remote fixture as a pressure balancing shower valve (assumed 20 psi) located 48 ft above the pump; street pressure as 25 psi as read from a gauge near the pump; the total equivalent length of pipe as 400 ft; the uniform pressure loss of this length as 5 psi per 100 ft; and pressure loss through the service meter as 6 psi and through a water softener as 9 psi.

Solution: From Equation 5-2, $(p_2 - p_1)/d$ becomes $(20\text{-}25) \times 144/62.4 = -11.5$ ft.

The building friction head becomes $(400 \times .05 + 6 + 9) \times 144/62.4 = 80.8$ ft.

The pump system friction head becomes $4 + 18 = 22$ ft.

The total dynamic head therefore becomes $48 - 11.5 + 80.8 + 22 = 139$ ft.

Example 5-1 (metric): Determine the required total dynamic head of a booster pump system for a building with its most remote fixture as a pressure balancing shower valve located 14.6 meters above the pump; street pressure as 172 kPa as read from a gauge near the pump; the total equivalent length of pipe as 120 meters; the uniform pressure loss of this length as 35 kPa per 30 meters; and pressure loss through the service meter as 41 kPa and through a water softener as 62 kPa.

Solution: From Equation 5-2, $(p_2 - p_1)/d$ becomes $(138 - 172)/9.8 = -3.50$m.

The building friction head becomes (120 × 35/30 + 41 + 62)/9.8 = 24.6 m.

The pump system friction head becomes 1.22 + 5.49 = 6.70 m.

The total dynamic head therefore becomes 14.6 – 3.50 + 24.6 + 6.70 = 42.4 m.

The nature of centrifugal pumps on a building water supply is that as faucets and valves of plumbing fixtures close throughout the building, pump pressure increases until the pump dead heads. For example, the difference in pump head from maximum flow to no flow may be 30 ft (9.14 m) on a 7½ HP (5.60 kW) pump. This head variation will cause flow variations from each plumbing fixture. This variation may be objectionable to building occupants as well as faucet and valve manufacturers. Hence, pump systems with a constant pressure feature have been developed. The discharge of each pump in the pump system flows through a pressure-reducing valve. Another method of control, variable-speed drives, involves reducing the rotational speed of the pump impeller as building flow demand decreases. With the trend toward decreasing costs of adjustable frequency drives, such drives are chosen for this speed reduction. Obviously, variable-speed pump systems have a lower operating cost than constant-pressure pump systems not only at maximum flow but also more significantly at the lower flow. Less obvious is the operating penalty of an oversized constant-pressure pump whether the excess size is derived from an overestimate of the building flow demand or an erroneously low indication of the typical street pressure. Variable-speed pumps do not have a penalty from either cause.

The best economy of a variable-speed pump is obtained with its pressure sensor located at the top of a riser. At this location the set point of the sensor is merely what is desired of a fixture, for example, 20 psi (138 kPa) for a shower valve. At low building demand, the pump system will adjust for this set point combined with the static amount for elevation. As demand grows, the pump adds the appropriate amount for friction. When the sensor is chosen near the pump, its sensitivity to friction requirements is diminished.

Further economy of either system type is obtained by multiple pumps. In this way, many pumps operate to meet the building demand with all but one pump operating at its most efficient flow and pressure. The

Table 5-6 Hydropneumatic Tank Volume Ratios

Max. Pressure psi	Minimum Pressure, psi									
	10	20	30	40	50	60	70	80	90	100
20	0.288									
30	0.447	0.224′								
40	0.548	0.366	0.183							
50	0.618	0.464	0.309	0.155						
60	0.669	0.536	0.402	0.268	0.134					
70	0.708	0.590	0.472	0.354	0.236	0.118	r			
80	0.739	0.634	0.528	0.422	0.317	0.211	0.106			
90	0.764	0.669	0.573	0.478	0.382	0.287	0.191	0.096		
100	0.785	0.697	0.610	0.523	0.436	0.349	0.262	0.174	0.087	
110	0.802	0.722	0.642	0.561	0.481	0.401	0.321	0.241	0.160	0.080
120	0.817	0.742	0.668	0.594	0.520	0.445	0.371	0.297	0.223	0.148
130	0.829	0.760	0.691	0.622	0.553	0.484	0.415	0.346	0.276	0.207
140	0.840	0.776	0.711	0.646	0.582	0.517	0.453	0.388	0.323	0.259
150	0.850	0.789	0.729	0.668	0.607	0.546	0.486	0.425	0.364	0.304
160	0.859	0.801	0.744	0.687	0.630	0.572	0.515	0.458	0.401	0.343
170	0.866	0.812	0.758	0.704	0.650	0.596	0.541	0.487	0.433	0.379
180	0.873	0.822	0.770	0.719	0.668	0.616	0.565	0.514	0.462	0.411
190	0.879	0.830	0.782	0.733	0.684	0.635	0.586	0.537	0.489	0.440
200	0.885	0.838	0.792	0.745	0.699	0.652	0.606	0.559	0.512	0.466

Table 5-6(SI) Hydropneumatic Tank Volume Ratios

Max. Pressure, kPa	Minimum Pressure, kPa									
	69	138	207	276	345	414	483	552	621	690
138	0.288									
207	0.447	0.224								
276	0.548	0.366	0.183							
345	0.618	0.464	0.309	0.155						
414	0.669	0.536	0.402	0.268	0.134					
483	0.708	0.590	0.472	0.354	0.236	0.118				
552	0.739	0.634	0.528	0.422	0.317	0.211	0.106			
621	0.764	0.669	0.573	0.478	0.382	0.287	0.191	0.096		
690	0.785	0.697	0.610	0.523	0.436	0.349	0.262	0.174	0.087	
758	0.802	0.722	0.642	0.561	0.481	0.401	0.321	0.241	0.160	0.080
827	0.817	0.742	0.668	0.594	0.520	0.445	0.371	0.297	0.223	0.148
896	0.829	0.760	0.691	0.622	0.553	0.484	0.415	0.346	0.276	0.207
965	0.840	0.776	0.711	0.646	0.582	0.517	0.453	0.388	0.323	0.259
1034	0.850	0.789	0.729	0.668	0.607	0.546	0.486	0.425	0.364	0.304
1103	0.859	0.801	0.744	0.687	0.630	0.572	0.515	0.458	0.401	0.343
1172	0.866	0.812	0.758	0.704	0.650	0.596	0.541	0.487	0.433	0.379
1241	0.873	0.822	0.770	0.719	0.668	0.616	0.565	0.514	0.462	0.411
1310	0.879	0.830	0.782	0.733	0.684	0.635	0.586	0.537	0.489	0.440
1379	0.885	0.838	0.792	0.745	0.699	0.652	0.606	0.559	0.512	0.466

last pump will then take up minor demand variations. The number of pumps in the system may be as few as two and up to any number. In addition, the size of each pump may be identical or may vary. A triplex may have the building flow demand split up as 33 percent for each pump or two pumps at 40 percent and the last at 20 percent. When redundancy is desired, the split of a triplex may be each pump at 50 percent. A common control method to stage the pumps is to measure motor current. When current reaches a pump motor's rating, the next pump is brought online. Other methods include power measurement and flow measurement.

Pump systems generally have a variety of features. Low-flow shutdown features will sense either temperature increase or flow decrease. A low-suction-pressure switch detects suction pressure below the pump's NPSH limit or perhaps a regulatory limit. Similarly, a high-pressure switch avoids excessive pressures on the building's plumbing. A high temperature control either relieves discharge or shuts down the pump motor. Motor control includes under-voltage control, over-current control, motor overload control, and electric power disconnect. An alternator control switches which pump first operates on rising demand so that each pump of the system receives uniform wear. Minimum run timers avoid pump short cycling. Proof timers delay pump staging to avoid a pump start that may not be needed. A differential pressure switch on each pump detects pump failure. A time clock controls operating times to an occupancy schedule. A building management control interface offers pump system status to be remotely monitored or controlled. A microprocessor control becomes economically attractive when these features involve about a dozen input sensors or more.

Another application of a booster pump system is when code regulations only permit cross connection control on the water service by an air gap. Since the air gap destroys the utility pressure, a booster pump is required. The additional components to complete the arrangement, referred to as a break tank, include a tank open to atmosphere, an inlet float valve, an overflow pipe, and perhaps a low water sensor. The float valve is connected to the water service. Water in the tank feeds the pump. The pump head can be minimized if the break tank is located on an upper floor or even a penthouse. A smaller version of a break tank may be substituted elsewhere in the building for any type of backflow preventer or vacuum breaker.

Another application of a booster pump system is when a high-rise building is zoned by floor levels, with storage tanks at multiple levels. This is used to decrease the static head at the lower levels.

Hydropneumatic Tank

As part of a booster pump system, a hydropneumatic tank can be chosen to meet a low-flow demand without operating a pump. A hydropneumatic tank may also provide a method to shave peak flows on an existing water service or a distribution main.

The fundamental principle for sizing hydropneumatic tanks is based on the ideal gas law. This law is applied to the air inside the tank as the volume changes to serve minor demands in the building during minimal occupancy. The design of the tank is a pressure vessel with a flexible partition, water on one side and air on the other. The amount of air can be varied during installation through a port and then is assumed constant thereafter. The amount of water in the tank varies continuously. It has a single pipe connection. Typically the flexible partition is a rubber diaphragm, which moves as pressure varies. It effectively isolates the air from the water.

Recall that the product of pressure and volume of an ideal gas is proportional to its mass and temperature. Since the air is captured in the tank, its mass is constant. Its temperature is assumed to be constant. Hence,

$$pV = \text{a constant, or}$$

Equation 5-3 (Boyle's Law)

$$p_1V_1 = p_2V_2$$

where

p = tank air pressure, psia (kPa)
V = volume of air in the tank, ft^3 (m^3)
V_t = the total tank volume, ft^3 (m^3)
dV/dt = the average flow over time period, t_p, during low system demand

Then, when we define $(dV/dt)(t_p)$ as the drawdown volume, V_d, we can examine the volume in the tank between two pressure levels in the tank and equate it for the drawdown volume. That is,

$$V_1 - V_2 = V_d$$

Designating V_1 as the tank with all water expelled from it and applying the ideal gas law, we have

$$V_1 - V_2 = V_1 - V_1\left(\frac{p_1}{p_2}\right) = V_1\left(1 - \frac{p_1}{p_2}\right) = V_t\left(1 - \frac{p_1}{p_2}\right), \text{ or}$$

$$V_1 - V_2 = V_t\left(\frac{p_2 - p_1}{p_2}\right)$$

Rearranging and combining with the average low flow, we have the tank volume formula.

Equation 5-4

$$V_t = \frac{V_d}{\left(\frac{p_2 - p_1}{p_2}\right)}$$

The pressure ratio is a convenient volume ratio of drawdown volume to tank volume. For near sea level average conditions, Table 5-6 shows this ratio

Table 5-7 Tank Size Varying by Its Location in a Building

Minimum Pressure	Maximum Pressure	$(p_2-p_1)/(p_2)$	Tank Location	Example Tank Size
psi	psi	-	-	gallons
50	60	0.134	Top floor	747
85	100	0.131	Before pressure-reducing valve	765
70	80	0.106	After pressure-reducing valve	947

Table 5-7(SI) Tank Size Varying by Its Location in a Building

Minimum Pressure	Maximum Pressure	$(p_2-p_1)/(p_2)$	Tank Location	Example Tank Size
kPa	kPa	-	-	L
345	414	0.134	Top floor	2,830
586	690	0.131	Before pressure-reducing valve	2,895
483	551	0.106	After pressure-reducing valve	3,584

between any two levels of air pressure in the tank. For example, two pressure levels of 50 psi (345 kPa) and 40 psi (276 kPa) for a tank to draw out 60 gallons (227 L) require a tank volume of 60/0.155 = 387 gallons (227/0.155 = 1465 L).

In practice, tanks are chosen larger than as calculated to avoid a completely empty tank. The average flow during low system demand is taken as a fraction of the building peak flow, typically 0.5 percent for apartment buildings and 4 percent for hospitals. Other buildings generally fall in between these extremes. The time period is generally chosen to be 10 to 30 minutes and $p_2 - p_1$ is 10 psi (69 kPa). For tanks on private wells, $p_2 - p_1$ is typically taken to be 20 psi (138 kPa). Note that since p_2 is derived from the ideal gas law, it is an absolute pressure and must include the local prevailing atmospheric pressure (14.7 psi [100 kPa] at sea level).

In Table 5-7, an example of a four story building with a 10-gpm (37.8 L/min) requirement for 10 minutes is shown with a hydropneumatic tank selected in three different locations. When it is selected at a high elevation, we find that the tank is smaller than at a low elevation such as near the booster pump. The tank is smaller when positioned upstream of the pump's pressure-reducing valve than when downstream because of the larger range of pressures upstream of the valve.

Elevated Water Tank System

In an elevated water tank system, such as that illustrated in Figure 5-2, water is pumped from the street main to an elevated water storage tank (commonly called a gravity tank or house tank) located above the highest and most hydraulically remote point in the water supply system of the building. The height of the tank provides additional static head, which results in a higher pressure in the water distribution system. For each 2.31ft (0.7m) elevation of the tank, there is an increase in pressure of 1 psi (6.9 kPa).

An elevated water tank is made up of the following components:

1. The gravity tank stores water at atmospheric pressure.
2. Pumps (commonly called house pumps) fill the tank by pumping water into it from the source.

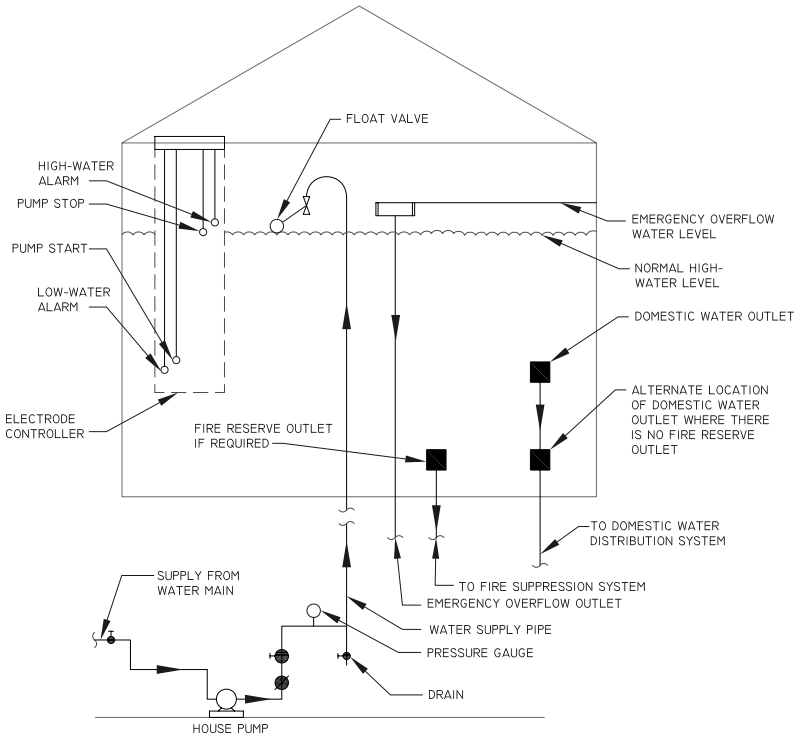


Figure 5-2 Piping Arrangement of an Elevated Water Tank

3. Controls turn the pump on and off when the water inside the tank reaches preset levels.
4. Alarms alert operating personnel that a malfunction exists.
5. Safety devices operate when a malfunction occurs to avoid potential accidents.

The piping arrangements between the various components of an elevated water tank system are illustrated in Figure 5-3.

The advantages of the elevated water tank system follow:

1. It is less complex than either of the other two systems.
2. The least number of components are required to control and operate the system.
3. The efficiency is greater and operating costs are lower than for the other systems.
4. A smaller pump capacity is required than for either of the other two systems.
5. Pressure fluctuation in the system is small.
6. Maintenance requirements are minimized.

The disadvantages of the elevated water tank system compared with the other two systems follow:

1. An exposed tank (or the enclosure around it) may be considered unsightly.
2. The building structure may require reinforcement to support the additional weight of the tank and water.
3. The water in the tank and the supply pipes from the tank are subject to freezing if the tank is exposed.
4. The water pressure on the highest floor(s) may be inadequate.
5. The possibility exists of a catastrophic tank failure flooding the roof with water.

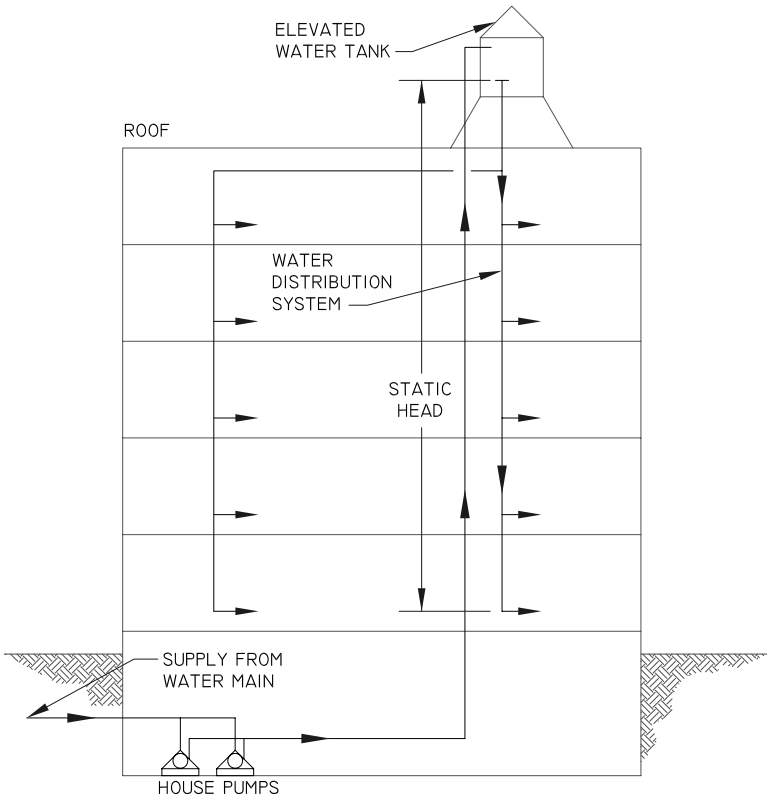


Figure 5-3 Simplified Downfeed Water Supply System with Simplified Elevated Water Tank

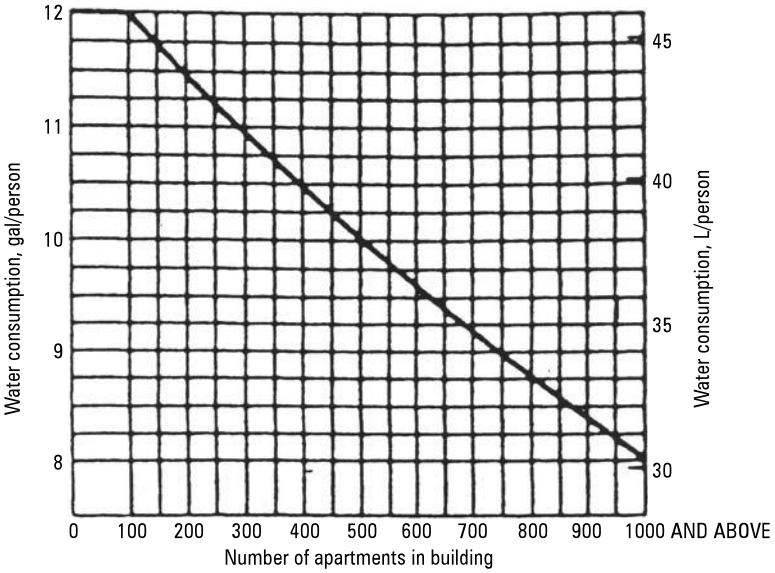


Figure 5-4 Estimated Water House Tank Storage Capacity, Multiple dwellings

The capacity of the house tank depends on the type of facility it will serve. Refer to Table 5-8 to find a recommended minimum domestic storage volume of gravity tanks for various building types except multiple dwellings. For multiple dwellings, refer to Figure 5-4.

To use Table 5-8, first determine the total number of fixtures, regardless of type. Multiply the number of fixtures by the gpm per fixture. Then multiply the resulting figure by the tank size multiplier. This figure is the domestic storage only. To this add 10% for constant uses of water, such as HVAC makeup and any process requirements if necessary. Fire protection water storage is also additional. Select a standard tank size equal to or exceeding the storage required. Standard wood roof tank sizes are given in Table 5-9. If the

Table 5-8 Size of Gravity Tanks

Number of fixtures	gpm per fixture	Tank size multiplier	Minimum domestic capacity, gal	Minimum pump capacity, gpm
Hotels and clubs				
1–50	0.65	30	2000	25
51–100	0.55	30	2000	35
101–200	0.45	30	3000	60
201–400	0.35	25	3000	100
401–800	0.275	25	3000	150
801–1200	0.25	25	3000	225
1201 and above	0.2	25	3000	300
Hospitals				
1–50	1	30	2000	25
51–100	0.8	30	2000	55
101–200	0.6	25	3000	85
201–400	0.5	25	3000	125
401 and above	0.4	25	3000	210
Schools				
1–10	1.5	30	2000	10
11–25	1	30	2000	15
26–50	0.8	30	2000	30
51–100	0.6	30	2000	45
101–200	0.5	30	3000	65
201 and above	0.4	30	3000	110
Industrial buildings				
1–25	1.5	30	2000	25
26–50	1	30	2000	40
51–100	0.75	30	3000	60
101–150	0.7	25	3000	80
151–250	0.65	25	3000	110
251 and above	0.6	25	3000	165
Office Buildings and Laboratories				
1–25	1.25	30	2000	25
26–50	0.9	30	2000	35
51–100	0.7	30	2000	50
101–150	0.65	25	3000	75
151–250	0.55	25	3000	100
251–500	0.45	25	3000	140
501–750	0.35	25	3000	230
751–1000	0.3	25	3000	270
1001 and above	0.275	25	3000	310

building's occupants are predominantly women, add 15% to the gallons of water storage requirements.

For multiple dwellings, first find the number of apartments. Using Figure 5-4, find the number of gallons storage per person. If the actual number of people is not available, an approximate number can be found by using two people per bedroom or four people per apartment, whichever is larger, and multiply by that number. Then multiply the number of people by the gallons (liters) required per person to find the domestic storage capacity of the house tank. To this, add 10% for constant uses of water, such as HVAC makeup. Add an additional number of gallons for fire protection water storage, if any. Then select a standard storage tank size equal to or larger than the required amount.

The capacity of the house pump(s) is determined by the quantity of water stored for domestic use. In general, a house pump should be capable of replacing the domestic reserve in about ½ to 2 hours—with

Table 5-9 Standard Wood House Tanks

Capacity, gal*	Dimension, ft+ Diameter × Stave	Number of dunnage beams	Dunnage, in
5,000	10 × 10	5	4 × 6
5,000	9 × 12	5	4 × 6
5,000	11 × 8	6	4 × 6
6,000	11 × 10	6	4 × 6
7,000	11½ × 10	6	4 × 6
7,500	12 × 10	6	4 × 6
7,500	11 × 12	6	4 × 6
8,000	12½ × 10	6	4 × 6
9,000	12 × 12	6	4 × 6
10,000	13 × 12	7	4 × 6
10,000	12 × 14	6	4 × 6
10,000	11 × 16	6	4 × 6
12,000	14 × 12	7	4 × 6
12,000	13 × 14	7	4 × 6
12,000	12 × 16	6	4 × 6
15,000	14 × 14	7	4 × 6
15,000	13½ × 16	8	4 × 6
20,000	16 × 16	8	6 × 6
25,000	17½ × 16	9	6 × 6
30,000	18 × 18	9	6 × 6
40,000	20 × 20	10	6 × 6
50,000	20 × 20	11	6 × 8

* 1 gal = 3.8 L
+ 1 ft = 0.3 m
++ 1 in = 25.4 mm
Source: I sseks Bros. Co.

1 hour a generally accepted value. A duplex pump arrangement (i.e. two pumps in parallel), with each pump full size, should be provided to allow one pump to be out of service without impairing the system.

A common problem with the gravity tank system is the lack of adequate water pressure on the upper floors of the building unless the tank is elevated to an impractical height. Under these conditions, a hybrid system comprised of the elevated tank plus a small booster pump or hydropneumatic system only for the top several floors can be used.

Expansion Tank

Besides the ideal gas law, another fundamental principle of sizing an expansion tank includes the density change of water. A water heater frequently requires a check valve on its inlet, and an expansion tank is typically installed between the inlet and the check valve. Temperature changes of the water in the heater tank and hot water distribution pipe cause volume changes of this water. Without the expansion tank, a temperature rise will add pressure to the heater tank and distribution pipe. A sufficient increase will open the water heater pressure relief valve. An ideally sized expansion tank will allow an initial charge of cold water at minimum pressure to rise up to a temperature set point of the water heater without the pressure relief valve opening.

The design of the expansion tank is generally the same as the hydropneumatic tank but typically of smaller volume. Its initial charge of air should correspond to the building's minimum water pressure.

In a system of water in a water heater and its related piping, the mass of water is constant during times of no demand. From the definition of density, we have this constant mass equal to the product of volume and density. Hence, between any two points of time,

Equation 5-5

$$V_{S1}d_1 = V_{S2}d_2$$

where

V_{S1} = volume of system at density, d_1 (ft^3), (lbs/ft^3)
V_{S2} = volume of system at density, d_2 (ft^3), (lbs/ft^3)

The volume change of water of the system is the same as the volume change of the air in the expansion tank. Hence, together with the density change of water in the system and the ideal gas law applied to the air in the tank, the change in volume between any two points of time can be set to equal

$$V_{S2} - V_{S1} = V_1 - V_2$$

where

V_1 = volume of air in the tank at pressure, p_1 (ft^3), (psia)
V_2 = volume of air in the tank at pressure, p_2 (ft^3), (psia)

Therefore,

$$V_{S1}\left(\frac{d_1}{d_2}\right) - V_{s1} = V_1 - V_1\left(\frac{p_1}{p_2}\right)$$

$$V_{S1}\left(\frac{d_1}{d_2} - 1\right) = V_1\left(1 - \frac{p_1}{p_2}\right)$$

$$V_{S1}\left(\frac{d_1 - d_2}{d_2}\right) = V_1\left(\frac{p_2 - p_1}{p_2}\right)$$

When we choose d_1 and p_1 as the conditions of the system at minimum temperature and pressure and d_2 and p_2 at maximum temperature and pressure, the minimum size expansion tank will be $V_t = V_1$, which we find to be

Equation 5-6

$$V_1 = V_t = V_{S1}\left(\frac{d_1 - d_2}{d_2}\right)\left(\frac{p_2}{p_2 - p_1}\right)$$

Hence, from a given volume of water in the pipe system and water heater, a minimum size expansion tank is found from the product of a water density ratio and a pressure ratio. From Equation 5-6, Table 5-10 shows water density ratios for several maximum temperatures, and Table 5-11 shows pressure ratios for average sea level conditions.

In practice, expansion tanks are chosen slightly larger than as calculated to avoid a completely empty tank; the volume of water in the hot water distribution is rarely significant compared to the tank volume; and p_2 is the pressure rating of the water heater. With the use of backflow preventers on the water service, it is encouraged to include the volume of both the cold and hot water distribution piping. Note that since p_2 is derived from the ideal gas law, it is an absolute pressure and must include the local prevailing atmospheric pressure (14.7 psi [101 kPa] at sea level). Finding the density ratio is fairly simple. As an example for the temperature range from 38°F (3.3°C) to 140°F (60°C), $(d_1 - d_2)/d_2$ is found to be (62.425 – 61.38)/61.38 = 0.0171 [(1 – 0.9832)/0.9832 = 0.0171]. Manufacturers regard $V_1 - V_2$ as an acceptance volume.

Table 5-10 Water Expansion Above 40°F

Temperature, °F	Water Density Ratio
100	0.0069
120	0.0115
130	0.0142
140	0.0171
150	0.0202
160	0.0235
170	0.0270
180	0.0307

Table 5-10(SI) Water Expansion Above 40°F

Temperature, °C	Water Density Ratio
37.8	0.0069
48.9	0.0115
54.4	0.0142
60	0.0171
65.6	0.0202
71.1	0.0235
76.7	0.0270
82.2	0.0307

Table 5-11 Expansion Tank Pressure Ratios

Pressure max, psi	Pressure min, psi	Pressure Ratio
100	40	1.91
100	50	2.29
100	60	2.87
100	70	3.82
100	80	5.73
125	40	1.64
125	50	1.86
125	60	2.15
125	70	2.54
125	80	3.10
150	40	1.50
150	50	1.65
150	60	1.83
150	70	2.06
150	80	2.35

Table 5-11(SI) Expansion Tank Pressure Ratios

Pressure max, kPa	Pressure min, kPa	Pressure Ratio
690	276	1.91
690	345	2.29
690	414	2.87
690	483	3.82
690	552	5.73
862	276	1.64
862	345	1.86
862	414	2.15
862	483	2.54
862	552	3.10
1034	276	1.50
1034	345	1.65
1034	414	1.83
1034	483	2.06
1034	552	2.35

EXCESS WATER PRESSURE

One of the main sources of trouble in a water-distribution system is excessive pressure. Unless a piece of equipment, fixture, or operation requires a specified high pressure, a water system should not exceed a maximum of 80 psi (551.6 kPa) (check local code). To ensure this, a PRV should be installed if the pressure on the outlet side of the meter and backflow preventor is more than 80 psi.

The purpose of a PRV is to reduce water pressure from higher, supply main pressures to desirable and

adequate flow pressures when water is required at fixtures, appliances, or equipment.

Pressure-Regulating Valves (PRV)

Types of PRV All PRVs fall into the following general categories:

- Single-seated—direct-operated or pilot-operated.
- Double-seated—direct-operated or pilot-operated.

Single-seated PRVs are used for dead-end service and when the flow to be regulated is intermittent. For dead-end service, the valve must be able to shut tight and not permit the passage of any water when there is no demand. Double-seated PRVs are used for continuous-flow conditions. They are not suited for dead-end service and should never be used for this purpose.

Direct-operated PRVs tend to have a reduction of the outlet pressure in direct proportion with the increase of the flow rate (fall-off pressure). Pilot-operated PRVs will maintain a close fluctuation of the outlet pressure independent of the flow rate assuming that the valve was sized properly.

Sizing, selection, and installation Initial cost, maintenance cost, and specific project requirements regarding flow rates and pressure should determine which PRV is recommended for a particular application.

Sizing and selection of a PRV can be performed after the following criteria are estimated: inlet pressure, outlet pressure, and capacity (flow rate). Inlet pressure is the maximum pressure expected upstream of the regulating valve. Outlet pressure is the pressure required downstream of the regulating valve. Fall-off pressure is the pressure drop through the PRV at full flow (subtract from set pressure). For large-capacity systems, which may also experience periods of low flow, or when extreme pressure reductions are expected, it is not advisable to have only one regulating valve.

A PRV sized to accommodate both small and large flows has, in general, a high noise level during operation. In addition, small flows will produce wiredrawing of the seat and possible chatter.

In addition to having economic advantages, the proper application of PRVs can greatly influence the overall performance of the system. Under most circumstances, a good application can increase system performance, reduce operating costs, and ensure a longer life expectancy for regulators.

For example, where initial pressures exceed 200 psi (1,379.0 kPa) or where there is a wide variation between the initial pressure and the reduced pressure, or where the initial pressure varies considerably, two-stage reduction is beneficial. Two-stage reduction is the use of two PRVs to reduce high service pressure proportionately and to eliminate an extremely wide variance between the initial and reduced pressure. It is recommended where the initial pressure is 200 psi (1,379.0 kPa) or more and where the ratio of initial to reduced pressure is more than 4 to 1 (e.g., 200 to 50 psi [1,379.0 to 344.7 kPa]), or where the initial pressure fluctuates greatly. The advantage of this installation is that neither valve is subjected to an excessive range of pressure reductions. This seems to stabilize the final reduced pressure, ensuring close and accurate performance. Also, this type of installation reduces the velocity of flow (there's less pressure drop across two regulators than across one), providing longer valve life.

Selection of PRVs and pressure settings is fairly simple. The first PRV could reduce from 250 to 150 psi (1,723.7 to 1,034.2 kPa) and the second from 150 to approximately 50 psi (1,034.2 to 344.7 kPa), or there could be some similar division. PRV size can be selected according to the manufacturer's capacity tables if it is remembered that each PRV should exceed the total capacity of the system.

Where there is a wide variation of demand requirements and where it is vital to maintain a continuous water supply as well as provide greater capacity, parallel installation is recommended. Parallel installation is the use of two or more smaller PRVs serving a larger supply pipe main. This type of installation should be employed wherever there is a wide variation of reduced-pressure requirements and where it is vital to maintain a continuous water supply. It also has the advantage of providing increased capacity beyond that provided by a single valve where needed. Multiple installation improves valve performance for widely variable demands and permits the servicing of an individual valve without the complete shutdown of the line, thus preventing costly shutdowns.

For a two-valve parallel installation, the total capacity of the valves should equal or exceed the capacity required by the system. One valve should be set at 10 psi (69.0 kPa) higher delivery pressure than the other. For example, assume that the system requires 400 gpm (25.2 L/s) and the reduced-flow pressure required is 50 psi (344.7 kPa). Select two valves, each rated at 200 gpm (12.6 L/s), with one valve set at 50 psi (344.7 kPa) and the other valve set 10 psi (69.0 kPa) higher at 60 psi (413.7 kPa). Thus, when low volume is required, the higher-set valve operates alone. When a larger volume is demanded, both valves open, delivering full-line capacity.

Another possible choice is to install two PRV combinations of different sizes. This is practical on larger installations where supply lines are 2 in. (50 mm) and larger and where there are frequent periods of small demand. The smaller PRV would have the 10-psi

(69.0-kPa) higher delivery pressure and thus operate alone to satisfy small demands, such as urinals and drinking fountains. When a larger volume is needed, the main PRV would open to satisfy the system demand. For example, take an apartment building requiring 300 gpm (18.9 L/s) at 60 psi (413.7 kPa). The selection might be a 4-in. (100-mm) PRV rated for 240 gpm (15.1 L/s) (80% of total maximum flow rate) and set at 60 psi (413.7 kPa) and a 1½-in. (40-mm) PRV rated for 60 gpm (3.8 L/s) and set at 70 psi (482.6 kPa).

Manufacturers have tables indicating recommended capacities and valve sizes for use in parallel installations.

WATER HAMMER

A well designed cold water distribution system minimizes velocity-related problems in a cost-effective manner. For an open system, every time a valve opens or a fixture is used there is a change in flow and pressure, but when excessive velocity is also present these hydrodynamic changes can be destructive. Excessive velocity-related problems include erosion, cavitation, entrained air separation, whistling, and water hammer.

Water hammer, or more formally hydraulic shock, which reminds the designer that there are non-audible components, is the term commonly used to describe the destructive forces, pounding noises, and vibrations that develop in a piping system when a column of noncompressible liquid flowing at a given velocity is abruptly stopped. The dynamic pressure wave generated at the point of impact travels back and forth through the piping system until the wave energy is dissipated, producing the characteristic sound associated with this phenomenom, as if someone was hitting the pipe with a hammer. See Figure 5-5(a).

Water hammer can occur in any noncompressible liquid piping system. A pumped waste system, a closed hydronic system, or a purified water system, as examples, all will exhibit water hammer for the same reasons as a cold water distribution system. Steam systems can produce sounds similar to that caused by hydraulic shock, and these sounds are also commonly known as water hammer. Steam system water hammer, by contrast, is caused by either a too rapid condensation of steam or a slug of condensate captured by high velocity steam and then forced through the pipe until slammed into an elbow.

Any device that abruptly stops the flow of water will generate a shock wave and, depending on installation circumstances, may cause water hammer. Common devices of concern include quick-closing electrical solenoid valves and pneumatic valves and pumps, as well as the quick hand closure of quarter-turn valves or fixture trim. Because of their high instantaneous flow and therefore accompanying high fluid velocity, water closet flushometer valves (flush valves) also frequently act as the source of water hammer.

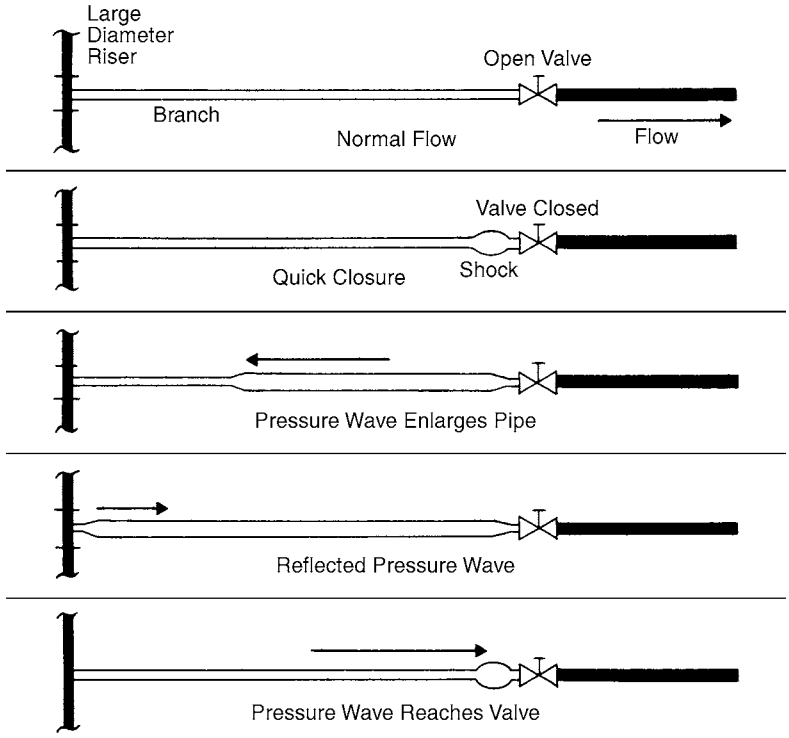


Illustration adapted from Plumbing & Drainage Institute, Standard PDI-WH201.

Figure 5-5(a) Illustrations of a Shock Wave

Although sound is generally associated with the occurrence of hydraulic shock, the absence of such noise does not necessarily prove that hydraulic shock is nonexistent. The sound may be annoying but is not inherently dangerous; like thunder and lightening, the cause of the sound is the dangerous part. For a given piped system the designer should verify that the circumstances that produce water hammer are either not present or, if present, are effectively controlled.

Shock Intensity

The intensity of a pressure wave is directly related to valve closure time. As valve closure time from full-open position to full-closed position approaches zero, the maximum pressure rise is reached, calculated by Equation 5-7, known as Joukowsky's formula:

Equation 5-7

$$P_r = \frac{wav}{144g}$$

where

P_r = Pressure rise above flow pressure, psi (kPa)
w = Specific weight of liquid, for water 62.4 lb/ft^3 (1,000 kg/m^3)
a = Velocity of pressure wave, fps (m/s)

v = Change in flow velocity, fps (m/s)
g = Acceleration due to gravity, 32 ft/s^2 (9.8 m/s^2)

The value of a can be determined by Equation 5-8:

Equation 5-8

$$a = \frac{A_w}{(1 + KB)^{½}}$$

where

A_w = Velocity of sound in water, at room temperature approximately 4,900 fps (1,490 m/s)
K = Ratio of modulus of elasticity of the fluid to the modulus of elasticity of the pipe
B = Ratio of pipe diameter to pipe wall thickness

For an installed cold water system the velocity of the pressure wave a can be taken to be a constant. For a typical metal pipe water system the pressure wave velocity averages 4,000–4,500 fps (1,200–1,400 m/s). Using Equation 5-7, the maximum pressure rise is approximately 60 times the change in velocity, and at a typical maximum design velocity of 8 fps (2.4 m/s), quick valve closure can produce a shock pressure of 480 psi (3,300 kPa). Most valves and fittings used in a water distribution system are designed and constructed for normal maximum working pressure of 150 psi (1,000 kPa). Subjecting a system to repeated pressure surges of almost 500 psi (3,450 kPa) can cause serious damage.

The time interval required for a pressure wave to travel from the point of closure (origin) to the point of reflection and back again is denoted by 2L/a, where L is the length of pipe from the point of closure to the point of reflection (typically a point of relief, as defined in PDI-WH201, such as a pipe at least 2 sizes larger or a water tank), and a is the velocity of a pressure wave as already defined. Quick valve closure may be defined as a closure time equal to or less than 2L/a seconds, with a beginning flow of at least 15 percent of full-open flow. When a valve closes in a time equal to or less than 2L/a seconds, the initial wave returns to hit the now completely closed valve, reflecting the full force of the wave back into the system. This oscillation continues every 2L/a seconds until the wave energy is dissipated. It is interesting to note that for a common branch length of, say, 20 ft (6 m), a 4,000 fps (1,200 m/s) pressure wave would complete this oscillation at a rate of 200 Hertz, definitely within the audible range.

As can be seen by reviewing Equation 5-7, shock intensity P_r is independent of flow pressure; however, for an open system this can be misleading. A standard hose bibb flows more water at higher pressure than at lower pressure, with no difference in time of closure. For a standard 1.6 gpf (6 lpf) flushometer, with a beginning static pressure of 25 psi (170 kPa), the maximum instantaneous flow reaches 40 gpm (150 lpm) with full closure about 12 seconds after peak flow. At 80 psi (550 kPa) the same flushometer will deliver 75 gpm (280 lps) with closure only 8 seconds later. Clearly, an open system operating at higher flow pressure is likely to have higher flow velocity and will generate more intense water hammer.

Plastic pipe cold water systems are becoming more common. From Equations 5-7 and 5-8 it is seen that the magnitude of the pressure wave is some function of pipe elasticity and wall thickness. Thermoplastic pipe materials such as PVC, PVDF, and polypropylene have thicker walls than metal pipe, but their modulus of elasticity is on the order of 100 times lower (10^5 versus 10^7 psi) (GPa) frequently dominating the equation, lowering the velocity of the pressure wave and therefore lowering the overall magnitude of the shock pressure wave. Where water hammer is a concern for a plastic pipe system, the pipe manufacturer should be contacted for appropriate design constants.

System Protection

The layout of the distribution system along with the designer-controlled parameters of Equations 5-7 and 5-8 need to be manipulated to minimize velocity-related problems in a cost-effective manner. A spring-loaded check valve could be installed at the discharge of a pump. A water PRV could be installed, or the outlet pressure of an existing PRV could be lowered. A pipe branch to a troublesome fixture could be up-sized. Air chambers or water hammer arresters could be installed.

It has been said that the existence of water hammer simply means that the pipe is too small. After all, the cross-sectional area of a 1½-in. (38-mm) pipe is about 2.5 times that of a 1-in. (25-mm) pipe. This larger size branch line to a water closet flushometer, for example, would decrease the water velocity and therefore shock wave intensity P_r by 60 percent. A set of 1-in. (25-mm) supplies to a lavatory would surely eliminate all possibility of dangerous water hammer on that branch, but of course it would also be difficult to economically justify this unusually large pipe.

Air chambers For hydraulic shock system protection, air chambers have essentially been replaced by premanufactured water hammer arresters. The air chamber device consists of a capped piece of pipe of various lengths, some with fittings to facilitate draining and recharging. Figure 5-6 shows examples of air chambers. Air chamber capacity requirements are shown in Table 5-12, taken from Dawson and Kalinske, Iowa Institute of Hydraulic Research. The two main components of any shock absorber are variable displacement and energy dampening. Air chambers exhibit superior variable displacement and rely on the naturally occurring dampening effects of the piping medium for their effectiveness. Figure 5-5(b) shows an oscilloscope image of the shockwave of

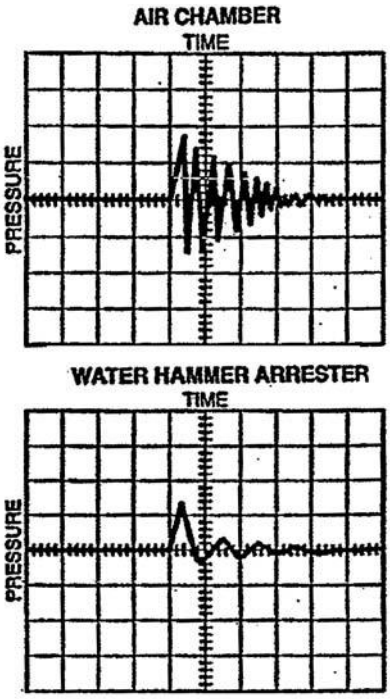


Figure 5-5(b) Time vs. Pressure Shockwave of System

a system protected by a properly sized, fully charged air chamber.

Properly sized air chambers, at best, are suitable only for the temporary control of shock. The entrapped air charge is rapidly depleted for a number of reasons, and, once gone, the waterlogged device provides no shock protection. Two primary reasons for the depletion of the entrapped air are entrainment caused by turbulence at a shock event and the increased solubility of gas under pressure. For the same reason that the opening of a can of soda releases carbon dioxide, or freshly drawn hot water forms white milky clouds of tiny bubbles, holding air at pressure against unsaturated water results in oxygen,

Table 5-12 Required Air Chambers

Nominal Pipe Diam., in. (mm)	Pipe Length, ft (m)	Flow Pressure, psi (kPa)	Velocity, fps (m/s)	Required Air Chamber	
				Volume, in.^{3} (cm^3)	Phys. Size, in. (cm)
½ (12.71)	25 (7.62)	30 (207)	10 (3.04)	8 (1.3)	¾ × 15 (1.9 × 38.1)
½ (12.71)	100 (30.5)	60 (414)	10 (3.04)	60 (9.8)	1 × 69½ (2.5 × 176.5)
¾ (19.1)	50 (15.25)	60 (414)	5 (1.52)	13 (2.1)	1 × 5 (2.5 × 12.7)
¾ (19.1)	200 (61.0)	30 (207)	10 (3.04)	108 (17.7)	1¼ × 72½ (3.2 × 184.2)
1 (25.4)	100 (30.5)	60 (414)	5 (1.52)	19 (3.1)	1¼ × 12 7/10 (3.2 × 32.3)
1 (25.4)	50 (15.25)	30 (207)	10 (3.04)	40 (6.6)	1¼ × 27 (3.2 × 68.6)
1¼ (31.8)	50 (15.25)	60 (414)	10 (3.04)	110 (18.0)	1¼ × 54 (3.2 × 137.2)
1½ (38.1)	200 (61.0)	30 (207)	5 (1.52)	90 (14.8)	2 × 27 (5.1 × 68.6)
1½ (38.1)	50 (15.25)	60 (414)	10 (3.04)	170 (27.9)	2 × 50½ (5.1 × 128.3)
2 (50.8)	100 (30.5)	30 (207)	10 (3.04)	329 (53.9)	3 × 44½ (7.6 × 113.0)
2 (50.8)	25 (7.62)	60 (414)	10 (3.04)	150 (24.6)	2½ × 31 (6.4 × 78.7)
2 (50.8)	200 (61.0)	60 (414)	5 (1.52)	300 (49.2)	3 × 40½ (7.6 × 102.9)

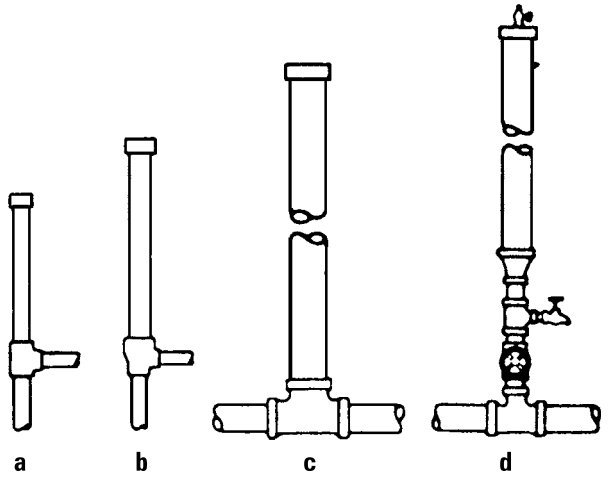


Figure 5-6 Air Chambers: (a, b) Plain Air Chambers, (c) Standpipe Air Chamber, (d) Rechargeable Air Chamber

nitrogen, carbon dioxide, and other trace gases of air being absorbed into the water (Dalton's law of partial pressures combined with Henry's law of proportional solubility). This depletion of the air charge occurs continuously, even as the system sits idle.

Water hammer arresters The appropriate use of engineered water hammer arresters, also known as water shock absorbers, is an integral part of an overall cost-effective design. Water hammer arresters are able to rapidly attenuate shock pressure and confine its effects to that section of piping in which it was generated. To ensure consistent long-term operation, commercially available water hammer arresters have a sealed gas chamber separated from the noncompressible fluid by either a bellows or piston arrangement, as illustrated in Figures 5-7(a) and 5-7(b). There are two industry accepted certifications that the manufacturer of an engineered water hammer arrester may obtain, ASSE 1010 and PDI-WH201. ANSI standard A-112.26.1 was administratively withdrawn in 1995, which is to say that it is no longer maintained.

High pressure, purified water or other special application water hammer arrester models are available with varying construction materials and field adjustable gas chamber contents and pressures. For a purified water system or an application where bacterial control is required, the detrimental stagnant water and dead-end nature of a water hammer arrester must be weighed against the hydraulic shock-relieving benefits.

Water hammer arrester sizing and placement In response to the lack of an industry standard for sizing and placement of engineered

Table 5-13 Water Hammer Arrester Sizing

Size	AA	A	B	C	D	E	F
Fixture Units	1-3	1–11	12–32	33–60	61–113	114–154	155–330

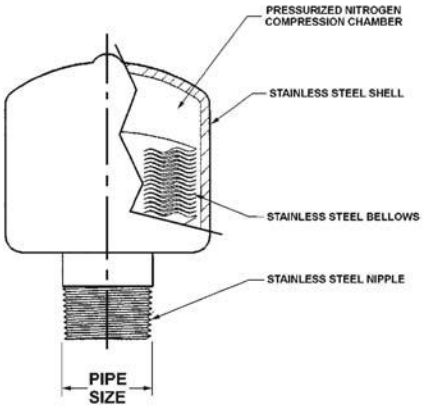


Figure 5-7(a) Bellows

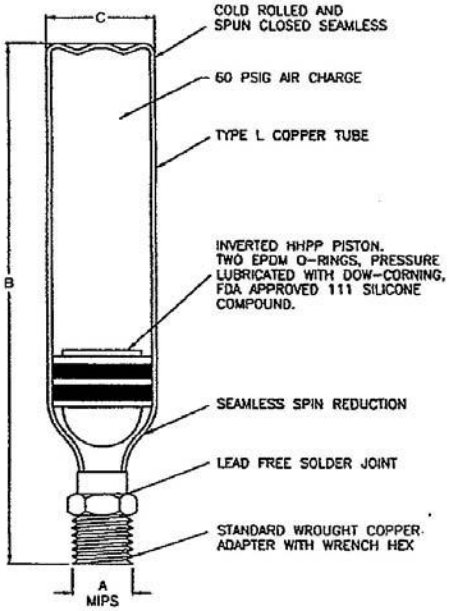


Figure 5-7(b) Piston

Table 5-14 Densities of Pure Water at Various Temperatures

Temperature, °F	Density, lb/cu.ft.	Temperature, °F	Density, lb/cu.ft.
32	62.418	100	61.988
35	62.421	120	61.719
39.2	82.424	140	61.386
40	62.423	160	61.008
50	62.408	180	60.586
60	62.388	200	60.135
70	62.300	212	59.843
80	82.217		

water hammer arresters, the Plumbing and Drainage Institute (PDI) first published the standard PDI-WH201 in 1965, and ASSE 1010 was first copyrighted in 1967. (PDI-WH201 is available as a free download from the PDI website, www.pdionline.org.)

Engineered water hammer arresters can be certified in any of seven sizes, each having a different capacity to control shock, ranging in size from Type AA through Type F. The certified size is based on successful completion of tests under specific experimental conditions, such as pipe size, pipe length, flow pressure, endurance, and limiting surge pressures to less than 150 psi.

Table 5-13 was devised by PDI, based on industry experience and the supply fixture unit (SFU) sizing method for single and multiple fixture branch lines, to help the designer rapidly choose appropriately sized water hammer arresters. The SFU values used to complete Table 5-13 have been taken from a certain edition of the National Plumbing Code. As plumbing codes evolve, fixture unit values change. Without diminishing the value of Table 5-13, the designer, by understanding its history and purpose, is thus better able to use the tool appropriately.

Water hammer arrester sizing and placement guidelines according to PDI-WH201 include the following:

- Size water hammer arresters for use on cold and hot water branch lines according to Table 5-13.
- When water flow pressure exceeds 65 psi (450 kPa), select the next larger size water hammer arrester.
- When the branch line exceeds 20 ft (6 m) in length, an additional water hammer arrester should be used, each sized for half the total fixture unit load.
- The preferred location for the water hammer arrester is at the end of the branch line between the last two fixtures served.
- The preferred location for the second water hammer arrester, when required, is approximately midway along the branch line.
- A water hammer arrester for a branch serving a piece of equipment with a quick-closing valve should be placed as close as possible of the equipment isolation valve.

SIZING WATER PIPING

Water can be regarded as an noncompressible fluid, and, for calculations, it is customary to assume that water has a uniform density of 62.4 lb/ft^3 (1 kg/L),

which holds nearly constant through a temperature range of 32–60°F (0–15.6°C). See Table 5-14.

For calculations involving high temperature (above 200°F [93.3°C]), it is desirable to take into account the changes in density, vapor pressure, and viscosity with temperature.

Hazen-Williams Formula

Among the empirical formulae for piping friction losses that have been developed, the Hazen-Williams equation is widely used, particularly for fire protection and city water systems. In a convenient form, it reads as follows:

Equation 5-9 (Hazen-Williams Formula)

$$f = 0.2082\left(\frac{100}{C}\right)^{1.85}\left(\frac{q^{1.85}}{d^{4.8655}}\right)$$

where

f = Friction head, ft of liquid/100 ft of pipe (m/100m)
C = Surface roughness constant (dimensionless)
q = Fluid flow, gpm (L/s)
d = Inside diameter of pipe, in. (mm)

This formula is most accurate for the flow of water in pipes larger than 2 in. (5.1 cm) and at velocities less than 10 fps (3 m/s).

Equation 5-9 yields accurate results only when the kinematic viscosity of the liquid is about 1.1 centistokes, which is the case for water at 60°F (15.6°C). However, the kinematic viscosity of water varies with temperature, from 1.8 centistokes at 32°F (0°C) to 0.29 centistokes at 212°F (100°C); therefore, the tables using Hazen-Williams are subject to this error, which may increase the friction loss by as much as 20% at 32°F (0°C) and decrease it by as much as 20% at 212°F (100°C). Values of C, for various types of pipes, are shown in Table 5-15 with the corresponding multipliers that should apply to the values of the head loss, f, for various temperatures.

Figure 5-8 is a copy of N 1.85 graph paper used to analyze water flow at various gpm (note three lines of gpm at the bottom—choose one). If you know two points on the graph and connect a line between (which can be extended), you can determine the pressure at any other flow in gpm (using the same bottom line). Usually static head at 0 gpm is used as one of the points, and another point at a residual pressure with a certain gpm flowing.

Table 5-15 Surface Roughness Coefficient (C) Values for Various Types of Pipe

Type of Pipe	Values of C		
	Range (High = Best, smooth, well-laid Low = Poor or corroded)	Average Value for Good, Clean, New Pipe	Value Commonly Used for Design Purposes
Asbestos cement	160–140	150	140
Fiber	—	150	140
Bitumastic-enamel-lined iron or steel centrifugally applied	160–130	148	140
Cement-lined iron or steel centrifugally applied	—	150	140
Copper, brass, lead, tin or glass pipe and tubing	150–120	140	130
Wood stave	145–110	120	110
Welded and seamless steel	150–80	140	100
Continuous-interior, riveted steel (no projecting rivets or joints)	—	139	100
Wrought iron	150–80	130	100
Cast iron	150–80	130	100
Tar-coated cast iron	145–80	130	100
Girth-riveted steel (projecting rivets in girth seams only)	—	130	100
Concrete	152–85	120	100
Full-riveted steel (projecting rivets in girth and horizontal seams)	—	115	100
Vitrified clay	—	115	100
Spiral-riveted steel (flow with lap)	—	110	100
Spiral-riveted steel (flow against lap)	—	110	90
Corrugated steel	—	60	60

Value of C	150	140	130	120	110	100	90	80	70	60
Multiplier to Correct Tables	0.47	0.54	0.62	0.71	0.84	1.0	1.22	1.50	1.93	2.57

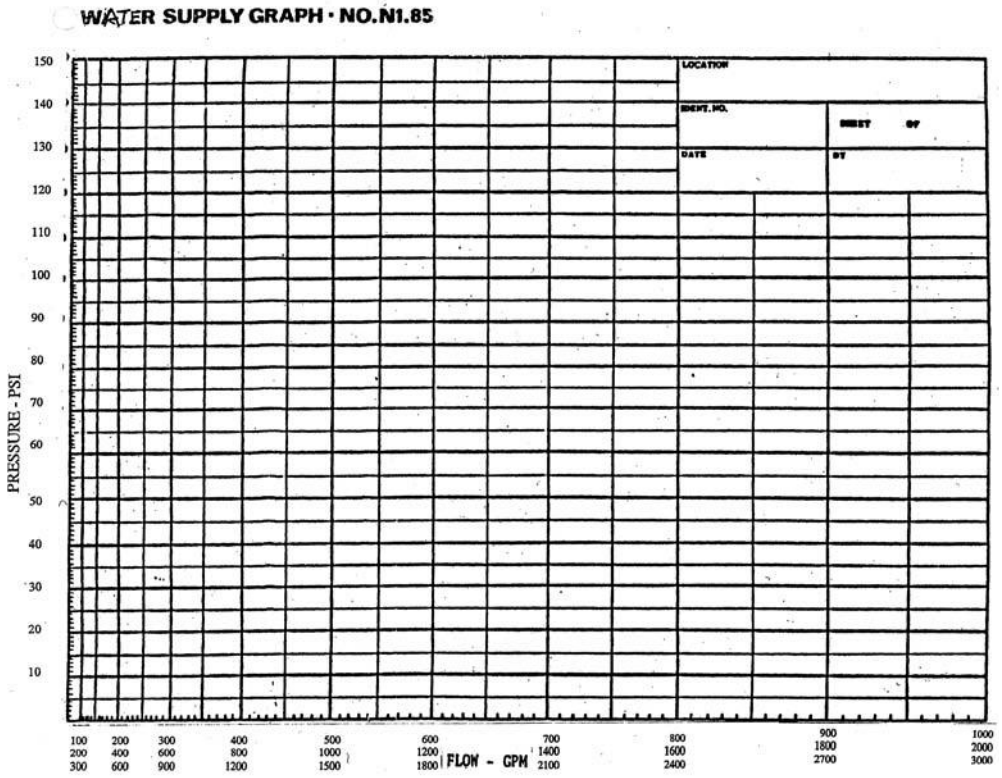


Figure 5-8 Water Supply Graph

Darcy-Weisbach Formula

The more popular equation used by the plumbing and process piping industry is the Darcy-Weisbach Formula. In a convenient form, it reads as follows:

Equation 5-10 (Darcy-Weisbach Formula)

$$h_f = f\left(\frac{L}{D}\right)\left(\frac{V^2}{2g}\right)$$

Also, $p = h_f \times \left(\frac{\varphi}{144}\right)$

where

h_f = friction head loss, ft of fluid
p = friction head loss, psi
f = coefficient of friction or friction factor, dimensionless (from Colebrook equation or Moody diagram)
L = length of pipe, ft
D = inside diameter of pipe, ft
V = average velocity of flow, fps
g = gravitational acceleration, 32.2 ft/sec/sec
φ = lbs/ft^3

The assumptions made for deriving this formula from test data are uniform flow, cold or hot water distribution systems, round pipe or duct, and turbulent flow (above Reynolds number 4,000).

The factor f takes into account viscosity (temperature), pipe roughness, and Reynolds number.

For laminar flow (below Reynolds number of 2,000), the roughness of the pipe has no effect on friction, and f becomes 64/R.

For turbulent flow, f can be determined by the C.F. Colebrook Formula, Moody diagrams, or from manufacturers' data or various handbooks.

Equation 5-11 (Colebrook Formula)

$$\frac{1}{\sqrt{f}} = -2\log_{10}\left[\left(\frac{\varepsilon}{3.7D}\right) + \left(\frac{2.51}{R\sqrt{f}}\right)\right]$$

also, $R = \frac{VD}{v}$

where

R = Reynolds number (Figure 5-9)
f = Friction Factor (dimensionless)
ε = Absolute roughness, in ft
D = Inside diameter of pipe, ft
V = Average pipe velocity, ft/sec
v = Kinematic Viscosity, ft^2/sec

Since the Colebrook equation is complicated, f may be obtained from a graph developed by L.F. Moody (see Figure 5-10). This graph shows the relation between the friction factor f, the Reynolds Number R, and the relative roughness ε/D. The f obtained is valid for any selected fluid and fluid temperatures since viscosity and density are accounted for in the Reynolds number.

See Table 5-16 for some values of ε (absolute roughness) and Table 5-17 for some values of f.

For domestic plumbing, design tables or graphs will be provided by the local code documents and/or the pipe manufacturers or various ASPE publications (see Figure 5-11 through 5-14). The graphs, which are

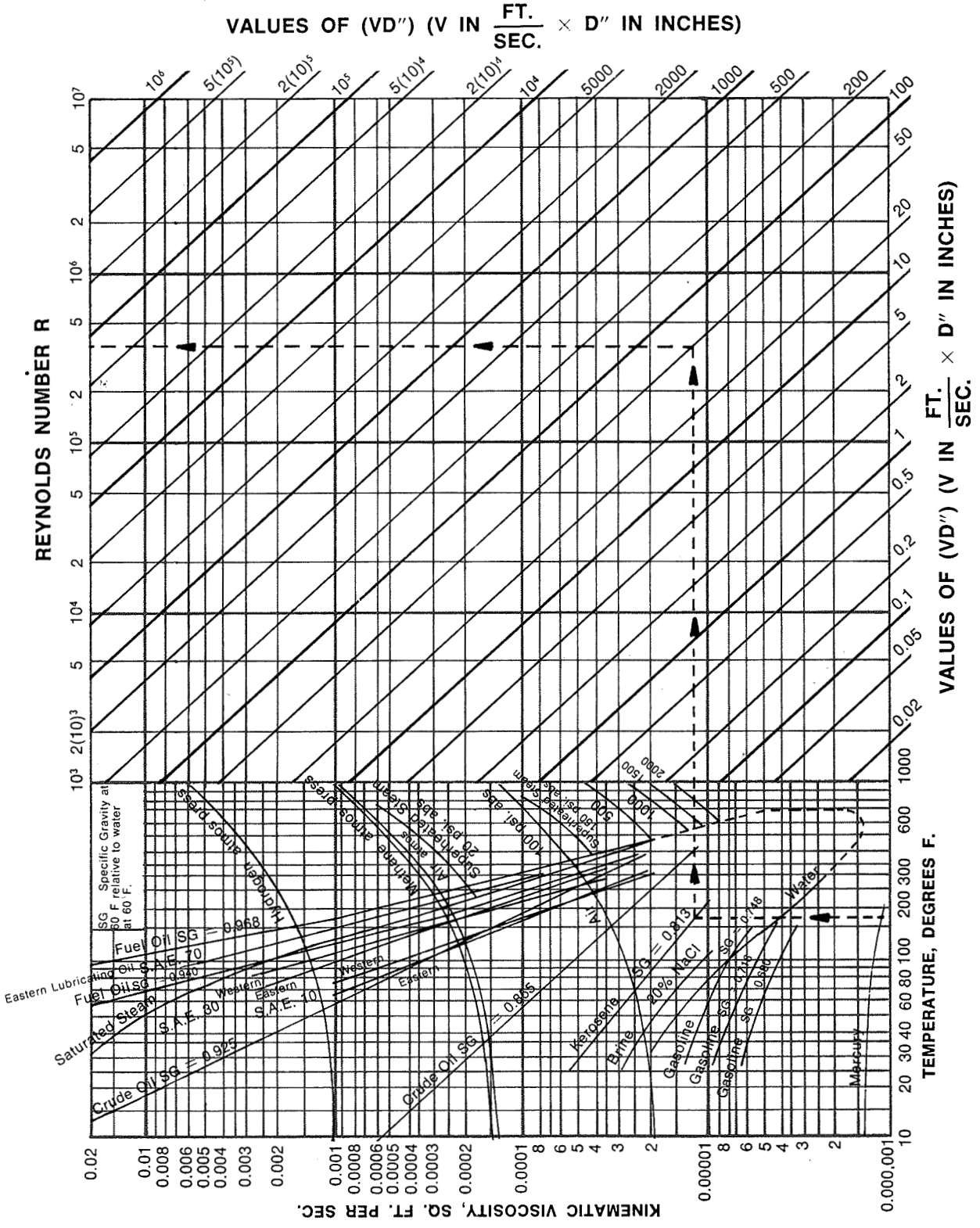


Figure 5-9 Kinematic Viscosity and Reynolds Number Chart

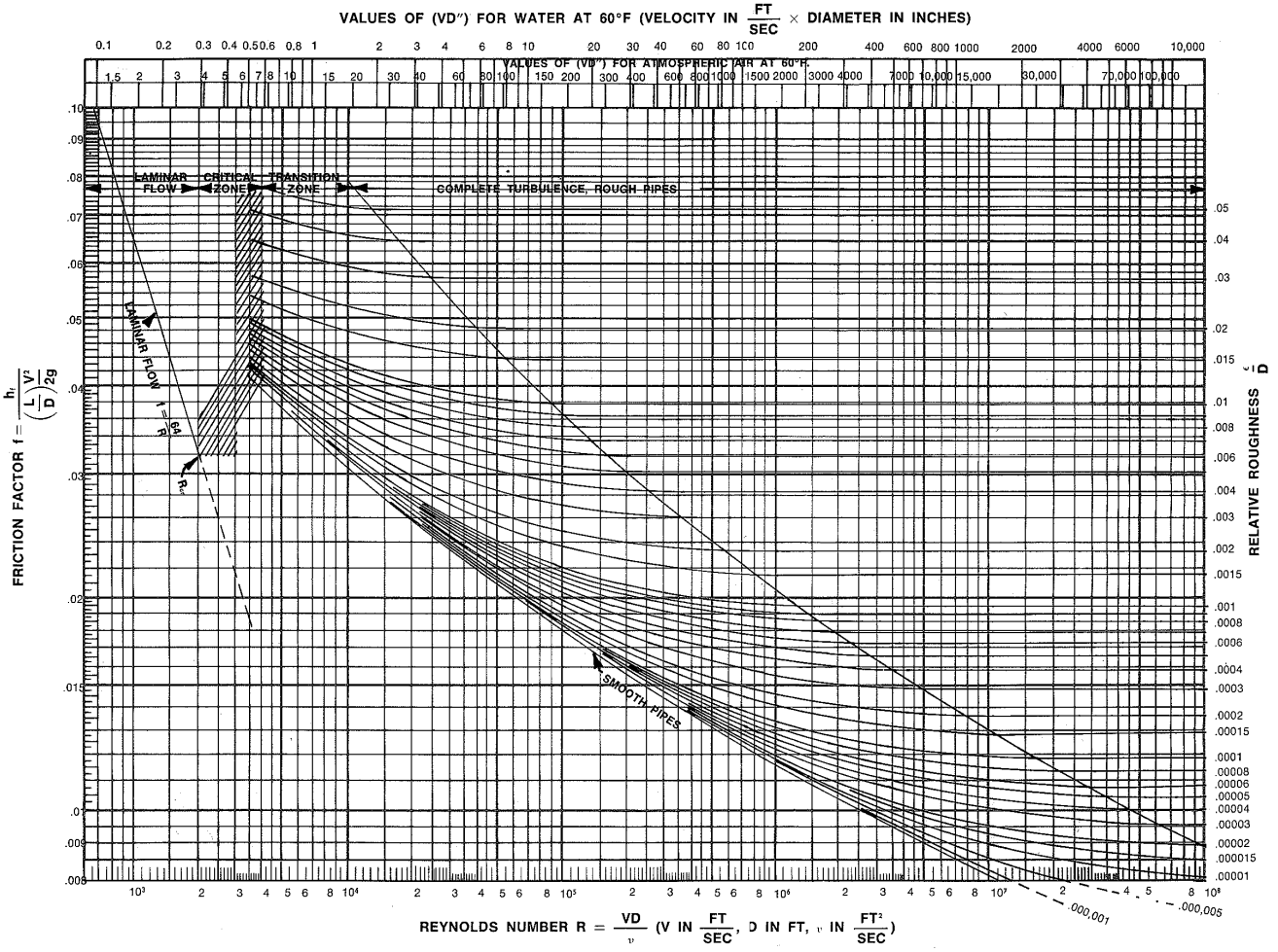


Figure 5-10 Friction factors for any Kind and Size of Pipe

Table 5-16 Values of ε (Absolute Roughness)

Type of pipe (new, clean, condition)	Absolute roughness (in feet)
Drawn tubing—glass, brass; plastic	0.000005
Commercial steel or wrought iron	0.00015
Cast iron—asphalt dipped	0.0004
Galvanized iron	0.0005
Cast iron—uncoated	0.00085
Wood stave	0.0006-0.0003
Concrete	0.001-0.01
Riveted steel	0.003-0.03

Table 5-17 Average Values for Coefficient of Friction, f.

Nominal Pipe Size, inches	Brass, Copper or Lead	Galvanized Iron or Steel
½	0.022	0.044
¾	0.021	0.040
1¼	0.020	0.038
1½	0.020	0.036
1	0.019	0.035
2	0.018	0.033
2½	0.017	0.031
3	0.017	0.031
4	0.016	0.030

preferred to be used, will show the relationships of pressure drop (in psi or ft of water head) per 100 ft of equivalent length (actual length, plus allowance for hand valves and fittings), gpm or L/minute, pipe size, and velocity. To size piping, you must keep in mind all four items, and a graph shows them best. You need to know two items to get on the graph.

For this chapter we have tried to use the latest technical information sources available at the moment to aid you in understanding what is available. It must be understood that where we have used manufacturer's information that it is *not* to be used for your design. In some cases it will be obsolete! When picking a product for your design, you must use the latest manufacturer's literature. Also, you must use the latest code that applies to the location of the building.

Factors Affecting Domestic Water Pipe Sizing

The three factors affecting the sizing of a water line are the demand flow rate (gpm [L/s]), the velocity (fps [m/s]), and the pressure available for piping friction loss (psi [kPa]).

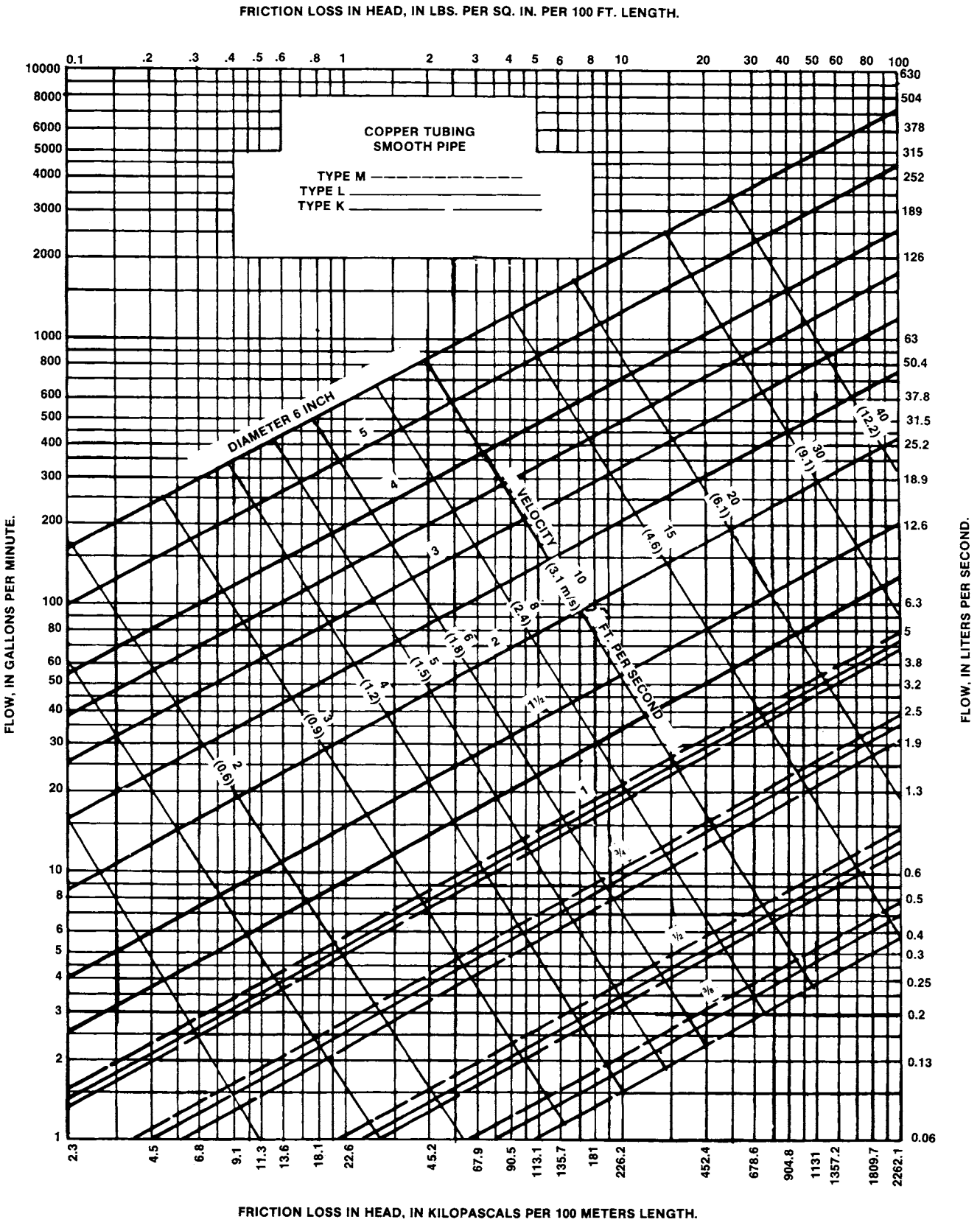


Figure 5-11 Pipe Sizing Data, Smooth Pipe

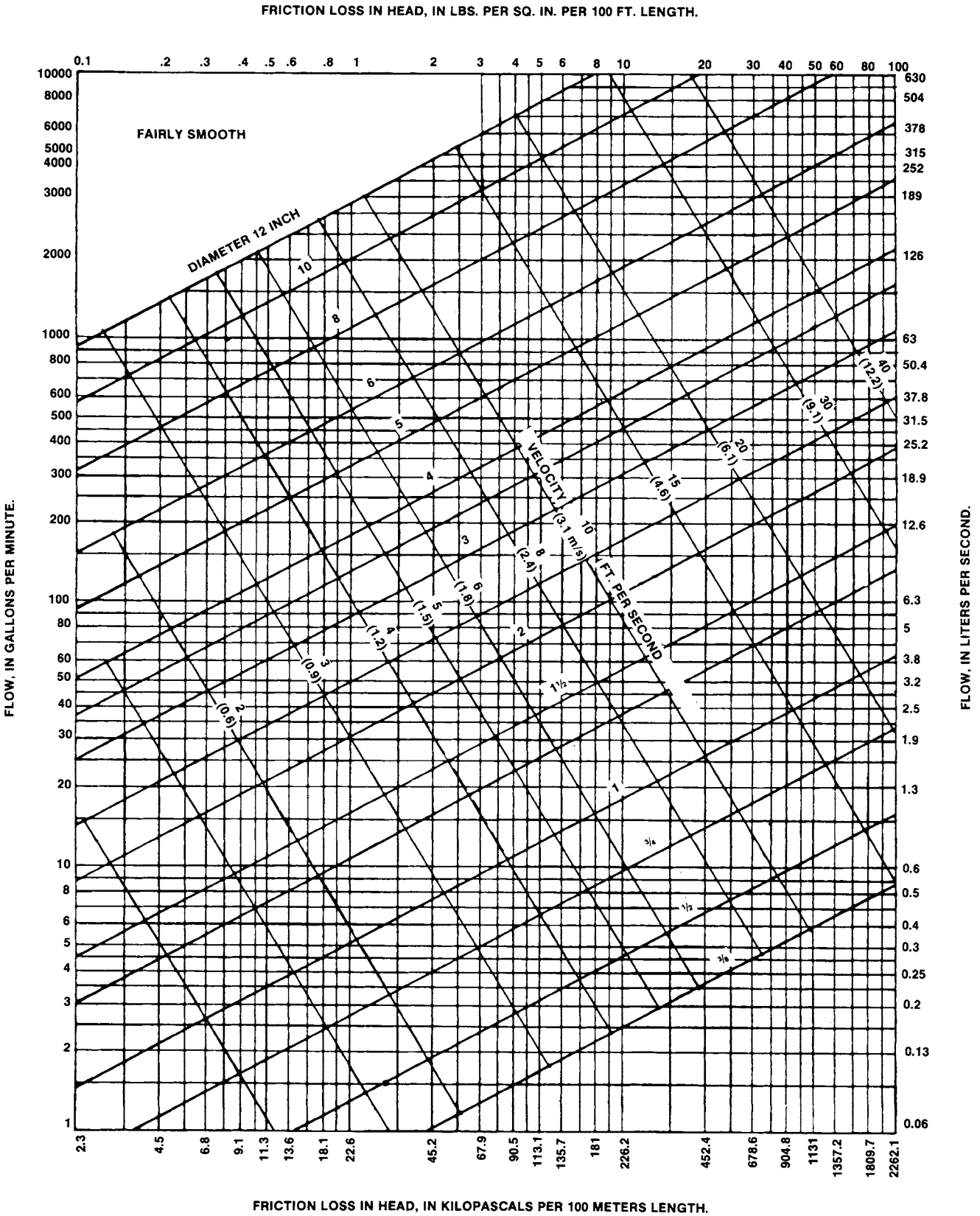


Figure 5-12 Pipe Sizing Data, Fairly Smooth Pipe

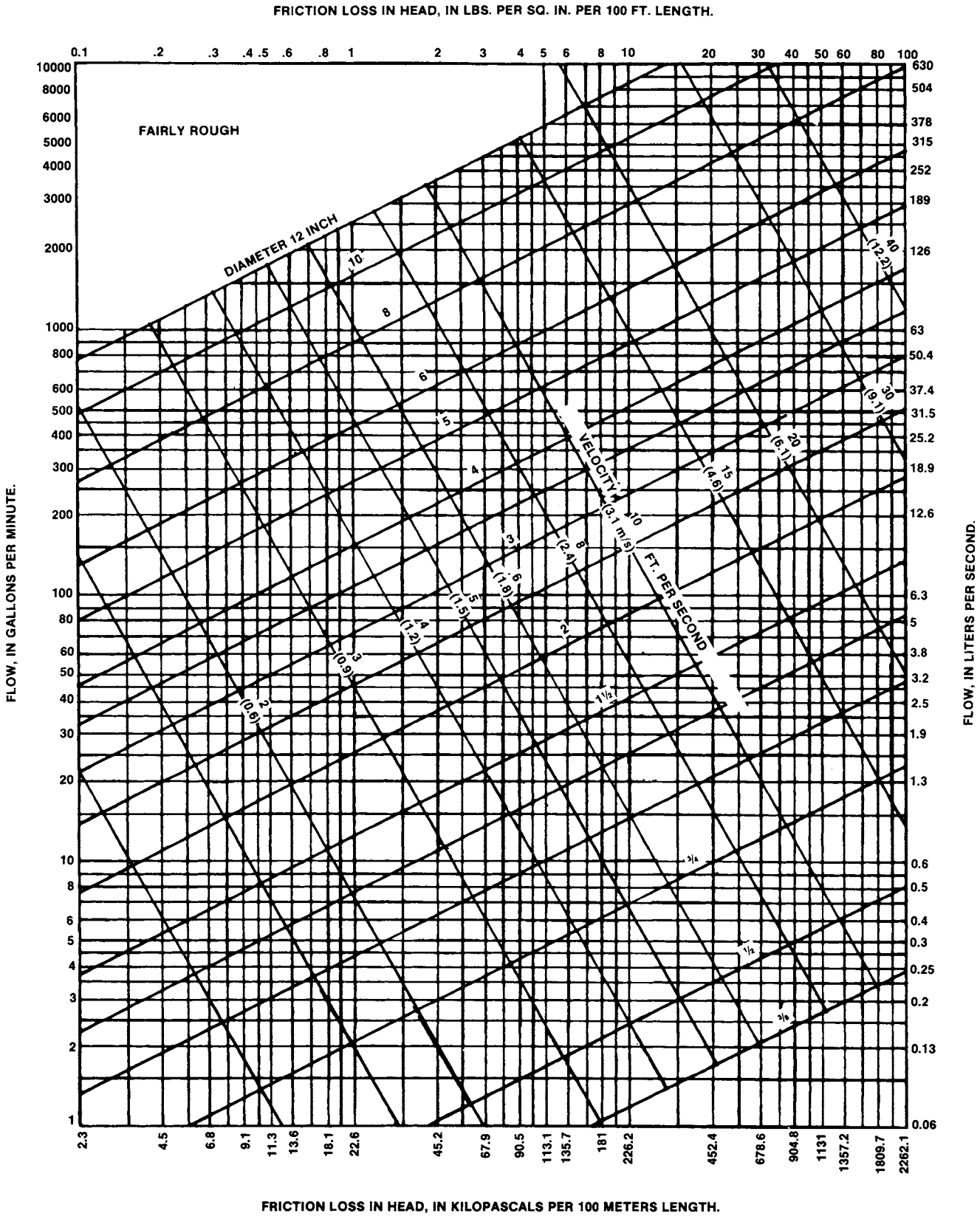


Figure 5-13 Pipe Sizing Data, Fairly Rough Pipe

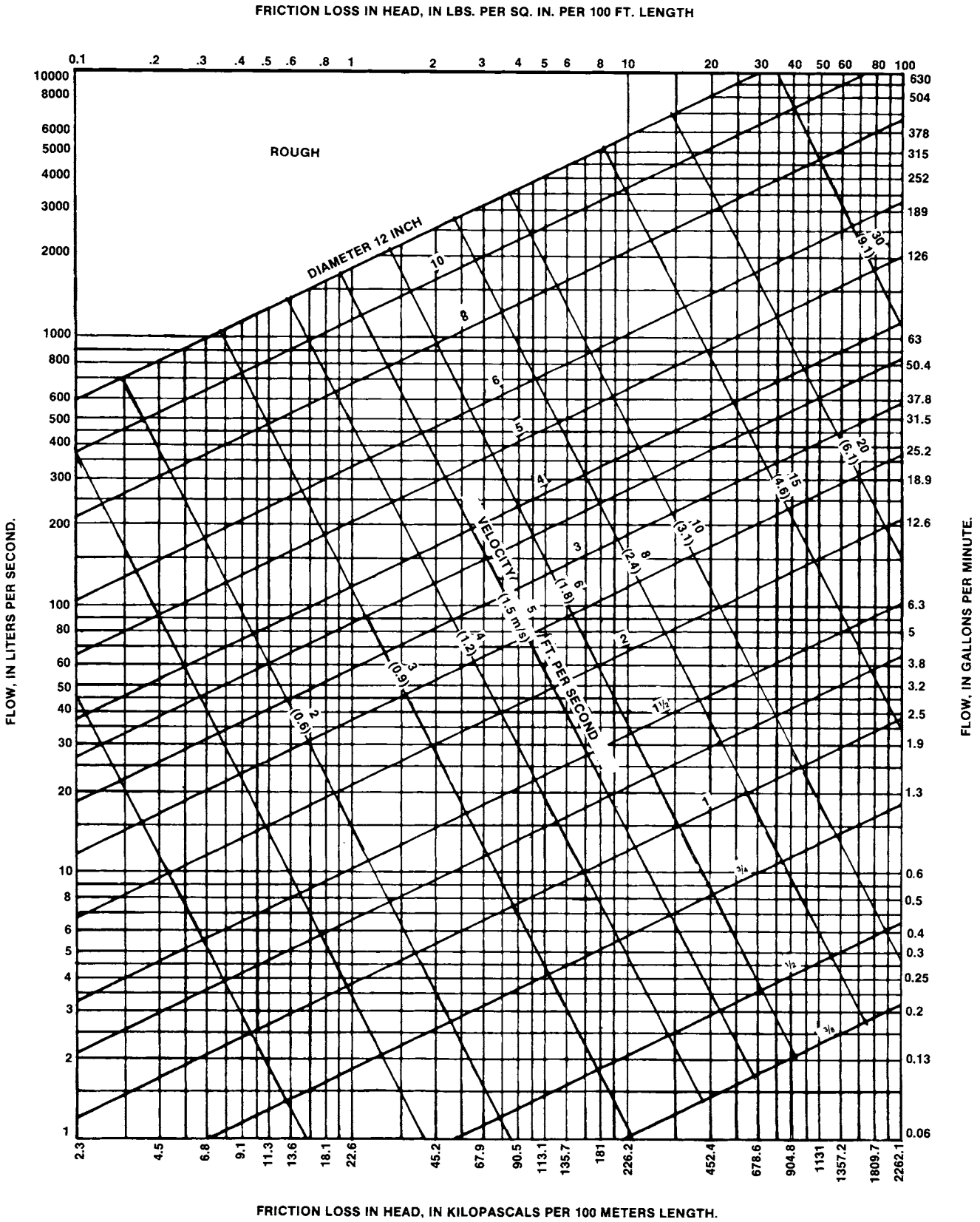


Figure 5-14 Pipe Sizing Data, Rough Pipe

Table 5-18 Load Values Assigned to Fixtures[a]

Fixture	Occupancy	Type Of Supply Control	Load Values, in Water Supply Fixture Units (wsfu)		
			Cold	Hot	Total
Bathroom group	Private	Flush tank	2.7	1.5	3.6
Bathroom group	Private	Flush valve	6.0	3.0	8.0
Bathtub	Private	Faucet	1.0	1.0	1.4
Bathtub	Public	Faucet	3.0	3.0	4.0
Bidet	Private	Faucet	1.5	1.5	2.0
Combination fixture	Private	Faucet	2.25	2.25	3.0
Dishwashing machine	Private	Automatic	—	1.4	1.4
Drinking fountain	Offices, etc.	⅜″ valve	0.25	—	0.25
Kitchen sink	Private	Faucet	1.0	1.0	1.4
Kitchen sink	Hotel, restaurant	Faucet	3.0	3.0	4.0
Laundry trays (1 to 3)	Private	Faucet	1.0	1.0	1.4
Lavatory	Private	Faucet	0.5	0.5	0.7
Lavatory	Public	Faucet	1.5	1.5	2.0
Service sink	Offices, etc.	Faucet	2.25	2.25	3.0
Shower head	Public	Mixing valve	3.0	3.0	4.0
Shower head	Private	Mixing valve	1.0	1.0	1.4
Urinal	Public	1″ flush valve	10.0	—	10.0
Urinal	Public	¾″ flush valve	5.0	—	5.0
Urinal	Public	Flush tank	3.0	—	3.0
Washing machine (8 lb)	Private	Automatic	1.0	1.0	1.4
Washing machine (8 lb)	Public	Automatic	2.25	2.25	3.0
Washing machine (15 lb)	Public	Automatic	3.0	3.0	4.0
Water closet	Private	Flush valve	6.0	—	6.0
Water closet	Private	Flush valve	2.2	—	2.2
Water closet	Public	Flush valve	10.0	—	10.0
Water closet	Public	Flush valve	5.0	—	5.0
Water closet	Public or private	Flushometer tank	2.0	—	2.0

For SI: 1 inch = 25.4 mm, 1 pound = 0.454 kg.

a. For fixtures not listed , loads should be assumed by comparing the fixture to one listed using water in similar quantities and at similar rates. The assigned loads for fixtures with both hot and cold water supplies are given for separate hot and cold water loads and for total load. The separate hot and cold water loads being three-fourths of the total load for the fixture in each case.

Table 5-19 Estimating Demand

Supply Systems Predominantly for Flush Tanks			Supply Systems Predominantly for Flush Valves		
Load	Demand		Load	Demand	
Water supply Fixutre units	Gallons per minute	Cubic feet per minute	Water supply fixture units	Gallons per minute	Cubic feet per minute
1	3.0	0.04104	—	—	—
2	5.0	0.0684	—	—	—
3	6.5	0.86892	—	—	—
4	8.0	1.06944	—	—	—
5	9.4	1.256592	5	15.0	2.0052
6	10.7	1.430376	6	17.4	2.326032
7	11.8	1.577424	7	19.8	2.646364
8	12.8	1.711104	8	22.2	2.967696
9	13.7	1.831416	9	24.6	3.288528
10	14.6	1.951728	10	27.0	3.60936
11	15.4	2.058672	11	27.8	3.716304
12	16.0	2.13888	12	28.6	3.823248
13	16.5	2.20572	13	29.4	3.930192
14	17.0	2.27256	14	30.2	4.037136
15	17.5	2.3394	15	31.0	4.14408
16	18.0	2.90624	16	31.8	4.241024
17	18.4	2.459712	17	32.6	4.357968
18	18.8	2.513184	18	33.4	4.464912
19	19.2	2.566656	19	34.2	4.571856
20	19.6	2.620128	20	35.0	4.6788
25	21.5	2.87412	25	38.0	5.07984
30	23.3	3.114744	30	42.0	5.61356
35	24.9	3.328632	35	44.0	5.88192
40	26.3	3.515784	40	46.0	6.14928
45	27.7	3.702936	45	48.0	6.41664
50	29.1	3.890088	50	50.0	6.684
60	32.0	4.27776	60	54.0	7.21872
70	35.0	4.6788	70	58.0	7.75344
80	38.0	5.07984	80	61.2	8.181216
90	41.0	5.48088	90	64.3	8.595624
100	43.5	5.81508	100	67.5	9.0234
120	48.0	6.41664	120	73.0	9.75864
140	52.5	7.0182	140	77.0	10.29336
160	57.0	7.61976	160	81.0	10.82808
180	61.0	8.15448	180	85.5	11.42964
200	65.0	8.6892	200	90.0	12.0312
225	70.0	9.3576	225	95.5	12.76644
250	75.0	10.026	250	101.0	13.50168
275	80.0	10.6944	275	104.5	13.96956
300	85.0	11.3628	300	108.0	14.43744
400	105.0	14.0364	400	127.0	16.97736
500	124.0	16.57632	500	143.0	19.11624
750	170.0	22.7256	750	177.0	23.66136
1,000	208.0	27.80544	1,000	208.0	27.80544
1,250	239.0	31.94952	1,250	239.0	31.94952
1,500	269.0	35.95992	1,500	269.0	35.95992
1,750	297.0	39.70296	1,750	297.0	39.70296
2,000	325.0	43.446	2,000	325.0	43.446
2,500	380.0	50.7984	2,500	380.0	50.7984
3,000	433.0	57.88344	3,000	433.0	57.88344
4,000	535.0	70.182	4,000	525.0	70.182

Demand To size piping, we must know the gpm (L/s) in the pipe at each size location. To get the gpm (L/s), we use water supply fixture units (WSFU) for the various plumbing fixtures (see Table 5-18 from IPC 2003). It is best to try to pick some fixture that is similar if the exact fixture is not in the table. It is best to use the applicable code and not a textbook.

Note that the fixtures are listed as flush valve or flush tank depending on their water control device. Also, they are listed as public or private. Private fixtures are those used only by the space occupant (such as a hotel room) and are not open to the public for walk-in use.

For piping systems that have both domestic plumbing fixtures and process equipment that has a certain infrequent gpm, divide the gpm by 7.5 gpm/WSFU and add to the total. For items that have continuous or semi-continuous flow, add in the gpm when sizing the pipe.

You must determine the total WSFU for flush tank and other fixtures and separately only for flush valve fixtures. Then, determine the gpm of each (flush tank and flush valve separately). The one that has the greater gpm is the predominant; thereafter, to get the total gpm, you must use the predominant fixture type (for gpm conversions see Table 5-19 or Figure 5-15 graph). Add all the WSFUs (hot and cold separately) from the ends of the piping to the meter. Then convert the WSFUs to gpm separately for hot and cold water (do not exceed the WSFU fixture total).

After you know the gpm of all branches and mains and after you know the pressure drop to be allowed (to size the pipe), you can then go to the pipe graphs. Most codes will tell you the minimum pipe size to the final fixture connection and also its maximum length (see Table 5-20). They will also tell you the minimum flow rate and the minimum flow pressure (see Table 5-21). You must check this information with the manufacturer's requirements.

As stated previously you must use the plumbing code that applies to your project location. There are several other national codes (such as UPC), state codes, and even city codes. We have chosen IPC table examples for no particular reason. The IPC currently uses the old Hunter's Curve fixture unit conversion to gpm developed in 1924. If an engineer is designing a facility where this code requirement is in effect, the information must be used. Since that time, however, recent tests and studies conducted by many authorities over the years, mainly due to the reduced water flow of modern fixtures and different life patterns, have determined that use of the curves leads to oversized piping. If this code is not the approved code for the local area, the use of modern fixture units to gpm conversions is recommended. Refer to Table 5-5, based on recent studies.

See Figure 5-16 for a form for your consideration to be used to keep track of the WSFUs and other data.

See Figure 5-17 for a piping sketch showing usual code definitions of the domestic water piping system.

Velocity The second factor affecting the sizing of a water line is velocity. A maximum velocity of 10 fps (3 m/s), which is suggested by some model plumbing codes, is much too high for domestic plumbing installations. Even 8 fps (2.4 m/s), as listed in other codes, is very high for many types of domestic water piping and very subject to water hammer. A velocity above 6 or 7 fps (1.8 or 2.1 m/s) normally creates noise. Also, depending on the piping material used and the temperature, hardness, contained air bubbles, and pH of the water, velocities above 4 fps (1.2 m/s) can cause erosion of some piping material.

Another justification for lower velocities in a system is water hammer. The impact of water hammer is directly proportional to the change in velocity and is equal to approximately 60 times the velocity change. For instance, if water traveling at 15 fps (4.6 m/s) is stopped suddenly, the increase in pressure within the pipe line will be approximately 900 psi (6,205.3 kPa). This increased pressure can do considerable damage to piping systems and connected equipment.

See the pipe manufacturer's information for the specific type of pipe, maximum desired flow rates, and chemical resistance. Suggested maximum velocity for various pipe materials are presented below:

Steel	4–8 fps
Copper (K, L)	5–8 fps cold
	2–3 fps > 140°F
	4–5 fps < 140°F
PVC	4–6 fps
CPVC	5 fps
Polyethylene	6–8 fps
RFP	4–6 fps

Pressure The third factor affecting the sizing of a water line is the pressure available for piping friction loss. The first step in ascertaining pressure available for friction loss is determining (from the local water department or by a hydrant flow test) the maximum and minimum water pressures at the street connection (or the stop valve at a well system) at the flow rate to be encountered at the project site. The maximum and minimum pressures may be nearly the same or they may vary greatly depending on the time of year, hour of the day, type of adjacent buildings, new construction, etc. Care must be taken to handle the high pressure as well as the low pressure. If the maximum pressure is above 80 psi, and a pressure-regulating device is installed, the pressure regulator

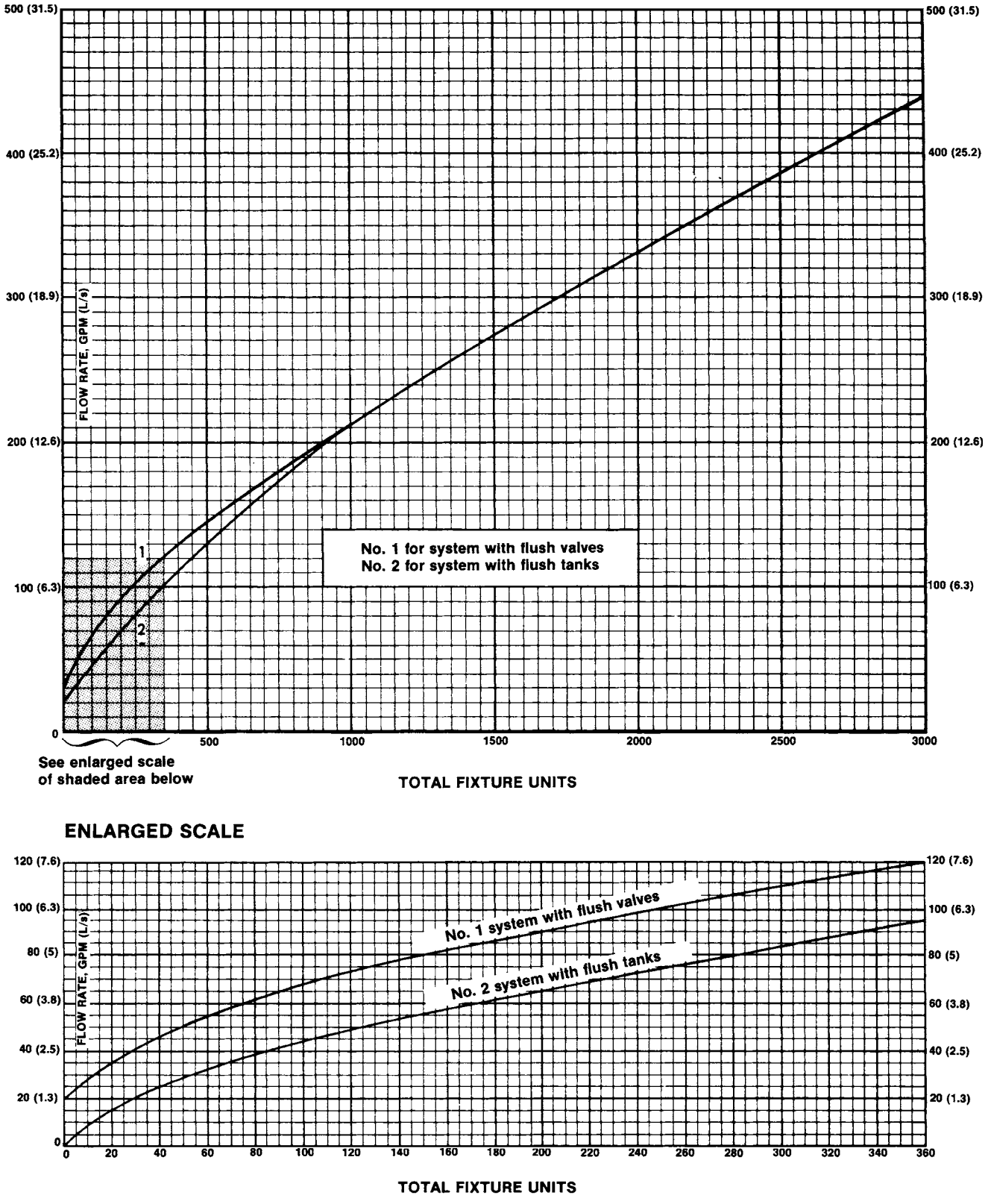


Figure 5-15 Conversion of Fixture Units, fu, to gpm (L/s)

Table 5-20 Minimum Sizes of Fixture Water Supply Pipes

Fixture	Minimum Pipe Size, Inches
Bathtubs[a] (60" × 32" and smaller)	½
Bathtubs[a] (larger than 60" × 32")	½
Bidet	⅜
Combination sink and tray	½
Dishwasher, domestic[a]	½
Drinking fountain	⅜
Hose bibbs	½
Kitchen sink[a]	½
Laundry, 1, 2 or 3 compartments[a]	½
Lavatory	⅜
Shower, single head[a]	½
Sinks, flushing rim	¾
Sinks, service	½
Urinal, flush tank	½
Urinal, flush valve	¾
Wall hydrant	½
Water closet, flush tank	⅜
Water closet, flush valve	1
Water closet, flushometer tank	⅜
Water closet, one piece[a]	½

For SI: 1 inch = 25.4 mm, 1 foot = 304.8 mm, 1 pound per square inch = 6.895 kPa.

a. Where the developed length of the distribution line is 60 feet or less, and the available pressure at the meter is a minimum of 35 psi, the minimum size of an individual distribution line supplied from a manifold and installed as part of a parallel water distribution system shall be one nominal tube size smaller than the sizes indicated.

Table 5-21 Water Distribution System Design Criteria Required Capacity At Fixture Supply Pipe Outlets

Fixture Supply Outlet Serving	Flow Rate[a], (Gpm)	Flow Pressure, psi
Bathtub	4	8
Bidet	2	4
Combination fixture	4	8
Dishwasher, residential	2.75	8
Drinking fountain	0.75	8
Laundry tray	4	8
Lavatory	2	8
Shower	3	8
Shower, temperature controlled	3	20
Sillcock, hose bibb	5	8
Sink, residential	2.5	8
Sink, service	3	8
Urinal, valve	15	15
Water closet, blow out, flushometer valve	35	25
Water closet, flushometer tank	1.6	15
Water close;, siphonic, flushometer valve	25	15
Water closet, tank, close coupled	3	8
Water closet, tank, one piece	6	20

For SI: 1 pound per square inch = 6.895 kPa, 1 gallon per minute = 3.785 L/m.

a. For additional requirements for flow rates and quantities, see Section 604.4.

Fixture or Group	Public or Private	Quantity	Fixture Units for Individual Fixtures			Total Fixture Units			Min gpm	Min Pressure	Min Pipe
			Hot	Cold	Total	Hot	Cold	Total			
Total Fixture unit count											

Figure 5-16 Form to Track WSFUs and Other Data

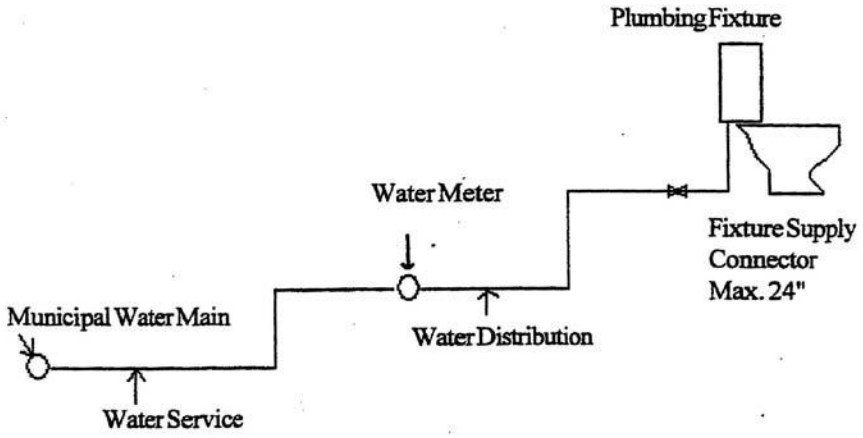


Figure 5-17 Domestic Water piping Sketch

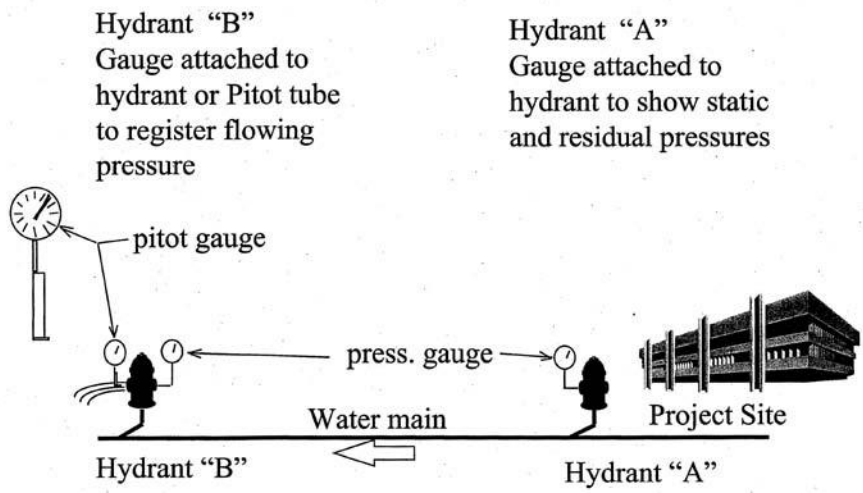


Figure 5-18 Method for Conducting a Water Flow Test

will introduce an additional pressure loss (fall off) in the piping system when water is flowing.

The city water pressure should be determined from a fire hydrant flow test, which is taken as close to the site as possible and includes static and residual pressures at the desired flow rate (above normal use without your building) (see Figure 5-18). The residual pressure, with all the above considerations taken into account, is the pressure to be used as a starting point in calculating other pressure requirements. The effective pressure point is where flowing and non-flowing water meet.

If a pressure-regulating device is installed, the available pressure after the fall-off pressure must be used (on outlet side of meter or backflow preventer).

The water meter creates a loss of pressure. Get the pressure drop from the manufacturer's flow charts. The pressure drop is determined from charts indicating the total flow rate in gpm (L/s), the size and type of the meter, and the pressure drop for the corresponding flow. The loss is given in psi (kPa). The selection of meter size is very important in the final sizing of the piping system and is one variable the designer can sometimes control. Usually the city will provide a certain size and type (or may give you a size option). The larger the meter, the less the pressure drop through it but the higher the initial installation price and monthly charge. On the other hand, a larger meter may mean a smaller-sized piping system, which might prove to be more economical in the long run. If a system does not have ample pressure, a means of preserving the available pressure is to use a larger meter, thereby decreasing pressure loss. This fact may enable the designer to eliminate the use of a water-pressure booster system, thereby substantially reducing the plumbing system costs.

Disc-type positive displacement magnetic drive meters are used for measuring the quantity of cold water used by residential and small commercial buildings where water volumes are low and low-flow sensitivity is important. See Table 5-22a for typical flow characteristics.

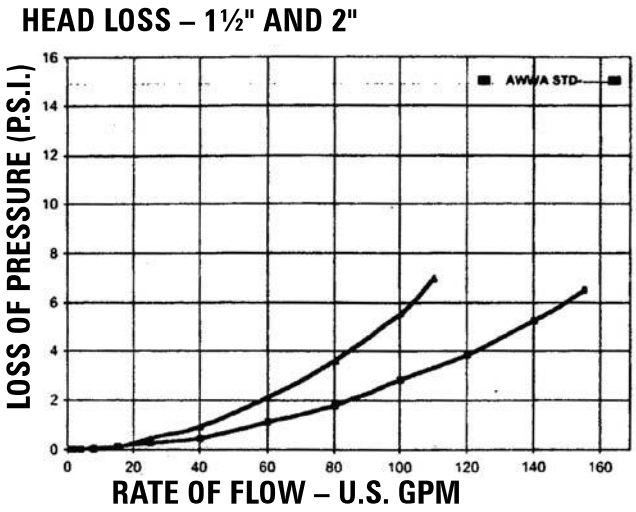
Compound magnetic drive meters are used for applications where accuracy is required over a wide range of water flow rates. Example users would be hotels, schools, industry, large apartments, etc. See Table 5-22b.

Horizontal turbine meters are used for potable water applications where flow is consistently moderate to high and accuracy is an essential part of charging for the water. See Table 5-22c.

The designer must decide if he wants to lose or preserve the water pressure available at the street. What water pressure do you desire on the outlet side of the meter? The PRV normally goes on the outlet side of the meter, and the backflow prevention goes on the inlet side of the meter.

The designer must determine the flow rate from the most hydraulically remote fixture or equipment that has the highest total pressure drop from the outlet of the meter when all flow pressure losses are added, excluding that for the piping. Some iteration will be required to find the one place with the highest pressure drop. For example, see the system shown in Figure 5-19. To find the critical circuit, determine which final fixture or device requires the most pressure (from the meter outlet). The flush valve water closet needs 15 psi (103.4 kPa) and has no static loss. The backflow preventer has 16 psi (110.3 kPa) pres-

Table 5-22(a) Disc-type Positive Displacement Magnetic Drive Meter

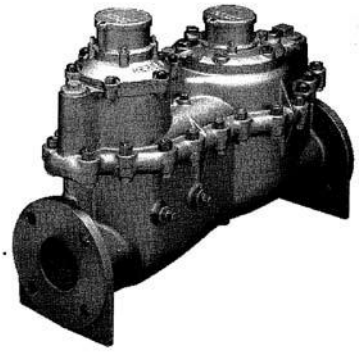


NOTE: Performance curves are typical only and NOT a guarantee of performance.

Flow Characteristics

Meter Size	Typical Low Flow (95%) Minimum)	Typical Operating Range (100% ± 1.5%)	Maximum Continuous Operation
1½"	1½ GPM	5 to 100 GPM	50
2"	2 GPM	8 to 160 GPM	80

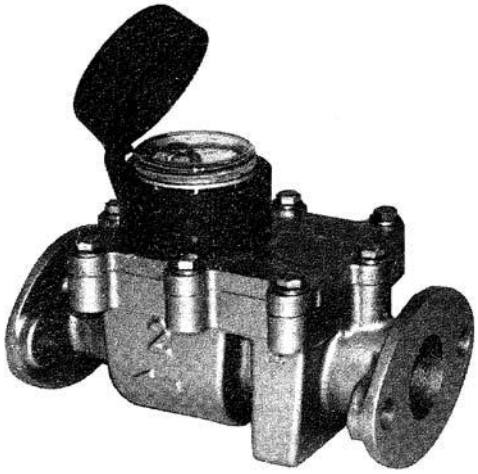
Table 5-22(b) Compound Magnetic Drive Meter



Flow Characteristics

Meter Size	Typical Low Flow (95%) Minimum)	Typical Operating Range (100% ± 1.5%)	Maximum Continuous Operation	Maximum Intermittent Flow
1½"	2 GPM	4 to 120 GPM	120 GPM	120 GPM
2"	2½ GPM	4 to 160 GPM	160 GPM	160 GPM

Table 5-22(c) Horizontal Turbine Meter



Flow Characteristics

Meter Size	Typical Low Flow (95%) Minimum)	Typical Operating Range (100% ± 3%)	Maximum Continuous Operation
2"	¼ GPM	1 to 160 GPM	80 GPM
3"	½ GPM	4 to 320 GPM	160 GPM
4"	¾ GPM	6 to 500 GPM	250 GPM
6"	1½ GPM	10 to 1000 GPM	500 GPM
8"	2 GPM	16 to 1600 GPM	800 GPM

sure drop and 8.66 psi (59.7 kPa) static for a total loss of 24.66 psi (170 kPa). Going to the dishwasher, there is a total of 40 psi (275.8 kPa) loss—25 psi (172.4 kPa) for the dishwasher plus 5 psi (34.5 kPa) loss through the water heater plus 10 psi (69 kPa) loss through the softener. Therefore, the piping to the dishwasher is the governing critical circuit, for it has the highest total when the needed flow pressures and static losses are added.

The pressure required at each fixture or appliance can be determined from codes and/or manufacturer's information. A suggested pressure requirement for various fixtures is given in Table 5-21. Manufacturer's information governs. If there is an elevation difference between the meter and the governing fixture or appliance, the static pressure loss required to reach the governing fixture or appliance must be calculated. The static loss (or gain) is figured at 0.433 psi/ft (9.8 kPa/m) of elevation difference, above or below the meter. The difference in elevation is usually a pressure loss to the system, as fixtures are normally at a higher elevation than the source. If the fixture is lower than the source, there will be an increase in pressure and the static pressure is added to the initial pressure. This holds true when you calculate the meter outlet pressure—the elevation difference between the city main and the meter must be accounted for.

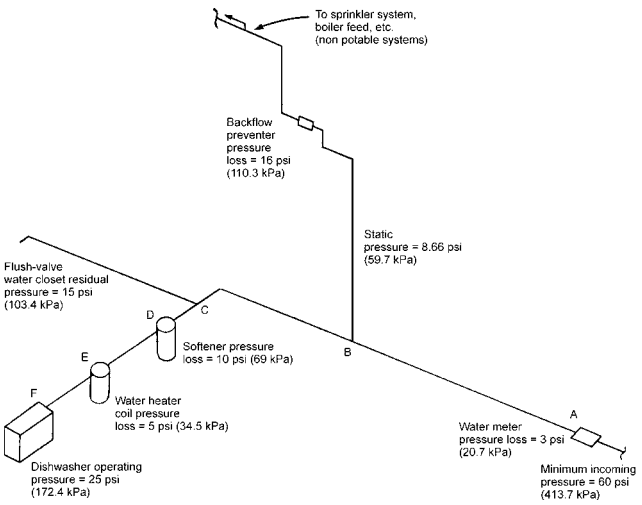


Figure 5-19 Establishing the Governing Fixture or Appliance

Review of Previous Comments and Calculations

A review and summary of what the designer needs to do is as follows:

1. Determine the lowest effective pressure available at the city water main connection. This is known as the residual pressure of the main.
2. Select a water service pipe size and type (to the meter) and calculate its pressure drop (do you want the drop to be high or low?). Also determine any pressure drop or increase due to elevation change (water main to water meter) including the service losses through the service pipe, which includes the curb valve. An allowance shall be made for future development of the area where the project is located, generally 5 psi.
3. Select (or given by the city) the water meter type and size and determine its pressure drop (do you want the drop to be high or low?).
4. Determine the outlet pressure at the meter (item 1—item 2—item 3).

   The designer must now determine the most hydraulically remote point (the piping main and branch) using the greatest amount of needed end pressure and total pressure drops of the appliances and devices in the circuit piping to the end fixture or appliance when flowing. Several circuits may need to be analyzed. Hand valves and fittings are omitted at this step.
5. Add the flow pressure drops of all appliances and devices in the critical circuit. Examples include softener or other water treatment, water heater, PRV, control valve or solenoid, and reduced-pressure backflow preventer.
6. Determine the pressure needed at final fixture or appliance, as well as the static pressure drop or increase due to elevations.
7. Calculate the pressure drop allowed for the piping (item 4—item 5—item 6).

   The designer must now determine the equivalent length (sometimes called developed length) of pipe to which the available pressure drop will be applied and the allowable pressure drop per 100 ft of equivalent length.
8. Measure the actual length of the critical circuit (ft). To get the equivalent length, multiply the actual length by some factor. Some codes suggest 1.25, others 1.5. If the critical circuit has a lot of fittings, use the higher number.
9. Determine the available flow pressure drop per 100 ft for the critical circuit ([item 7/item 8] × 100).
10. Using gpm totals, starting from the farthest connection back to the meter, and allowable pressure drop per 100 ft, go to the pipe graphs (Figures 5-11 to 5-14) and select the pipe sizes for the hydraulically remote point. Don't go above your maximum desired velocity. When you get to the maximum velocity line, follow it (the maximum flow rate) to the left.

    The designer must now determine how to size all the other piping.

The designer has several choices as to methods:

- Uniform pressure loss method—Use the same pressure drop for *all* piping, including the critical circuit. This is the most commonly used method.
- Branch length method—Use the uniform pressure loss for the critical circuit piping. Then calculate a new equivalent length for each branch and size the branches (not the critical circuit) based on the new equivalent length pressure drop per 100 ft ([item 7/new equivalent length] × 100).
- Constant velocity method—Designer bases size on velocity only, then adds the pressure drops not to exceed that total allowable (used for short lengths and/or few connections).
- Total pressure loss method—Every circuit uses all the available pressure from the meter to the end user. This is very difficult to do by hand, but some computer programs can do this. However, the pipe sizes for the branches become very small and the velocity too high at the branches near the meter (available pressure too high).

Examples of Methods of Pipe Sizing

Example 5-3

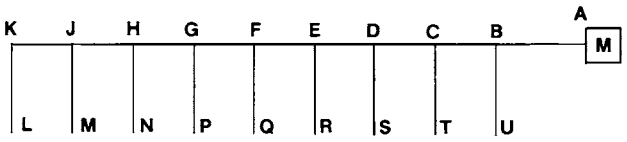
Figure 5-20 illustrates how to determine the pressure available for friction.

In the system shown (with a main line running from the meter, point A, to the governing fixture or

METHOD A						
Section	Developed Length in Section, ft (m)	Developed Length from Point A, ft (m)	Friction Loss, psi/100 ft (kPa/100 m)	Friction Loss in Section, psi (kPa)	Total Pressure Loss from Friction, psi (kPa)	Pressure at End of Section for Friction, psi (kPa)
A–B	10 (3.1)	10 (3.1)	10 (226.2)	1 (6.9)	1 (6.9)	9 (62.1)
B–C	10 (3.1)	20 (6.1)	10 (226.2)	1 (6.9)	2 (13.8)	8 (55.2)
C–D	10 (3.1)	30 (9.1)	10 (226.2)	1 (6.9)	3 (20.7)	7 (48.3)
D–E	10 (3.1)	40 (12.2)	10 (226.2)	1 (6.9)	4 (27.6)	6 (41.4)
E–F	10 (3.1)	50 (15.2)	10 (226.2)	1 (6 9)	5 (34.5)	5 (34.5)
F–G	10 (3.1)	60 (18.3)	10 (226.2)	1 (6.9)	6 (41.4)	4 (27.6)
G–H	10 (3.1)	70 (21.3)	10 (226.2)	1 (6.9)	7 (48.3)	3 (20.7)
H–J	10 (3.1)	80 (24.4)	10 (226.2)	1 (6.9)	8 (55.2)	2 (13.8)
J–K	10 (3.1)	90 (27.4)	10 (226.2)	1 (6.9)	9 (62.1)	1 (6.9)
K–L	10 (3.1)	100 (30.5)	10 (226.2)	1 (6.9)	10 (69)	0 (0)

METHOD B						
Section	Developed Length in Section, ft (m)	Developed Length from Point A, ft (m)	Pressure at Start, psi (kPa)	Friction Loss, psi/100 ft (kPa/100 m)	Friction in Section, psi (kPa)	Pressure at End, psi (kPa)
M–J	10 (3.1)	90 (27.4)	2 (13.8)	10 (226.2)	1 (6.9)	1 (6.9)
N–H	10 (3.1)	80 (24.4)	3 (20.7)	10 (226.2)	1 (6.9)	2 (13.8)
P–G	10 (3.1)	70 (21.3)	4 (27.6)	10 (226.2)	1 (6.9)	3 (20.7)
Q–F	10 (3.1)	60 (18.3)	5 (34.5)	10 (226.2)	1 (6 9)	4 (27.6)
R–E	10 (3.1)	50 (15.2)	6 (41.4)	10 (226.2)	1 (6.9)	5 (34.5)
S–D	10 (3.1)	40 (12.2)	7 (48.3)	10 (226.2)	1 (6.9)	6 (41.4)
T–C	10 (3.1)	30 (9.1)	8 (55.2)	10 (226.2)	1 (6.9)	7 (48.3)
U–B	10 (3.1)	20 (6.1)	9 (62.1)	10 (226.2)	1 (6.9)	8 (55.2)

METHOD C						
Section	Friction Loss, psi/100 ft (kPa/100 m)	Friction Loss in Section, psi (kPa)	Pressure at Start, psi (kPa)	Friction Loss, psi/100 ft (kPa/100 m)	Friction in Section, psi (kPa)	Pressure at End, psi (kPa)
M–J	20 (452.4)	2 (13.8)	0 (0)	11.1 (251.1)	1.1 (7.6)	0.90 (6.2)
N–H	30 (678.6)	3 (20.7)	0 (0)	12.5 (282.8)	1.25 (8.6)	1.75 (12.1)
P–G	40 (904.8)	4 (27.6)	0 (0)	14.3 (323.5)	1.43 (9.9)	2.57 (17.7)
Q–F	50 (1131)	5 (34.5)	0 (0)	16.6 (375.5)	1.66 (11.5)	3.34 (23)
R–E	60 (1357.2)	6 (41.4)	0 (0)	20 (452.4)	2 (13.8)	4 (27.6)
S–D	70 (1583.5)	7 (48.3)	0 (0)	25 (565.5)	2.5 (17.2)	4.5 (31)
T–C	80 (1809.7)	8 (55.2)	0 (0)	33.3 (753.3)	3.33 (23)	4.66 (32.1)
U–B	90 (2035.9)	9 (62.1)	0 (0)	50 (1131)	5 (34.5)	4 (27.6)



PLAN OF SYSTEM

Figure 5-20 Determining Pressure Available for Friction

appliance, point L—the critical circuit), each section of the line is 10 ft (3.1 m) in equivalent length for a total of 100 ft (30.5 m) from A to L. This includes an allowance for fittings. The allowable pressure drop for pipe friction is 10 psi (69 kPa). The first tabulation is the friction loss in the system.

Section A–B has an equivalent length of 10 ft (3.1 m). The uniform pressure drop is 10 psi/100 ft (226.2 kPa/100 m). If it is assumed that precisely sized pipe is selected (for our theoretical case) to give a pressure loss (due to friction) of exactly 10 psi/100 ft (226.2 kPa/100 m), the pressure loss in this section (A–B) is 1 psi (6.9 kPa) and the pressure for friction at point B is 9 psi (62.1 kPa). In section K–L, at point L, there is 0 pressure left for friction. This is the governing fixture (and the critical circuit).

Method A uses the same uniform pressure loss in the branches as was used in the critical circuit line to the governing fixture. The pressure available for friction at the end of each branch is not 0. At point M, it is 1 psi (6.9 kPa); at point R, it is 5 psi (34.5 kPa); and at point U it reaches a maximum of 8 psi (55.2 kPa). Unless the pressure to each of the other fixtures is used up as piping friction loss or fixture pressure drop, it tends to cause more water than necessary to flow through the branches nearest the meter to use the excess available pressure. However, in a complex piping system this is the typical method used. It is the most common method used for design purposes.

Method B illustrates the total pressure loss method. All the available friction piping pressure in each of the branches is used. In actual practice, this method cannot be utilized. The average pressure loss in each section closer to the meter is very high, far higher than is normally accepted. Many engineers and designers would be concerned with the high pressure loss as well as with the high velocity in the small pipe that results. The next-to-last column shows the pressure drop that must be used for each branch.

Method C is the branch length method. The critical circuit is sized on the uniform pressure drop of the critical system (Method A), and the branches are sized on their own allowable friction pressure drop. At section M–J, the total allowable pressure drop over the

entire system (point A to point M) is 10 psi (69 kPa). Point M has an equivalent length of 90 ft (27.4 m) from point A. This gives an allowable pressure drop of 11.1 psi (7.6 kPa), (10/90) per 100 ft (30.5 m) and an unused frictional pressure of 0.9 psi (6.2 kPa). By going through all the branches in the same manner and working out the pressure drop for the new equivalent length, the branches can be sized. One can see that the unused frictional pressure varies from 0.9 psi (6.2 kPa) to a maximum of 4.66 psi (32.1 kPa). These pressures are less than those resulting from Method A, and the average pressure drops are less than those resulting from Method B. Consequently, Method C is frequently used by designers. In actual practice, it is not necessary to calculate the average pressure drop for each branch. Usually the branches are close together and the changes in the average pressure drop are very small.

Velocity Method

Another method designers use to size water piping is the velocity method. The average pressure drop available for piping friction is calculated, and, if it is greater than 7 or 8 psi/100 ft (158.4 or 181 kPa/100m), the lines are sized on the basis of a 4 to 6 fps (1.2 or 1.8m/s) velocity. In this method, the main line is conservatively sized and the short branches may slightly exceed the average pressure drop. However, the total pressure drop of the system cannot exceed the allowable piping pressure loss for friction. This is sometimes used for small systems with few connections of similar type.

Pressure Loss in Pipe Fittings and Valves

It is not unusual for a designer to need to determine the pressure drop in an existing system. Also, a designer may wish to affirm the pressure drop in a critical system just sized, particularly if an equipment change is made.

In this case, the designer can determine from the piping graphs (Figures 5-11 to 5-14) the pressure drop in all piping. By measurement or other information, the designer can determine the actual pressure drop of the installed fixtures and appliances, and the pressure at the meter outlet.

For fittings and valves, the designer can use equivalent lengths. See Table 5-23. Note that these are not affected by the flow velocity and are therefore inaccurate.

For more accurate equivalent lengths, the designer should use K values or C_v values (design coefficients). See Tables 5-24 through 5-27. These are available from manufacturers and several ASPE manuals. They take into account the effect of velocity on the pressure drop through the fitting or valve. For pressure loss through 3-, 4-, and 6-in. RPZ, refer to Table 5-5.

Table 5-23 Allowance for Friction Loss in Valves and Threaded Fittings

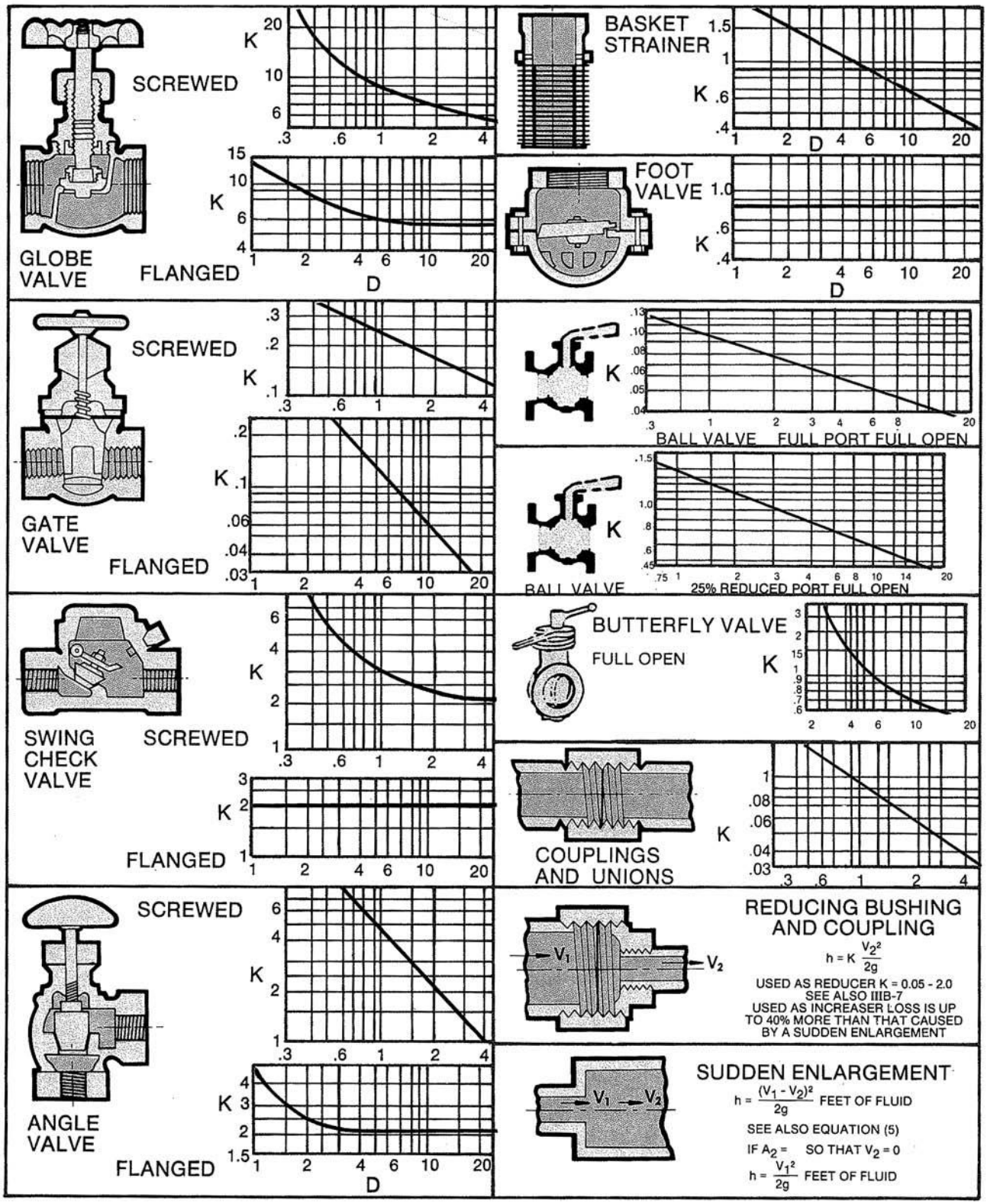
Equivalent Length of Pipe for Various Fittings (ft)							
Diameter of Fitting (in.)	90° Standard Elbow	45° Standard Elbow	Standard T 90°	Coupling or Straight Run of T	Gate Valve	Globe Valve	Angle Valve
⅜	1	0.6	1.5	0.3	0.2	8	4
½	2	1.2	3	0.6	0.4	15	8
¾	2.5	1.5	4	0.8	0.5	20	12
1	3	1.8	5	0.9	0.6	25	15
1¼	4	2.4	6	1.2	0.8	35	18
1½	5	3	7	1.5	1	45	22
2	7	4	10	2	1.3	55	28
2½	8	5	12	2.5	1.6	65	34
3	10	6	15	3	2	80	40
4	14	8	21	4	2.7	125	55
5	17	10	25	5	3.3	140	70
6	20	12	30	6	4	165	80

Note: Allowances based on nonrecessed threaded fittings. Use ½ the allowances for recessed threaded fittings or streamline solder fittings.

Table 5-23(M) Allowance for Friction Loss in Valves and Threaded Fittings

Equivalent Length of Pipe for Various Fittings (ft)							
Diameter of Fitting (in.)	90° Standard Elbow	45° Standard Elbow	Standard T 90°	Coupling or Straight Run of T	Gate Valve	Globe Valve	Angle Valve
9.5	0.3	0.2	0.5	0.09	0.06	2.4	1.2
12.7	0.6	0.4	0.9	0.18	0.12	4.6	2.4
19.1	0.8	0.5	1.2	0.24	0.15	6.1	3.7
25.4	0.9	0.6	1.5	0.27	0.18	7.6	4.6
31.8	1.2	0.7	1.8	0.4	0.24	10.7	5.5
38.1	1.5	0.9	2.1	0.5	0.3	13.7	6.7
50.8	2.1	1.2	3.1	0.6	0.4	16.8	8.5
63.5	2.4	1.5	3.7	0.8	0.5	19.8	10.4
76.2	3.1	1.8	4.6	0.9	0.6	24.4	12.2
101.6	4.3	2.4	6.4	1.2	0.8	38.1	16.8
127	5.2	3.1	7.6	1.5	1.0	42.7	21.3
152.4	6.1	3.7	9.1	1.8	1.2	50.3	24.4

Note: Allowances based on nonrecessed threaded fittings. Use ½ the allowances for recessed threaded fittings or streamline solder fittings.



$$h = K \frac{V^2}{2g} \text{ FEET OF FLUID}$$

Table 5-24 Typical Resistance Coefficients for Valves and Fittings

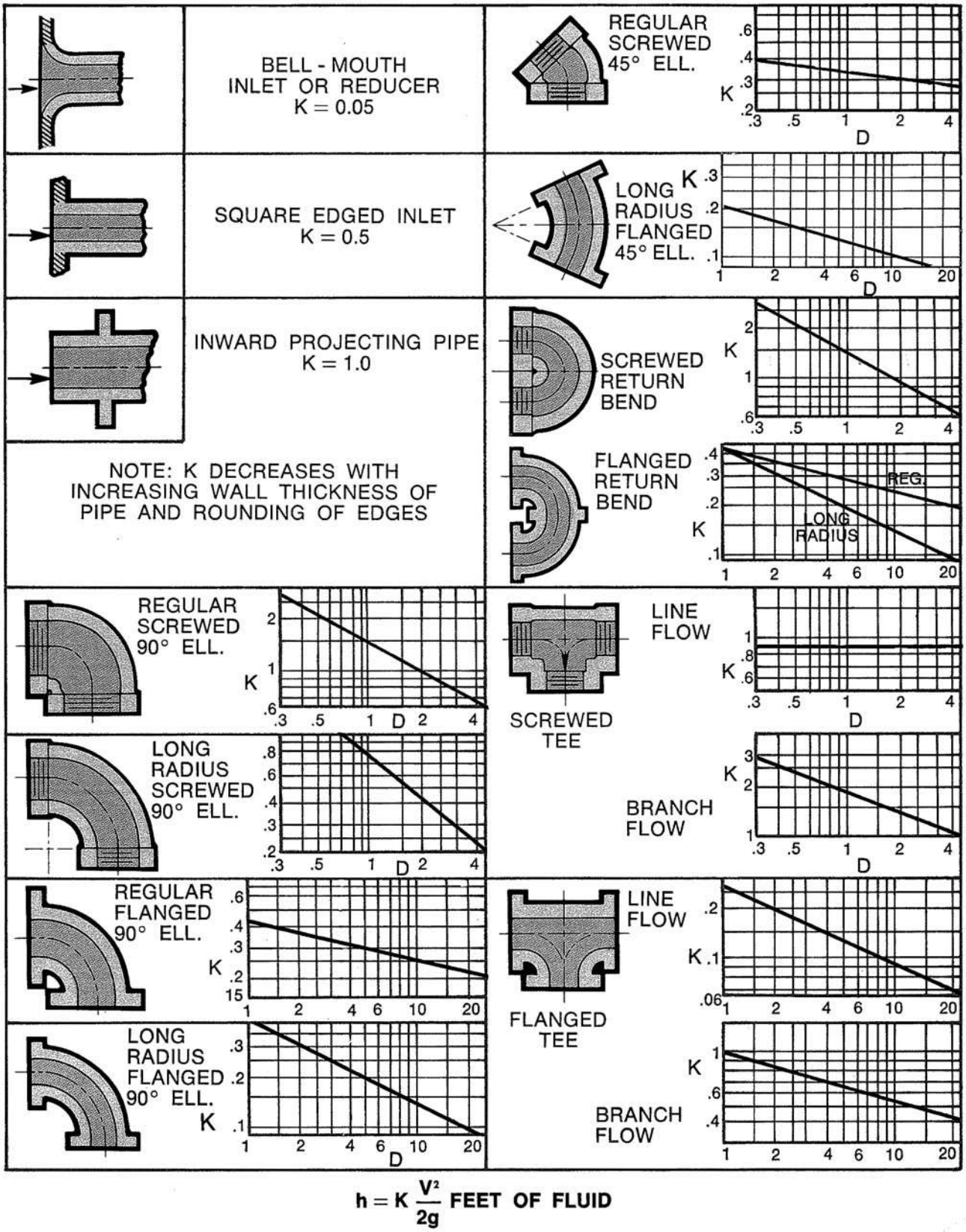


Table 5-25 Typical Resistance Coefficients for Valves and Fittings

Table 5-26 Flow Data, C_V Values for Valves

Fig. Nos.	Valve Size ⅛	¼	⅜	½	¾	1	1¼	1½	2	2½	3	3½	4	5	6
GATES															
S & T-22	.5	2	4.9	9.1	22	40	65	95	175						
S & T-180	—	5.6	10.7	17.6	32	50	95	130	220						
S & T-111-113-131-133 134-135-136-174-176	—	5.6	10.7	17.6	32	54	97	135	230	337	536	710	960	1,525	2,250
(T & F-617-619-667-669 607-609) (CS-102-103 302-303-602-603) (F-637-639-DI-102)									215	335	510	710	945	1,525	2,250
GLOBES															
S & T-211 (BWY)-235Y 275Y	.61	1.16	2.2	3.64	6.65	11.1	20	28	48	70	111	—	198		
T-275-B	—	1.16	2.21	3.64	6.65	11.1	20	28	48	70	111				
F-718-(CS-132-133 332-333-632-633 (738)									45	70	105	—	195	315	465
CHECKS															
S & T-413-433-473 (Swing)	—	1.3	2.5	4.8	14.3	24	43	60	102	150	238	315	435	675	1,000
S & T-480 (Poppet)			3.70	6.86	16.3	30	49	72	130						
F-908 (Swing)									150	243	356	—	665	1,073	1,584
T & F-918-968-938 (Swing)									137	221	327	—	605	975	1,440
W-900-W (Wafer)												—	505	806	1,200
W-F-910-960 (Poppet)											330	—	595	950	1,400

Table 5-27 Continuation of Flow Data C_V Values for Valves.

Liquid Flow:

$$Q = C_v \sqrt{\frac{\Delta P}{S}}$$

where

Q = flow rate (gallons per minute

ΔP = pressure drop across valve (psi)

S = specific gravity of media

(THROTTLING FACTORS)

For throttling use with disc partially open. Multiply C_V by factor.

Note: Gate valves are not throttled.

8	10	12	14	16	18	20	24	Percent Open 0	10	20	30	40	50	60	70	80	90	100
4,150	6,700	9,925	13,800	18,375	23,600	29,600	43,570											
								0	.35	.65	.90	.93	.96	.98	.99	1.00	1.00	1.00
								0	.03	.035	.06	.1	.16	.24	.32	.47	.68	1.00
860	1,390							0	.35	.65	.90	.93	.96	.98	.99	1.00	1.00	1.00
2,937	4,730	6,985						**WARNING**										
2,670	4,300	6,350						The Fluid Flow factors contained herein are calculated values. They are therefore approximations and cannot be used for highly critical flow or pressure drop calculations.										
2,200	3,550	5,250						For very precise flow measurements, tests must be conducted on any valve mentioned within this catalog.										
2,600	4,175	6,150	8,575	11,400														

Equation 5-12

$$\Delta h = \frac{kV^2}{2g}$$

$$\Delta P = \left(\frac{Q}{C_v}\right)^2 \text{S.G.}$$

Δh = Fluid head (ft)

V = Velocity (ft/sec)
g = Acceleration of gravity (ft/sec^2)
P = psi
Q = gpm
SG = Specific gravity (water = 1.0); for water, $\Delta h \times 0.43$ = psi
C_v = Flow through a valve where pressure loss of 1 psi occurs

TESTING, CLEANING, AND DISINFECTION OF DOMESTIC WATER SUPPLY SYSTEMS

Testing

Prior to disinfection, connection to faucets and equipment, and installation of pipe insulation, the domestic water system should be hydrostatically tested for leakage. A typical test for interior piping is accomplished by capping all system openings, filling the system with water, and then pumping a static head into the system at a minimum 1½ times the working pressure (100 psi [689.5 kPa] minimum) for a period of not less than two hours. The aforementioned test requirements are acceptable to most inspectors, but note that 80 psi (551.6 kPa) is the maximum pressure allowed by most designs and codes.

Under conditions where systems are subject to freezing, and with the approval of the authority having jurisdiction, an air test may be substituted for the water test. This can be accomplished by connecting an air compressor to the system, bringing the system up to 40 psi (275.8 kPa), checking for leaks with liquid soap, repairing any leaks, and then subjecting the system to a minimum 1½ times the working pressure (100 psi [689.5 kPa] minimum) for a minimum of two hours. Do not use an air test for most plastic piping, particularly PVC or CPVC.

Any equipment that may be damaged by these tests should be disconnected or isolated and shut off from the system.

Cleaning and Disinfecting

New or repaired potable water systems shall be cleaned and disinfected prior to use whenever required by the administrative authority. The method to be followed should be per AWWA or as follows (or as required by the administrative authority):

1. Cleaning and disinfection applies to both hot and cold, domestic (potable) water systems and should be performed after all pipes, valves, fixtures, and other components of the systems are installed, tested, and ready for operation.
2. All domestic yard, hot and cold water piping should be thoroughly flushed with clean, potable water prior to disinfection to remove dirt and other contaminants. Screens of faucets and strainers should be removed before flushing and reinstalled after completion of disinfection.
3. Disinfection should be done using chlorine, either gas or liquid. Calcium or sodium hypochlorite or another approved disinfectant may be used. Use nonhazardous materials that can be drained to the city sewer.
4. A service cock should be provided and located at the water service entrance. The disinfecting agent should be injected into and through the system from this cock only.
5. The disinfecting agent should be injected by a proportioning pump or device through the service cock slowly and continuously at an even rate. During disinfection, flow of the disinfecting agent into the main connected to the public water supply is not permitted.
6. All sectional valves should be opened during disinfection. All outlets should be fully opened at least twice during injection and the residual checked with orthotolidin solution.
7. If chlorine is used, when the chlorine residual concentration, calculated on the volume of water the piping will contain, indicates not less than 50 parts per million (ppm) or milligrams per liter (mg/L) at all outlets, then all valves should be closed and secured.
8. The residual chlorine should be retained in the piping systems for a period of not less than 24 hours.
9. After the retention, the residual should be not less than 5 ppm. If less, then the process should be repeated as described above.
10. If satisfactory, then all fixtures should be flushed with clean, potable water until residual chlorine by orthotolidin test is not greater than that of the incoming water supply (this may be zero).
11. All work and certification of performance should be performed by approved applicators or qualified personnel with chemical and laboratory experience. Certification of performance should indicate the following:
    - Name and location job and date when disinfection was performed.
    - Material used for disinfection.
    - Retention period of disinfectant in piping system.

- ppm (mg/L) chlorine during retention.
- ppm (mg/L) chlorine after flushing.
- Statement that disinfection was performed as specified.
- Signature and address of company/person performing disinfection.

12. Upon completion of final flushing (after retention period) the contractor should obtain a minimum of one water sample from each hot and cold water line and submit samples to a state/province and/or local, approved laboratory. Samples should be taken from faucets located at the highest floor and furthest from the meter or main water supply. The laboratory report should show the following:
    - Name and address of approved laboratory testing the sample.
    - Name and location of job and date the samples were obtained.
    - The coliform organism count. *An acceptable test shall show the absence of coliform organisms.* (Some codes require an acceptable test for two consecutive days.)
    - Any other tests required by local code authorities.
13. If analysis does not satisfy the minimum requirements, the disinfection procedure must be repeated.
14. Before acceptance of the systems, the contractor should submit to the architect (engineer) for his review three copies of the laboratory report and three copies of the certification of performance as specified.
15. Under no circumstances should the contractor permit the use of any portion of domestic water systems until they are properly disinfected, flushed, and certified.

NOTE: It should be understood that local code requirements, if more stringent than above suggested procedures, shall be included in the specifications.

REFERENCES

1. American Water Works Association (AWWA). *AWWA cross connection control manual*. New York.
2. AWWA. *AWWA standard for disinfecting water mains*, AWWA C601.
3. AWWA. *AWWA standard for disinfection of water storage facilities*, AWWAD105.
4. AWWA. *Standard for hypochlorites*, AWWA B300, AWWA M22.
5. AWWA. *Standard for liquid chlorine*, AWWAB301.
6. Manas, V.T. *National plumbing code illustrated handbook*. New York: McGraw-Hill.
7. n.a. 1978. Piping systems fundamentals and application. *Plant Engineer Magazine.*
8. US Department of Commerce, National Bureau of Standards. BMS 65, *Methods of estimating loads in plumbing systems*, by R.B. Hunter. Washington, D.C.
9. US Department of Commerce, National Bureau of Standards. BMS 66, *Plumbing manual*. Washington, D.C.
10. US Department of Commerce, National Bureau of Standards. BMS 79, *Water distributing systems for buildings*, by R.B. Hunter. Washington, D.C.
11. White, George Clifford. 1972. *Handbook of chlorination*. New York: Van Nostrand Reinhold.
12. Mironer, Alan. *Engineering Fluid Mechanics*. New York: McGraw-Hill, 1979.
13. Westaway, C. R., A. W. Loomis, ed. *Cameron Hydraulic Data.* 15th ed. Woodcliff Lake, N.J.: Ingersoll-Rand Co., 1977.
14. Hydraulic Institute
15. Copper Development Association Inc.
16. International Code Council
17. Nibco Inc.
18. Hershey Meters Co.
19. American Society of Plumbing Engineers, *Domestic Water Heating Design Manual.*
20. Steele, Alfred. *Engineered Plumbing Design II.*
21. American Society of Heating, Refrigerating and Air-Conditioning Engineers Inc.
22. Handbook/Applications/Chapter 48 "Service Water Heating."
23. Plumbing and Drainage Institute
24. Frankel, M. "Facility Piping Systems Handbook", 2nd ed., McGraw Hill, 2002.

Copper is the material of choice.

Make it affordable by specifying ASME B31.9 Building Services Piping - Section 930.2

Mechanically Formed Extruded Outlets for Copper Tube (ASME Code for Pressure Piping, B31)

Compare for Yourself:

	MAT.	LABOR	TOTAL
WROUGHT TEE FITTINGS (4 x 4 x 2) **	**$142**	**$108**	**$250**
PRESS FITTINGS (4 x 4 x2) MCAA	**$123**	**$ 29**	**$152**
T-DRILL FITTINGS (4 x 4 x 2)**	**0**	**$ 14.95**	**$ 14.95**

OTHER CODES AND COMPLIANCES

ASTM Designation: F 2014-00
Standard Specification for Non-Reinforced Extruded Tee Connections For Piping Applications
ASME B31.5c - 1992 - Refrigeration Piping
IAPMO PS 85-95 - Tools for Mechanically Formed Tee Connections in Copper Tubing
International Plumbing Code 2006, 2003, 2000 - Section 605.5.1 Mechanically Formed Tee Fittings
International Mechanical Code 2006, 2003, 2000 - Section 1203.3.8 Mechanically Formed Tee Fittings
Uniform Plumbing Code 2006, 2003, 2000, 1997 - Section 606.1.3 Mechanically Formed Tee Fittings
Uniform Mechanical Code 2006, 2003, 2000, 1997 - Section 1201.2.1.4.2.1 Mechanically Formed Tee Fittings
Canadian Plumbing Code - Section 2.3.3.2.(1) Extracted Tees
NFPA 99 - Section 4.3.2.2.2 Vacuum System Piping Network (F)

MasterSpec (AIA) Basic 15060 - Mechanically Formed Tee Connectors
IAPMO - File # 1935 Since 1979
National Standard Plumbing Code - Section 4.2.8.2 Mechanically Formed Tee
U.S. ARMY CORPS OF ENGINEERS - (Since 1983) Section 15P1, Plumbing 12.43, HVAC 15601.2, Oil and GAS Heating 15601.3 Copper Tube Extracted Joint
Naval Facilities Engineering Command (Since 1990) - Section NFGS 15400 Plumbing 3.1.7 Copper Tube Extracted Joint
Veterans Administration (Since 1984) - Section 15400 Plumbing, 15501 Sprinkler, 15705 HVAC, 15651 Refrigeration Copper Tube Extracted Joint
ASPE Data Book - Volume 4 - Chapter 2 - Mechanically Formed Tee Fittings
Epcot Plumbing Code - Section 605.15.5 Mechanically Formed Tee Connections

*(Revision of ASME B31.9 - 1996)
ASME Code for Pressure Piping, B31

USABLE ON M, L, OR K COPPER

PLUMBING • HVAC • SPRINKLER • REFRIGERATION • MAINTENANCE • PROCESS PIPING

INSTALLERS ARE TRAINED AND CERTIFIED

For 30 years ***T-DRILL*** has been used in commercial construction and by industrial users such as these: Alberta Custom Tee, Ltd., Alfa Laval, Anheuser-Busch, ANVIL, Carrier Corp., Coors Brewing, Dow Chemical, Ford Motor Co., General Electric, Northrop Grumman, Hill-Phoenix, Hussman, Kysor-Warren, Lochinvar, NASA, NIBCO, Norfolk Naval Shipyard, Pall Corp., Parker-Hannifin, Rheem Inc., TRANE, TYCO, Wolfe Aircraft, Wolverine

T-DRILL

ASSOCIATE MEMBER -
COPPER DEVELOPMENT ASSOCIATION

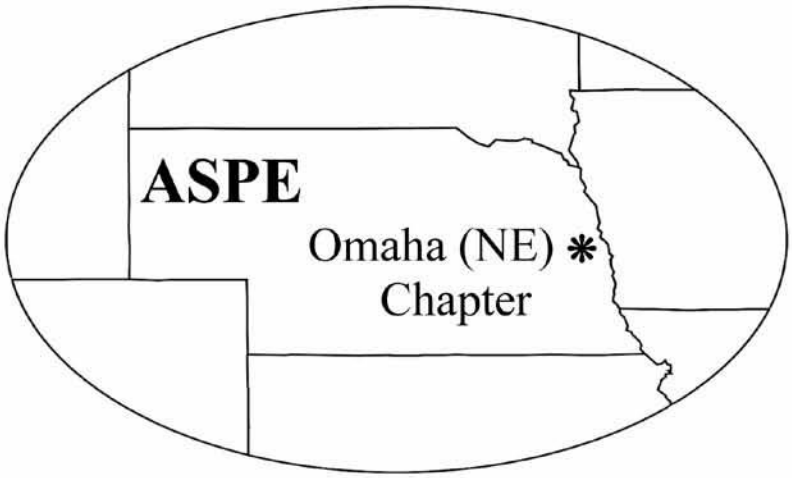
Contact us for more information on how to bid with T-DRILL

1740 Corporate Drive, Norcross, Georgia 30093
1-800-554-2730 FAX: (770) 925-3912
E-Mail: dnelson@t-drill.com Website: www.t-drill.com

** RSMeans Plumbing Cost Data 2007 and RSMeans Mechanical Cost Data 2007

Copyright R.S. Means Co. All rights reserved.

REV 8/06



The Omaha Chapter of ASPE acknowledges the following advertisers and sponsors for their support over the years.

Bill Batson, Willco Inc.

Bob Jedlicka, Mack McClain Associates

Chris Rearick, Service Reps., Inc.

Dave McArdle, Specified Design Consultants Inc.

Doug Pasmore, William D. Anderson Co.

Jack Trisler, Hydronic Energy Inc

John Papera, In Depth Marketing

Mark Reinhardt, Specified Design Consultants Inc.

Mike Green, Central Sales Inc.

Ron Thompson, Allied Systems Inc.

Alvine and Associates, Inc.

Berlinger Claccio Dennell Mabrey (bcdm)

Boyd Rydel, Mid-American Sales Group, Inc.

Dale Snackel and Company

Farris Engineering

Geary Engineering Inc.

HDR Architecture Inc.

Leo A. Daley

Martech, ACAD Technical Services

M.E. Group Inc.

ASPE SM

Omaha Chapter — P. O. Box 241266 —Omaha, NE 68124

Members located in the states of Nebraska (Beaver Crossing, Bellevue, Elkhorn, Gretna, Lincoln and Omaha); Iowa (Carter Lake, Cedar Rapids, Red Cliff, West Des Moines); South Dakota (Aberdeen); Kansas (Kansas City); Utah (Salt Lake City).

6 Domestic Water Heating Systems

INTRODUCTION

Proper design of the domestic hot water supply system for any building is extremely important. Careful planning on the basis of all available data will ensure an adequate supply of water at the desired temperature to each fixture at all times. A properly designed system must, of course, conform to all the regulations of the authority having jurisdiction (AHJ).

The design objectives for an efficient hot water distribution system include the following:

1. Providing adequate amounts of water at the prescribed temperature to all fixtures and equipment at all times.
2. A system that will perform its function safely.
3. The utilization of an economical heat source.
4. A cost-effective and durable installation.
5. An economical operating system with reasonable maintenance.

A brief discussion of each of these objectives is warranted. Any well-designed system should deliver the prescribed temperature at the outlet almost instantaneously to avoid the wasteful running of water until the desired temperature is achieved. The hot water should be available at any time of the day or night and during low-demand periods as well as peak flows.

Safety must be built into any hot water system, and these features must operate automatically. The three paramount dangers to be guarded against are domestic hot water system contamination by steam or boiler water additives, excessive pressures, and excessive temperatures. Contamination should be avoided by using double-wall heat exchangers or by installing a pressure gradient monitoring system. Exploding hot water heaters and scalding water at fixtures is prevented by designing properly sized temperature and pressure (T&P) relief valves and thermostatic mixing valves.

Health concerns such as control of Legionella bacterial growth also must be considered in the design of domestic hot water systems. Legionella control measures are included in the design whenever hot water is supplied to high-risk occupancies. These occupancies are typically hospitals and nursing homes where Legionella can potentially be fatal for immunosuppressed people. It is also good engineering practice to address Legionella in hotels.

An economic heat source is of prime importance in conserving energy. Various sources include coal, gas, oil, steam, condensate, waste hot water, and solar energy. The availability and cost of any of these sources or combinations of these sources dictate selection. If an especially economical source is not adequate to satisfy the total demand, then it can be used to preheat the cold water supply to the heater. Gas-fired water heater efficiency varies greatly by product. Efficiencies range from as low as 75% for small residential units to 97% for high-end commercial units.

An economical and durable installation can be achieved by judicious selection of the proper materials and equipment. The piping layout also has a marked effect on this objective and will determine the ease of replacement and repair.

Cost-effective operation and maintenance also depend upon the proper selection of materials and equipment. The choice of instantaneous, semi-instantaneous, or storage-type heaters, the selection of insulation on heaters and piping, the location of piping (avoiding cold, unheated areas), the ease of circulation (the avoidance of drops and rises in piping), bypasses around pumps and tanks, and adequate valving accessibility all are items affecting the operation and maintenance of a system.

The design of a domestic water heating system begins with estimating the facility's load profile and identifying the peak demand times. To accomplish these steps, the designer must conduct discussions with the users of the space, determine the building type, and learn of any owner requirements. The information thus gathered will establish the required capacity of the water heating equipment and the general type of system to be used.

DOMESTIC WATER HEATER SIZING

Sizing and selecting a domestic water heater system constitute an art form more than an exact science. For anything other than a small residential system, you cannot simply go to a table or chart and make your selection. Codes do not indicate how much hot water is required. They provide only generalizations such as "Hot and cold water shall be supplied to all sinks, lavatories, showers, etc." The codes do, however, give information about pipe materials and minimum and maximum flow rates to fixtures (combined cold and hot water), and they address safety concerns such as maximum temperatures and required safety devices.

A number of factors must be considered when sizing a system, and experience plays a big part. Every system is different, so the path that leads to final selection is different for every system. Two buildings can be physically the same (i.e., have the same number of fixtures), but the quantity of water required in the two buildings may be different if the buildings are to be occupied by different groups of people. For instance, an apartment building for older people would have a different use profile than one that primarily houses families.

Information Gathering

The first step to sizing a domestic hot water heater system is to collect the information needed to define the system parameters and narrow the options. Some of the information will be readily available, but some may require further investigation. The following is a fairly long list of questions; however, not all items apply to every situation.

- In what type of building will the system be installed?
- Where is the building located?
- What code or codes should be followed?
- Do any local amendments apply?
- Does the owner or operator of the building have any unusual requirements?
- Does the owner or operator of the building prefer a particular type of system?
- Are there any other hot water systems in the building?
  - If so, is the owner or operator satisfied with them?
- What area of the building will the system serve?
- What is the area used for?
- How many plumbing fixtures will there be?
- What kind of fixtures will there be?
- Who will be using them?
- Are there any high-usage fixtures, such as hot tubs or laundry machines?
- Are there plans to expand the facility in the future?
- Will there be laundry or a health club area?
- If so, how many areas will be used simultaneously?
- How much space is available for the system?
- What energy sources are available? Natural gas? Propane? Steam? Hot water? Fuel oil? Heat reclamation?
- Which energy source is most economical for the location?
- Where in the building will the equipment be placed?
- Will flues or combustion air be a problem due to the location?
- What is the cold water source?
- What is the water hardness?
- Will the system be inactive for long periods?
- How far from the heater will the furthest fixture be?

Water Heater Sizing Methods

With the information you have gathered, you can calculate the load (i.e., recovery rate and storage volume) required for the facility. Once again, this is not a straightforward process. There are several methods for calculating the load of a building. One method is not always better than another, although one may be better suited for the particular application. Two methods from the American Society of Plumbing Engineers (ASPE) are outlined here. Several other methods are available; most of them are from other societies, public, private and government sources, or water heater manufacturers. They also are valuable resources, as they include some building types and applications not addressed by these two methods. When designing any project for a government or public entity, their standards shall be used.

Method 1: The first method utilizes average hourly data (gallons per hour) for various types of buildings and occupancies. The sizing chart is shown on Table 6-1. To calculate using this method, count the fixtures, multiply the number of fixtures by the gallons per hour for the fixture in the particular type of building, and add them. You then multiply this total by the simultaneous usage factor to get the maximum hourly demand for the system. The minimum recommended storage volume then is calculated by multiplying the total demand by the storage factor. This is a simple method, but it has limitations:

Table 6-1 Hot Water Demand per Fixture for Various Types of Buildings (Gallons[Liters] of Water per Hour per Fixture, Calculated at a Final Temperature of 140°F [60°C])

Fixture	Apartment	Club	Gymnasium	Hospital	Hotel	Industrial Plant	Office Building	Private Residence	School	YMCA
1 Basins, private lavatory	2(7.6)	2(7.6)	2(7.6)	2(7.6)	2(7.6)	2(7.6)	2(7.6)	2(7.6)	2(7.6)	2(7.6)
2 Basins, public lavatory	4(15)	6(23)	8(30)	6(23)	8(30)	12(45.5)	6(23)	—	15(57)	8(30)
3 Bathtubs	20(76)	20(76)	30(114)	20(76)	20(76)	—	20(76)	—	30(114)	
4 Dishwashers[a]	15(57)	50-150 — (190-570)	—	50-150 — (190-570)	50-200 — (190-760)	20-100 (76-380)	—	15(57)	20-100 — (76-380)	20-100 (76-380)
5 Foot basins	3(11)	3(11)	12(46)	3(11)	3(11)	12(46)	—	3(11)	3(11)	12(46)
6 Kitchen sink	10(38)	20(76)	—	20(76)	30(114)	20(76)	20(76)	10(38)	20(76)	20(76)
7 Laundry, stationary tubs	20(76)	28(106)	—	28(106)	28(106)	—	20(76)	—	28(106)	
8 Pantry sink	5(19)	10(38)	—	10(38)	10(38)	—	10(38)	5(19)	10(38)	10(38)
9 Showers	30(114)	150(568)	225(850)	75(284)	75(284)	225(850)	30(114)	30(114)	225(850)	225(850)
10 Service sink	20(76)	20(76)	—	20(76)	30(114)	20(76)	20(76)	15(57)	20(76)	20(76)
11 Hydrotherapeutic showers				400(1520)						
12 Hubbard baths				600(2270)						
13 Leg baths				100(380)						
14 Arm baths				35(130)						
15 Sitz baths				30(114)						
16 Continuous-flow baths				165(625)						
17 Circular wash sinks				20(76)	20(76)	30(114)	20(76)		30(114)	
18 Semicircular wash sinks				10(38)	10(38)	15(57)	10(38)		15(57)	
19 Demand Factor	0.30	0.30	0.40	0.25	0.25	0.40	0.30	0.30	0.40	0.40
20 Storage capacity factor[b]	1.25	0.90	1.00	0.60	0.80	1.00	2.00	0.70	1.00	1.00

a Dishwasher requirements should be taken from this table or from manufacturers' data for the model to be used, if this is known.

b Ratio of storage tank capacity to probable maximum demand per hour. Storage capacity may be reduced where an unlimited supply of steam is available from a central street steam system or large boiler plant.

Reprinted from *ASPE Data Book: Vol. 4. Service Hot Water Systems*, American Society of Plumbing Engineers, 1989, Westlake, CA: Author. Copyright ©1989, American Society of Plumbing Engineers.

Figure 6-1 Occupant Demographic Classifications

No occupants work	High Demand
Public assistance and low income (mix)	
Family and single-parent households (mix)	
High number of children	
Low income	
Families	Medium Demand
Public assistance	
Singles	
Single-parent households	
Couples	Low Demand
High population density	
Middle income	
Seniors	
one person works, 1 stays home	
All occupants work	

Reprinted from Domestic Hot Water Heating Design Manual (p. 24), American Society of Plumbing Engineers, 1998, Westlake, CA: Author. Copyright ©1998, American Society of Plumbing Engineers.

- It can be applied only to the types of facilities listed.
- It is to be used only for the sizing of storage tank systems.
- It does not consider the type of occupants.
- It does not address high-use or high-volume fixtures.

Method 2: The second method of calculating hot water usage is outlined in *Domestic Water Heating Design Manual*, which addresses specific occupancies (see Figure 6-1 and Table 6-2) and tailors the calculation process to the type of building. There is a separate method of calculating the load for each building type, based on its individual operating characteristics. Not all types of facilities are addressed, but those that are can be accurately calculated using this method. It can be used to establish the sizing for systems using a storage tank, instantaneous, or semi-instantaneous heater. It also addresses additional concerns such as high-usage or high-volume fixtures.

BASIC FORMULAE AND UNITS

The equations in this chapter are based on the principle of energy conservation. The fundamental formula for this expresses a steady-state heat balance for the heat input and output of the system:

Equation 6-1:

$$q = r\,w\,c\,\Delta T$$

where

q = Time rate of heat transfer, Btu/h (kJ/h)
r = Flow rate, gph (L/h)
w = Weight of heated water, lb (kg)
c = Specific heat of water, Btu/lb/°F (kJ/kg/K)
ΔT = Change in heated water temperature (temperature of leaving water minus temperature of incoming water, represented as $T_h - T_c$, °F [K])

For purposes of this discussion, the specific heat of water is constant, c = 1 Btu/lb/°F (c = 4.19 kJ/kg/K), and the weight of water is constant at 8.33 lb/gal (999.6 kg/m^3).

Table 6-2 Low, Medium, and High Guidelines: Hot Water Demand and Use for Multifamily Buildings

Demand	Peak 5-min gal (L)/person	Peak 15-min gal (L)/person	Peak 30-min gal (L)/person	Maximum per hour, gal (L)/person
Low	0.4 (1.5)	1.0 (4.0)	1.7 (6.5)	2.8 (10.5)
Medium	0.7 (2.6)	1.7 (6.4)	2.9 (11.0)	4.8 (18.0)
High	1.2 (4.5)	3.0 (11.5)	5.1 (19.5)	8.5 (32.5)

Demand	Maximum 2 Hours, gal (L)/person	Maximum 3 Hours, gal (L)/person	Maximum Day, gal (L)/person	Average Day, gal (L)/person
Low	4.5 (17.0)	6.1 (23.0)	20.0 (76.0)	14.0 (54.0)
Medium	8.0 (31.0)	11.0 (41.0)	49.0 (185.0)	30.0 (113.6)
High	14.5 (55.0)	19.0 (72.0)	90.0 (340.0)	54.0 (205.0)

Note: These volumes are for domestic hot water delivered to the tap at 120° F (49° C).

Reprinted from Domestic Hot Water Heating Design Manual (p. 25), American Society of Plumbing Engineers, 1998, Westlake, CA: Author. Copyright ©1998, American Society of Plumbing Engineers.

Equation 6-2:

$$q = gph\left[\left(\frac{1\ Btu}{lb/°F}\right)\left(\frac{8.33\ lb}{gal}\right)(\Delta T)\right]$$

$$\left\{q = \frac{m^3}{h}\left[\left(\frac{4.188\ kJ}{kg/K}\right)\left(\frac{999.6\ kg}{m^3}\right)(\Delta T)\right]\right\}$$

Example 6-1: Calculate the heat output rate required to heat 600 gph from 50 to 140°F (2.27 m^3/h from 283.15 to 333.15K).

Solution: From Equation 6-2,

$$q = 600\ gph\left[\left(\frac{8.33\ Btu}{gal/°F}\right)(140–50°F)\right] = 449{,}820\ Btu/h$$

$$\left\{q = \frac{2.27\ m^3}{h}\left[\left(\frac{4188.32\ kJ}{m^3/K}\right)(333.15–283.15\ K)\right] = 475\ 374\ kJ/h\right\}$$

Note: The designer should be aware that water heaters installed in high elevations must be derated based on the elevation. The water heaters' manufacturers' data should be consulted for information on required modifications.

HEAT RECOVERY—ELECTRIC WATER HEATERS

It takes 1 Btu of energy to raise 1 lb of water 1°F. Since 1 kW is equal to 3413 Btu and 1 gal of water weighs 8.33 lb, then it would take 1 kW of electrical power to raise 410 gal (1552.02 L) of water 1°F. This can be expressed in a series of formulae, as follows:

Equation 6-3:

$$\frac{410\ gal}{\Delta T} = \text{gal of water per kW at } \Delta T$$

$$\left(\frac{1552.02\ L}{\Delta T} = \text{L of water per kW at } \Delta T\right)$$

Equation 6-4:

$$\frac{gph \times \Delta T}{410\ gal} = \text{kW required}$$

$$\left(\frac{1552.02\ L}{\Delta T} = \text{kW required}\right)$$

Equation 6-5:

$$\frac{gph}{\text{gal of water per kW at } \Delta T} = \text{kW required}$$

$$\left(\frac{L/h}{\text{L of water per kW at } \Delta T} = \text{kW required}\right)$$

where

ΔT = Temperature rise (temperature differential), °F (°C)
gph = Gallons per hour of hot water required
L/h = Liters per hour of hot water required

Equation 6-3 can be used to establish a simple table based on the required temperature rise.

Temperature Rise, ΔT, °F (°C)	Gal (L) of Water per kW
110 (43)	3.73 (14.12)
100 (38)	4.10 (15.52)
90 (32)	4.55 (17.22)
80 (27)	5.13 (19.42)
70 (21)	5.86 (22.18)
60 (16)	6.83 (25.85)
50 (10)	8.20 (31.04)
40 (4)	10.25 (38.8)

This table can be used with Equation 6-5 to solve for the kW electric element needed to heat the required recovery volume of water.

Example 6-2: An electric water heater must be sized based on the following information: (a) 40 gph (151.42 L/h) of hot water at a temperature of 140°F (60°C) is required. (b) The incoming water supply during winter is 40°F (4°C).

Solution: Using Equation 6-5 and the above table, we find the following:

$$\frac{40\ gph}{4.1\ gal\ (100°F)} = 9.8\ kW\ required$$

$$\left(\frac{151.42\ L/h}{15.52\ L\ (38°C)} = 9.8\ kW\ required\right)$$

HOT WATER TEMPERATURE

The generally accepted minimum hot water temperatures for various plumbing fixtures and equipment are given in Table 6-3. Both temperature and pressure should be verified with the client and checked against local codes and the manuals of equipment used.

Table 6-3 Typical Hot Water Temperatures for Plumbing Fixtures and Equipment

Use	Temperature °F	Temperature (°C)
Lavatory:		
Hand washing	105 (40)	
Shaving	115 (45)	
Showers and tubs	110 (43)	
Therapeutic baths	95 (35)	
Surgical scrubbing	110 (43)	
Commercial and institutional laundry	140–180 (60–82)	
Residential dishwashing and laundry	120 (48)	
Commercial, spray-type dishwashing (as required by the NSF): Single- or multiple-tank hood or rack type:		
Wash	150 min. (66 min.)	
Final rinse	180–195 (82–91)	
Single-tank conveyor type:		
Wash	160 min. (71 min.)	
Final rinse	180–195 (82–91)	
Single-tank rack or door type:		
Single-temperature wash and rinse	165 min. (74 min.)	
Chemical sanitizing glassware:		
Wash	140 (60)	
Rinse	75 min. (24 min.)	

Note: Be aware that temperatures, as dictated by codes, owners, equipment manufacturers, or regulatory agencies, occasionally will differ from those shown.

MIXED WATER TEMPERATURE

Mixing water at different temperatures to make a desired mixed water temperature is the main purpose of domestic hot water systems.

P is a hot water multiplier and can be used to determine the percentage of supply hot water that will blend the hot and cold water to produce a desired mixed water temperature.

Equation 6-6:

$$P = \frac{T_m - T_c}{T_h - T_c}$$

where

P = Hot water ratio, unitless
T_h = Supply hot water temperature, °F (°C)
T_c = Inlet cold water temperature, °F (°C)
T_m = Desired mixed water temperature, °F (°C)

Values of P for a range of hot and cold water temperatures are given in Table 6-4.

Example 6-3: A group of showers requires 25 gpm (1.58 L/s) of 105°F (41°C) mixed water temperature. Determine how much 140°F (60°C) hot water must be supplied to the showers when the cold water temperature is 50°F (10°C).

Solution:

$$P = \frac{105 - 50°F}{140 - 50°F} = 0.61$$

$$\left(P = \frac{41 - 10°C}{60 - 10°} = 0.61 \right)$$

Therefore,

0.61 (25 gpm) = 15.25 gpm of 140°F water required

[0.61 (1.58 L/s) = 0.96 L/s of 60°C water required].

Table 6-2 also may be used to determine P.

WATER HEATERS

The most commonly used type of water heater for office buildings, multiple-unit dwellings, and other similar establishments is the directly heated, automatic storage heater. Such heaters are simple, inexpensive to install, and very low maintenance. They are generally low-demand heaters, with low Btu input, so the heating of the water is spread over several hours. This reduces the amount of heating medium required. Commonly used heating mediums are electricity, fuel gas, and steam.

Instantaneous types of water heaters must have sufficient capacity to provide the maximum flow rate of hot water at an adequate temperature. The instantaneous heater finds its best application where water heating demands are constant, such as swimming pools, certain dishwasher booster requirements, and industrial processes, or where space conditions are a prime consideration. Because of these high flow rates and the typical on/off operation, the efficiencies of instantaneous heaters are lower than those of storage-type heaters.

Booster heaters are used to raise the temperature of the regular hot water supply to some higher-than-normal temperature needed to perform special functions. Booster heaters are utilized in applications such as commercial dishwashers where there is a limited use of very hot water. They can be located near their point of intended use and have simple controls, minimal waste, and smooth operation.

Semi-instantaneous heaters contain between 10 and 20 gallons of domestic water storage, according to their rated heating capacity. This small quantity of water is adequate to allow the temperature control system to react to sudden fluctuations in water flow and to maintain the outlet water temperature within ±5°F (2.7°C). The temperature control system is almost always included with this type of heater as a package.

Copper-fin heaters typically are used in conjunction with a storage tank. These heaters tend to have a high recovery rate, are more thermally efficient, and

Table 6-4 Hot Water Multiplier, P

T_h = 110°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)			
	110	105	100	95
45	1.00	0.92	0.85	0.77
50	1.00	0.92	0.83	0.75
55	1.00	0.91	0.82	0.73
60	1.00	0.90	0.80	0.70
65	1.00	0.89	0.78	0.67

T_h = 120°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)					
	120	115	110	105	100	95
45	1.00	0.93	0.87	0.80	0.73	0.67
50	1.00	0.93	0.86	0.79	0.71	0.64
55	1.00	0.92	0.85	0.77	0.69	0.62
60	1.00	0.92	0.83	0.75	0.67	0.58
65	1.00	0.91	0.82	0.73	0.64	0.55

T_h = 130°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)							
	130	125	120	115	110	105	100	95
45	1.00	0.94	0.88	0.82	0.76	0.71	0.65	0.59
50	1.00	0.94	0.88	0.81	0.75	0.69	0.63	0.56
55	1.00	0.93	0.87	0.80	0.73	0.67	0.60	0.53
60	1.00	0.93	0.86	0.79	0.71	0.64	0.57	0.50
65	1.00	0.92	0.85	0.77	0.69	0.62	0.54	0.46

T_h = 140°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)									
	140	135	130	125	120	115	110	105	100	95
45	1.00	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53
50	1.00	0.94	0.89	0.83	0.78	0.72	0.67	0.61	0.56	0.50
55	1.00	0.94	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.47
60	1.00	0.94	0.88	0.81	0.75	0.69	0.63	0.56	0.50	0.44
65	1.00	0.93	0.87	0.80	0.73	0.67	0.60	0.53	0.47	0.40

T_h = 150°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)										
	150	145	140	135	130	125	120	115	110	105	100
45	1.00	0.95	0.90	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.52
50	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50
55	1.00	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53	0.47
60	1.00	0.94	0.89	0.83	0.78	0.72	0.67	0.61	0.56	0.50	0.44
65	1.00	0.94	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.47	0.41

T_h = 160°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)										
	160	155	150	145	140	135	130	125	120	115	110
45	1.00	0.96	0.91	0.87	0.83	0.78	0.74	0.70	0.65	0.61	0.57
50	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55
55	1.00	0.95	0.90	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.52
60	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50
65	1.00	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53	0.47

Table 6-4 Hot Water Multiplier, P (continued)

T_h = 180°F Hot Water System Temperature

T_c, CW Temp. (°F)	T_m, Water Temperature at Fixture Outlet (°F)										
	180	175	170	165	160	155	150	145	140	135	130
45	1.00	0.96	0.93	0.89	0.85	0.81	0.78	0.74	0.70	0.67	0.63
50	1.00	0.96	0.92	0.88	0.85	0.81	0.77	0.73	0.69	0.65	0.62
55	1.00	0.96	0.92	0.88	0.84	0.80	0.76	0.72	0.68	0.64	0.60
60	1.00	0.96	0.92	0.88	0.83	0.79	0.75	0.71	0.67	0.63	0.58
65	1.00	0.96	0.91	0.87	0.83	0.78	0.74	0.70	0.65	0.61	0.57
110	1.00	0.93	0.86	0.79	0.71	0.64	0.57	0.50	0.43	0.36	0.29
120	1.00	0.92	0.83	0.75	0.67	0.58	0.50	0.42	0.33	0.25	0.17
130	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	—
140	1.00	0.88	0.75	0.63	0.50	0.38	0.25	0.13	—	—	—
150	1.00	0.83	0.67	0.50	0.33	0.17	—	—	—	—	—
160	1.00	0.75	0.50	0.25	—	—	—	—	—	—	—

T_h = 43°C Hot Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)			
	43	41	38	35
7	1.00	0.92	0.85	0.77
10	1.00	0.92	0.83	0.75
13	1.00	0.91	0.82	0.73
16	1.00	0.90	0.80	0.70
18	1.00	0.89	0.78	0.67

T_h = 49°C Hot Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)					
	49	46	43	41	38	35
7	1.00	0.93	0.87	0.80	0.73	0.67
10	1.00	0.93	0.86	0.79	0.71	0.64
13	1.00	0.92	0.85	0.77	0.69	0.62
16	1.00	0.92	0.83	0.75	0.67	0.58
18	1.00	0.91	0.82	0.73	0.64	0.55

T_h = 54°C Hot Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)							
	54	52	49	46	43	41	38	35
7	1.00	0.94	0.88	0.82	0.76	0.71	0.65	0.59
10	1.00	0.94	0.88	0.81	0.75	0.69	0.63	0.56
13	1.00	0.93	0.87	0.80	0.73	0.67	0.60	0.53
16	1.00	0.93	0.86	0.79	0.71	0.64	0.57	0.50
18	1.00	0.92	0.85	0.77	0.69	0.62	0.54	0.46

T_h = 60°C Hot Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)									
	60	58	54	52	49	46	43	41	38	35
7	1.00	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53
10	1.00	0.94	0.89	0.83	0.78	0.72	0.67	0.61	0.56	0.50
13	1.00	0.94	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.47
16	1.00	0.94	0.88	0.81	0.75	0.69	0.63	0.56	0.50	0.44
18	1.00	0.93	0.87	0.80	0.73	0.67	0.60	0.53	0.47	0.40

Table 6-4 Hot Water Multiplier, P (continued)

T_h = 66°C Hot-Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)										
	66	63	60	58	54	52	49	46	43	41	38
7	1.00	0.95	0.90	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.52
10	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50
13	1.00	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53	0.47
16	1.00	0.94	0.89	0.83	0.78	0.72	0.67	0.61	0.56	0.50	0.44
18	1.00	0.94	0.88	0.82	0.76	0.71	0.65	0.59	0.53	0.47	0.41

T_h = 71°C Hot-Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)										
	71	68	66	63	60	58	54	52	49	46	43
7	1.00	0.96	0.91	0.87	0.83	0.78	0.74	0.70	0.65	0.61	0.57
10	1.00	0.95	0.91	0.86	0.82	0.77	0.73	0.68	0.64	0.59	0.55
13	1.00	0.95	0.90	0.86	0.81	0.76	0.71	0.67	0.62	0.57	0.52
16	1.00	0.95	0.90	0.85	0.80	0.75	0.70	0.65	0.60	0.55	0.50
18	1.00	0.95	0.89	0.84	0.79	0.74	0.68	0.63	0.58	0.53	0.47

T_h = 82°C Hot-Water System Temperature

T_c, CW Temp. (°C)	T_m, Water Temperature at Fixture Outlet (°C)										
	82	79	77	74	71	68	66	63	60	58	54
7	1.00	0.96	0.93	0.89	0.85	0.81	0.78	0.74	0.70	0.67	0.63
10	1.00	0.96	0.92	0.88	0.85	0.81	0.77	0.73	0.69	0.65	0.62
13	1.00	0.96	0.92	0.88	0.84	0.80	0.76	0.72	0.68	0.64	0.60
16	1.00	0.96	0.92	0.88	0.83	0.79	0.75	0.71	0.67	0.63	0.58
18	1.00	0.96	0.91	0.87	0.83	0.78	0.74	0.70	0.65	0.61	0.57
43	1.00	0.93	0.86	0.79	0.71	0.64	0.57	0.50	0.43	0.36	0.29
49	1.00	0.92	0.83	0.75	0.67	0.58	0.50	0.42	0.33	0.25	0.17
54	1.00	0.90	0.80	0.70	0.60	0.50	0.40	0.30	0.20	0.10	—
60	1.00	0.88	0.75	0.63	0.50	0.38	0.25	0.13	—	—	—
66	1.00	0.83	0.67	0.50	0.33	0.17	—	—	—	—	—
71	1.00	0.75	0.50	0.25	—	—	—	—	—	—	—

are relatively small in size. They generally are used where large quantities of hot water are needed in a relatively short period or where higher efficiencies are required, such as in LEED-certified buildings. Due to their size they also are frequently used in retrofit situations.

Controls

The purpose for having controls on a hot water generator is to ensure a sufficient volume of hot water at the proper temperature for use is provided to a facility. The control components for water heaters differ depending on the type of heater and the manufacturer. Generally, water heater controls should be checked with the equipment manufacturer. Also, the various regulatory and testing agencies have requirements for controls that depend on the size and type of equipment used.

Stratification in storage type heaters and tanks

Because of its lighter density, warm water rises to the top of a storage tank. The result of this rising action, known as stratification, occurs in all un-recirculated tanks. It has been found that the amount of usable temperature water in stratified horizontal and vertical tanks is about 65% and 75%, respectively.

Stratification during recovery periods can be reduced significantly by mechanical circulation of the water in the tank. During periods of demand, however, it is useful to have good stratification since this increases the availability of water at a usable temperature. For example, if a tank were equally stratified between 140°F (60°C) at the top and 40°F (4°C) at the bottom, this tank, in theory, still could deliver half its volume at 140°F (60°C). But if the two layers were completely mixed, the tank temperature would drop to 90°F (32°C), which in most cases is an unusable temperature.

HOT WATER TEMPERATURE MAINTENANCE

Hot water of a desired temperature should be readily available at any fixture. Either a hot water circulation system or an electronically heated system shall be used to achieve this purpose.

Hot Water Circulation Systems

Hot water supply piping transmits heat to the surrounding lower-temperature air by conduction, convection, and radiation. Insulation reduces but does not eliminate this heat loss. In larger systems, if the heat loss is not addressed, the user wastes water while waiting for the desired temperature water to warm up the piping system. This is particularly true in systems using low-flow and electronic faucets where the wait time can be very long.

The sizing of the circulation system includes selection of the pump, sizing the supply and recirculation piping, and selecting the insulation type and thickness. Recirculation systems may not be practical for small systems but may be mandated for systems designed for such places as food establishments. In this situation, an alternate type of hot water maintenance such as heat tracing might be more practical. Proper sizing of the hot water circulating system is essential for the efficient and economical operation of the hot water system. Oversizing will cause the system to lose additional heat and result in unnecessary expenditures on equipment and installation. Undersizing will seriously hamper circulation and thus starve the fixtures of the desired water temperature.

The procedure for sizing the hot water circulating piping is as follows:

1. Calculate the heat loss rates of the hot water supply piping.
2. Calculate the heat loss rates of the hot water circulating piping.
3. Calculate the circulation rates for all parts of the circulating piping and the total circulation rate required.
4. Determine the allowable uniform friction head loss and the total head required to overcome friction losses in the piping when the water is flowing at the required circulation rate.
5. Calculate the rates of flow for various pipe sizes that will give the uniform pressure drop established in Step 4, and tabulate the results.
6. Size the system based upon the tabulation set up in Step 5.
7. With the sizes as established in Step 6, repeat Steps 2 through 6 as a check on the assumptions made.

As a guide to sizing circulation piping and circulation pumps, the following empirical methods are given but are not recommended in lieu of the more accurate procedures outlined above:

1. An allowance of ½ gpm (1.8 L/min) is assigned for each small hot water riser (¾–1 in. [1.9–2.54 cm]), 1 gpm (3.8 L/min) for each medium-size hot water riser (1¼-1½ in. [3.2–3.8 cm]), and 2 gpm (7.6 L/min) for each large-size hot water riser (2 in. [5 cm] and larger).
2. An allowance of 1 gpm (3.8 L/min) is assigned for each group of 20 hot water-supplied fixtures.

Self-Regulating Heat Trace Systems

A heat trace system is an economical, energy-efficient system for domestic hot water system maintenance. This type of system utilizes self-regulating cable installed on the hot water supply pipes underneath the standard pipe insulation. The cable adjusts its power output to compensate for variations in water and ambient temperatures. It produces more heat if the temperature drops and less heat if the temperature rises. The heating cable replaces supply-pipe heat losses at the point where heat loss occurs, thereby providing continuous, energy-efficient hot water temperature maintenance and eliminating the need for a recirculating system. Heat trace systems are most practical for smaller systems or situations where recirculation piping is impractical.

All heating cable components shall be UL listed for use as a part of the system to maintain hot water temperature. Component enclosures shall be rated NEMA 4X to prevent water ingress and corrosion. Installation shall not require the installing contractor to cut into the heating cable core to expose the bus wires. Connection systems requiring the installing contractor to strip the bus wires or that use crimps or terminal blocks shall not be acceptable. All components, except for the power connection, shall be re-enterable for servicing. No component shall use silicone to seal the electrical connectors. The system needs to comply to all other requirements of the AHJ.

RELIEF VALVES

Water heating systems shall be protected from excessive temperatures and pressures by relief valves. T&P relief valves are available either separately or combined. A combination T&P relief valve is preferred because it offers a more economical and yet effective protective procedure.

A relief valve on a water supply system is exposed to many elements affecting its performance, such as corrosive water that attacks materials and deposits of lime, which close up waterways and flow passages. For these reasons, the minimum size of the valve

should be ¾ in. (19 mm) for inlet and outlet connections, with the waterways within the valve of an area not less than the area of the inlet connection. Relief valves should be tested on a regular basis to ensure safe and proper operation.

All valves should have a discharge pipe connected to their outlets and terminate at a point where the discharge will cause no damage to property or injury to persons. The discharge pipe size shall be at least the size of the valve discharge outlet, shall be as short as possible, and shall run down to its terminal without sags or traps.

Typically, T&P relief valves are tested to comply with the standards of the American Society of Mechanical Engineers (ASME), the American Gas Association (AGA), or the National Board of Boiler and Pressure Vessel Inspectors (NBBPVI) and are so labeled. The designer should verify which agency's standards are applicable to the water heating system being designed and follow those standards for the sizes, types, and locations of required relief valves.

Sizing Pressure and Temperature Relief Valves

The following information applies to heaters with more than 200,000 Btu (211,000 kJ) input:

Temperature relief valves: These shall have the capacity to prevent water temperature from exceeding 210°F (99°C). They shall be water rated on the basis of 1,250 Btu (1,319 kJ) for each gph of water discharged at 30 lb (13.6 kg) working pressure and a maximum temperature of 210°F (99°C).

The temperature rating is the maximum rate of heat input to a heater on which a temperature relief valve can be installed and is determined as follows:

Equation 6-7:

$$\frac{\text{gph water heated} \times 8.33 \times \Delta T(°F)}{0.8} = \text{Btu valve capacity required}$$

$$\left(\frac{\text{L/h water heated} \times 1 \text{ kg/L} \times \Delta T(°C)}{0.8} = \text{kJ valve capacity required}\right)$$

Pressure relief valves: These shall have the capacity to prevent a pressure rise in excess of 10% of the set opening pressure. They shall be set at a pressure not exceeding the working pressure of the tank or heater.

The pressure rating is the maximum output of a boiler or heater on which a pressure relief valve can be used and is determined as follows:

Equation 6-8:

$$\text{gph water heated} \times 8.33 \times \Delta T(°F) = \text{Btu valve capacity required}$$

$$\left[\text{L/h water heated} \times 1.0 \text{ kg/L} \times \Delta T(°C) = \text{kJ valve capacity required}\right]$$

Determine the Btu capacity required and then refer to a manufacturer's catalog for valve size selection. Note that on high BTU systems, multiple T&P relief valves may be required at the storage tank.

THERMAL EXPANSION

Water expands as it is heated. This expansion shall be provided for in a domestic hot water system to avoid damage to the piping. Use of a thermal expansion tank in the cold water piping to the water heater will accomplish this. It is recommended the designer contact the manufacturer of the thermal expansion tank for information on installation and sizing. Plumbing codes require some type of thermal expansion compensation—especially when there is either a backflow prevention device on the cold water service to the building or a check valve in the system.

Relying only on the T&P relief valve to relieve the pressure is not good practice. Most local codes now require expansion tanks for systems more than 4 gal (8.8 L) in capacity.

The relevant properties of water are shown in Table 6-5.

Example 6-4: Using Table 6-5, determine the thermal expansion of a typical residence. Assume the initial heating cycle has incoming water at 40°F (4°C) and a temperature rise of 100°F (38°C). The water heater is 50 gal (189 L) capacity and the piping system volume is 10 gal (38 L).

Solution

Specific volume of water @ 40°F = 0.01602 ft^3/lb

Specific volume of water @ 140°F = 0.01629 ft^3/lb

$$\frac{S_v\ 40°F}{S_v\ 140°F} = \frac{0.01602}{0.01629} = 1.66\% \text{ increase in volume}$$

Total volume = 50-gal tank + 10-gal system = 60 gal

60 gal × 1.66% volume increase = 1 gal expansion

1 gal × 8.33 lb/gal × 0.01628 ft^3/lb = 0.1356 ft^3 = 19.5 $in.^3$

(Specific volume of water @ 4°C = 0.00100 m^3/kg

Specific volume of water @ 60°C = 0.00102 m^3/kg

$$\frac{S_v\ 4°C}{S_v\ 60°} = \frac{0.00100}{0.00102} = 1.66\% \text{ increase in volume}$$

Total volume = 189-L tank + 38-L system = 227 L

227 L × 1.66% volume increase = 3.79 L expansion

3.79 L × 1 kg/L × 0.0010 m^3/kg = 0.0038 m^3 = 380 cm^3 expansion)

THERMAL EFFICIENCY

When inefficiencies of the water heating process are considered, the actual input energy is higher than the usable, or output, energy. Direct-fired water heaters (i.e., those that use gas, oil, etc.) lose part of their total energy capabilities to such things as heated flue gases, inefficiencies of combustion, and radiation at heated surfaces. Their thermal efficiency, E_t, is defined as

Table 6-5 Thermal Properties of Water

Temperature		Saturation Pressure		Specific Volume		Density		Weight		Specific Heat	
°F	°C	psig	kPa	ft^3/lb	m^3/kg	lb/ft^3	kg/m^3	lb/gal	kg/m^3	Btu/lb-°F-h	J/kg-°C-h
32	0.0	29.8	3,019.6	0.01602	0.00100	62.42	999.87	8.345	1,001.40	1.0093	4,225.74
40	4.4	29.7	3,009.5	0.01602	0.00100	62.42	999.87	8.345	1,001.40	1.0048	4,206.90
50	10.0	29.6	2,999.4	0.01603	0.00100	62.38	999.23	8.340	1,000.80	1.0015	4,193.08
60	15.5	29.5	2,989.2	0.01604	0.00100	62.34	998.59	8.334	1,000.08	0.9995	4,184.71
70	21.1	29.3	2,969.0	0.01606	0.00100	62.27	997.47	8.325	999.00	0.9982	4,179.26
80	26.7	28.9	2,928.4	0.01608	0.00100	62.19	996.19	8.314	997.68	0.9975	4,176.33
90	32.2	28.6	2,898.0	0.01610	0.00100	62.11	994.91	8.303	996.36	0.9971	4,174.66
100	37.8	28.1	2,847.4	0.01613	0.00101	62.00	993.14	8.289	994.68	0.9970	4,174.24
110	43.3	27.4	2,776.4	0.01617	0.00101	61.84	990.58	8.267	992.04	0.9971	4,174.66
120	48.9	26.6	2,695.4	0.01620	0.00101	61.73	988.82	8.253	990.36	0.9974	4,175.91
130	54.4	25.5	2,583.9	0.01625	0.00101	61.54	985.78	8.227	987.24	0.9978	4,177.59
140	60.0	24.1	2,442.1	0.01629	0.00102	61.39	983.37	8.207	984.84	0.9984	4,180.10
150	65.6	22.4	2,269.8	0.01634	0.00102	61.20	980.33	8.182	981.84	0.9990	4,182.61
160	71.1	20.3	2,057.0	0.01639	0.00102	61.01	977.29	8.156	978.72	0.9998	4,185.96
170	76.7	17.8	1,803.7	0.01645	0.00103	60.79	973.76	8.127	975.24	1.0007	4,189.73
180	82.2	14.7	1,489.6	0.01651	0.00103	60.57	970.24	8.098	971.76	1.0017	4,193.92
190	87.8	10.9	1,104.5	0.01657	0.00103	60.35	966.71	8.068	968.16	1.0028	4,198.52
200	93.3	6.5	658.6	0.01663	0.00104	60.13	963.19	8.039	964.68	1.0039	4,203.13
210	98.9	1.2	121.6	0.01670	0.00104	59.88	959.19	8.005	960.60	1.0052	4,208.57
212	100.0	0.0	0.0	0.01672	0.00104	59.81	958.06	7.996	959.52	1.0055	4,209.83
220	104.4	2.5	253.3	0.01677	0.00105	59.63	955.18	7.972	956.64	1.0068	4,215.27
240	115.6	10.3	1,043.7	0.01692	0.00106	59.10	946.69	7.901	948.12	1.0104	4,230.34
260	126.7	20.7	2,097.5	0.01709	0.00107	58.51	937.24	7.822	938.64	1.0148	4,248.76
280	137.8	34.5	3,495.9	0.01726	0.00108	57.94	928.11	7.746	929.52	1.0200	4,270.54
300	148.9	52.3	5,299.6	0.01745	0.00109	57.31	918.02	7.662	919.44	1.0260	4,295.66
350	176.7	119.9	12,149.5	0.01799	0.00112	55.59	890.47	7.432	891.84	1.0440	4,371.02
400	204.4	232.6	23,569.4	0.01864	0.00116	55.63	891.11	7.172	860.64	1.0670	4,467.32
450	232.2	407.9	41,332.5	0.01940	0.00121	51.55	825.75	6.892	827.04	1.0950	4,584.55
500	260.0	666.1	67,495.9	0.02040	0.00127	49.02	785.22	6.553	786.36	1.1300	4,731.08
550	287.8	1030.5	104,420.6	0.02180	0.00136	45.87	734.77	6.132	735.84	1.2000	5,024.16
600	315.6	1528.2	154,852.5	0.02360	0.00147	42.37	678.70	5.664	679.68	1.3620	5,702.42

the heat actually transferred to the domestic water divided by the total heat input to the water heater. Expressed as a percentage, this is

Equation 6-9:

$$E_t = \frac{q - B}{q} \times 100\%$$

where

E_t = Thermal efficiency ratio, unitless
B = Internal heat loss of the water heater, Btu/h (kJ/h)
q = Time rate of heat transfer, Btu/h (kJ/h)

Refer to Equations 6-1 and 6-2 to determine q. Many water heaters and boilers provide input and output energy information.

Example 6-5: Calculate the heat input rate required for the water heater in Example 6-1 if this is a direct gas-fired water heater with a thermal efficiency of 80%.

Solution:

From Example 6-1, q = 449,820 Btu/h (475 374 kJ/h). Heat input =

$$\frac{q}{E_t} = \frac{449{,}820 \text{ Btu/h}}{0.80} = 562{,}275 \text{ Btu/h}$$

$$\left(\frac{q}{E_t} = \frac{475\ 374 \text{ kJ/h}}{0.80} = 594\ 217.5 \text{ kJ/h}\right)$$

SAFETY AND HEALTH CONCERNS

Legionella Pneumophila (Legionnaires' Disease)

Legionnaires' disease is a potentially fatal respiratory illness. The disease gained notoriety when a number of American Legionnaires contracted it during a convention. That outbreak was attributed to the water vapor from the building's cooling towers. The bacteria causing Legionnaires' disease are widespread in natural sources of water, including rivers, lakes,

streams, and ponds. In warm water, the bacteria can grow and multiply to high concentrations.

Prevention and control of Legionella bacteria is of major concern in health care facilities. It has been documented that there are several potential sources of the bacteria in hospitals. For the purposes of this section, only Legionella in domestic hot water systems is addressed. The Legionella bacteria can be found in many domestic hot and cold water systems in trace amounts. There are no health concerns with the bacteria until it colonizes (forming higher concentrations), and the bacteria are atomized and inhaled or aspired. In most documented cases of Legionnaires' disease the suggested mode of transmission was when water containing the organism was aerosolized in respirable droplets (1–5 micrometers in diameter) and inhaled or drops were aspired by a susceptible host. There is no indication the bacteria are of concern when swallowed. Nor does any data support Legionella being spread through person-to-person transmission. Legionella has been shown to most greatly affect immunosuppressed people. In a hospital, the following patients are most susceptible to Legionella infection: organ transplant patients, cancer patients receiving radiation or chemotherapy, patients with HIV, and surgical patients.

VARYING STANDARDS

There are varying published temperature ranges for Legionella bacterial growth. For instance, the Centers for Disease Control and Prevention (CDC) lists the favorable bacterial growth range of 90–113°F (32–45°C). The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) lists the favorable bacterial growth range of 77–108°F (25–42°C), and Matthew Freije, author of *Legionellae Control in Health Care Facilities,* lists the optimal temperature range for bacterial growth of 68–122°F (20–50°C) (95–115°F [35–46°C] ideal). The American Society for Healthcare Engineering (ASHE) and the Joint Commission on Accreditation of Healthcare Organizations (JCAHO) list the range of 77–108°F (25–42°C). Combining these ranges would indicate a potential range of growth of 68–122°F (20–50°C). All available information indicates that almost all bacteria die at temperatures above 130°F (54°C). The higher the temperature, the faster the bacteria die. Table 6-6 lists domestic water system temperatures as they relate to Legionella from the various agencies and organizations. Included on the table are three additional sources of temperature information: the City of Chicago Building Code, State of Illinois Plumbing Code, and ASPE. These were included as a sample of additional requirements from local jurisdictions and recommendations from plumbing organizations.

LEGIONELLA HOT SPOTS

Available information indicates almost all the Legionella bacteria die at temperatures above 130°F (54°C). The higher the temperature, the faster the bacteria die. Therefore, a common method of Legionella control is to maintain the domestic hot water system temperature above 130°F (54°C), with a preferable distribution system temperature of 140°F (60°C) and a return hot water temperature of at least 124°F (51°C). On older piping systems not having thermostatic mixing valves at all outlets, a system cannot be operated at 130°F (54°C) or above and still maintain code compliance. As mandated by most local codes, the maximum hot water temperature to plumbing fixtures in patient care areas is 115°F (46°C). This is to minimize scalding due to excessive water temperature. Often, the shower valves in the hospital facility are not of the thermostatic mixing valve type, which would allow the system to be operated at an elevated temperature. As a result, the hospital's domestic hot water systems are operated at approximately 115°F (46°C), with a return hot water temperature of 105–110°F (41–43°C). Unfortunately, 105–115°F (41–46°C), no matter what code you use,

Table 6-6 Recommended Water System Temperatures

	CDC	ASHRAE	FREIJE	ASHE/JCAHO	CCBC/ ISPC	IDPH	ASPE
Store DCW (maximum)	n	68°F	68°F	—	n	n	n
Favorable for Legionella Growth	90–105°F	77–108°F	68–122°F	77–108°F	n	n	n
Maximum DHW Discharge Temperature (patient care areas)	n	n	—	—	115°F	110°F	115°F
Maximum DHW Discharge Temperature (behavioral health)	n	n	—	—	n	100°F	n
Recirculating DHW (minimum)	n	124°F	122°F	124°F	n	n	n
Store DHW (minimum)	n	140°F	140°F	140°F	n	n	n
Flush (Thermal Shock Treatment)Minimum time	150°F @ 5 minutes	160–170°F @ 5–30 minutes		n	n	n	158°F @5 minutes

Lochinvar®

High Efficiency Water Heaters, Boilers and Pool Heaters

WE DON'T BUILD ALL PURPOSE WATER HEATERS. WE BUILD WATER HEATERS FOR ALL PURPOSES.

- **Residential, Commercial, Industrial**
- **High Efficiency Products**
- **2 Gallons to 5000 Gallons**
- **Up to 2 Million Btu/hr Inputs**
- **Multiple Venting Options**

80%-98% THERMAL EFFICIENCIES

LOW NOx Certified
PROTECTING THE ENVIRONMENT

Lochinvar
THE BUILT-IN ADVANTAGE

Lochinvar®
High Efficiency Water Heaters, Boilers and Pool Heaters

Lochinvar Corporation • 300 Maddox Simpson Pkwy • Lebanon, TN 37090 • 615-889-8900 / Fax: 615-547-1000
www.Lochinvar.com

is in the Legionella bacteria growth temperature range.

Bacterial growth is most prominent in stagnant areas such as storage tanks and dead ends of piping. Bacteria typically grows in the biofilm, scale, slime, and sediment found in these locations. It tends not to grow in sections of the piping distribution system that are actively flowing and have little biofilm or sediment buildup. Increased water velocity in a piping system can help reduce biofilm, but excessive water velocity can be detrimental to a piping system. Care should be taken not to exceed 7 feet per second of velocity in the pipe, or erosion could take place causing pipe failure. Legionella bacteria can reside in the piping system and in the scale buildup on shower heads. The shower head provides a sieve effect and the additional rough surface of the scale provides additional area for biofilm. Additional locations of bacterial growth include spas and whirlpools. There have also been reports of bacterial growing on natural rubber washers.

CONTROLLING LEGIONELLA

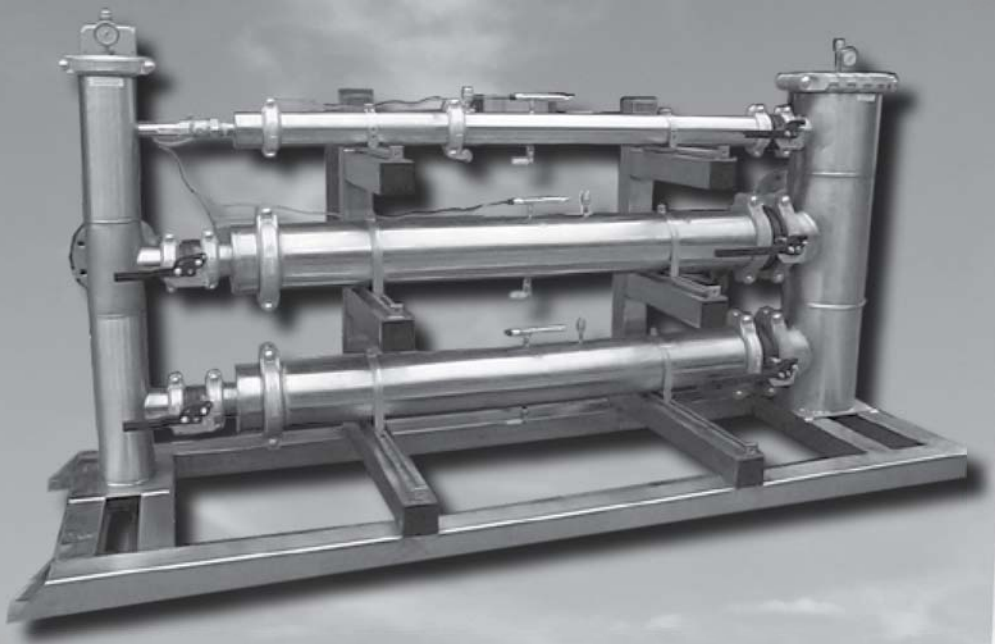
There are many methods of controlling the colonization of Legionella bacteria. These include elevated temperature maintenance, heat and flush cycles, copper-silver ionization, chlorine dioxide injection, halogens, ultraviolet (UV) radiation, ozone, hyperchlorination, and filtration/re-chlorination.

1. Elevated temperature maintenance, keeping the system temperature continually at or above 140°F (60°C) as recommended by several of the agencies noted previously, is the preferred method of control. However, it is impractical in large, old facilities as it would require replacement of all non-thermostatic-type shower valves.
2. The heat and flush is a method of disinfecting the entire piping system by elevating the system temperature to 150°F (66°C) or greater and flushing the high temperature water through every outlet for at least 30 minutes. The system should be flushed at 160–170°F (71–77°C) if there is some indication of a Legionella outbreak. This method has been proven to be effective in killing the bacteria present in most domestic hot water systems. Large quantities of biofilm in the piping system might require additional contact time with the elevated temperature water. The advantages of this method are that it involves no capital expenditures for equipment and can be implemented immediately. Its disadvantages are that in large facilities it is difficult to coordinate the flushing of the system without risking a scalding injury to patients and it is ineffective on fixtures having thermostatic mixing valves. This is a non-permanent solution to Legionella contamination. The bacteria will eventually come back and recolonize in the system.
3. Copper-silver ionization involves installing a flow-through ionization chamber containing copper-silver electrodes. As electrical current is applied to the electrodes, positively charged copper and silver ions are released into the water system. The positively charged ions bond to the microorganisms, causing them to die. The optimal concentration of copper-silver ions is said to be 400 parts per billion (ppb) for copper (Cu) and 40 ppb for silver (Ag). The advantages of this alternative are that the equipment is relatively easy to install and maintain and it provides permanent, continuous disinfection. The disadvantages are the initial equipment costs and continuing operating/maintenance costs. Copper-silver ionization is often recommended as an option for use on domestic hot water systems serving immunodeficient patient care areas.
4. Chlorine dioxide gas injection is effective in the control of Legionella bacteria in domestic hot water systems. It penetrates biofilm and slime and kills bacteria at its growth sites. Its advantages are that it stays in solution for long periods and, since it requires low concentrations, it minimizes chlorine-induced corrosion concerns. The disadvantages are that the equipment is best suited for use in small to medium-size applications; the equipment is fairly expensive; a chlorine dioxide gas generator is required for each hot water system; and water chemistry has to be closely monitored. For large facilities, it might be necessary to install multiple injectors. Chlorine dioxide is a viable option for use on domestic hot water systems serving immunodeficient patient care areas if closely monitored.
5. The use of halogens (chlorine, bromine, and iodine) at dosages ranging from 0.3–1.0 parts per million (ppm) is a viable option only if the water pH is precisely controlled. As the water pH drops, so does the efficiency of the halogen as a biocide. A final but critical consideration is the issue of carcinogenic halogenated compounds being dumped into the waterway. A byproduct of chlorine treatment of water is total trihalomethanes (TTHM), which may elevate the risk of certain cancers. While the risk may be small, the EPA is attempting to reduce TTHM concentrations in U.S. water systems. Halogens are therefore seldom recommended for use in health care facilities.
6. Ultraviolet (UV) radiation is effective in killing the bacteria as it flows through a single point in the system. It is effective only for use on small, localized systems and short runs of pipe. It is ineffective in large systems and does not eliminate the growth of existing colonies in other portions of the system. The effect of UV on Legionella within

DELTA P SYSTEMS, INC.

Quietly performing Monumental tasks.

When the National Park Service needed silent reliability, they turned to QuietFlow™ by Delta P Systems, Inc.



Delta P Systems, Inc.

3 East Tower Circle • Ormond Beach, FL 32174

Toll Free: 800-508-4218 • www.deltapsystems.com

protozoan vesicles (protozoan bodies loaded with Legionella cells) is also not known.

7. Ozone is effective in killing the bacteria in the immediate vicinity of the ozone generator. Its advantage is that TTHMs are not produced by ozone treatment. Its disadvantages are that decomposition of the ozone in the system quickly dissipates the concentrations required to kill bacteria; it can cause corrosion problems in older piping; it is ineffective in large systems; and it does not eliminate the growth of existing colonies in other portions of the system. This is also an expensive option.
8. Hyper-chlorination is effective in killing the bacteria but has several very important negative aspects. First, high chlorine concentrations are required to kill the bacteria. Second, chlorine byproducts are TTHMs, which are potential carcinogens. Third, chlorine is corrosive and can cause degradation leading to potential failure of the piping. It is therefore not recommended for regular use in most hospital facilities.
9. Filtration/rechlorination involves the use of 5-micron filters in conjunction with a rechlorination system. This method is used to filter foreign matter being introduced into the piping system from an unfiltered water supply and thus reducing the scale and sediments in which the biofilm can propagate. Rechlorination is then used to maintain a chlorine level more conducive to inhibiting biofilm growth. Chlorine concentrations should be closely monitored to prevent over-chlorination. This type of system is typically used on non-municipal-type water systems and does not apply to hospitals receiving a central water supply.

LEGIONELLA CONTROL RECOMMENDATIONS

For hospitals, JCAHO EC.1.7 requires the hospital to develop a management plan establishing and maintaining a utility systems management program to "reduce the potential for organizational illness." This management plan shall provide processes for "managing pathogenic agents in... domestic water and aerosolizing water systems." There are two approaches recommended in the CDC guidelines for Legionella prevention and control. The first approach involves periodic, routine culturing of water samples from the hospital's potable water system. For large hospitals the CDC does not recommend random sampling. For large hospital facilities the second approach listed is the more practical to implement. The recommended approach follows:

1. Educate the hospital staff to increase their awareness of the symptoms of legionellosis. Maintain a high index of suspicion for legionellosis and appropriately use diagnostic tests for legionellosis in patients with nosocomial pneumonia who are at risk of developing the disease and dying from the infection.
2. Initiate an investigation for a hospital source of Legionella upon identification of one case of definite or two cases of possible nosocomial Legionella disease.
3. Routinely use only sterile water for filling and terminal rinsing of nebulization devices.

For high risk factor areas such as operating rooms, ICU, AIDS, and cancer treatment areas, it often is recommended that the hospital install chlorine dioxide or copper-silver ionization equipment on the domestic hot water systems feeding these areas.

The following is a checklist for existing domestic hot water piping systems to help minimize system-wide Legionella growth.

1. Remove dead legs in the domestic hot water system. Establish a policy of removing leftover piping.
2. Replace heavily scaled shower heads.
3. Extend hot water recirculation lines to the furthest point from the supply to ensure full system circulation.
4. All new piping should be copper, which is more corrosion resistant than galvanized iron piping. The formation of rust pockets is conducive toward biofilm proliferation and Legionella growth. Corrosion leads to slime and scale buildup.
5. Change water and sanitize integral piping in whirlpools and spas frequently.

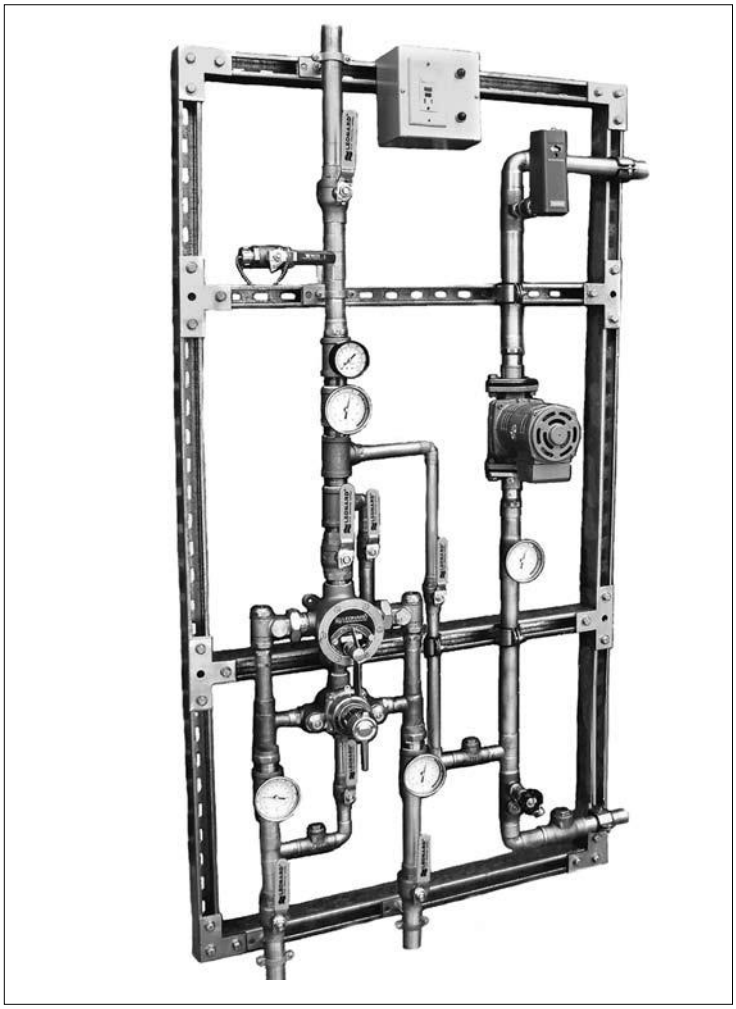
If the disease is detected and confirmed, disinfection of the piping system will be required. Of the above methods, the most immediately available form of disinfection is usually the heat and flush method. This will involve the least capital investment; it can be quickly implemented; and when properly executed it is effective in eradicating most existing bacteria colonies. After disinfection, a Legionella control system should be installed and a program should be instituted to monitor the bacteria levels in the piping. It is also advisable to get concurrence from the medical facility's relevant committees, such as the infection control committee.

Scalding[1]

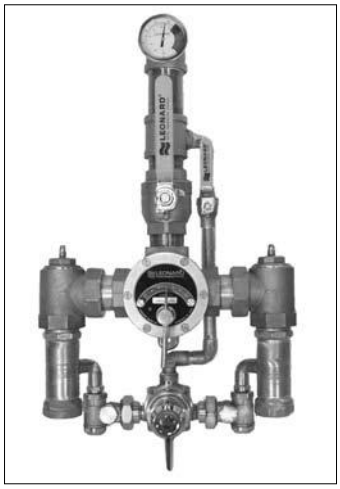
A research project by Moritz and Henriques at Harvard Medical College[2] looked at the relationship between time and water temperature necessary to produce a first-degree burn. A first-degree burn, the least serious type, results in no irreversible damage. The results of the research show it takes a 3-s exposure to 140°F (60°C) water to produce a first-degree burn. At 130°F (54°C), it takes approximately 20 s,

More Choices

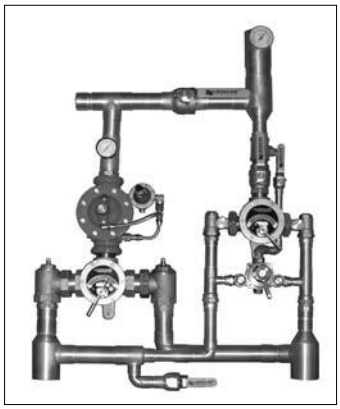
because water temperature control is all we do.



MEGATRON® Complete Water Temperature Control Stations in Seven Models!



New Generation High Low Systems in Six models!



High Capacity Manifold Systems in Seven Models!

At Leonard Valve, water temperature control is not a side-line, it's our lifeline. Since 1913 we have been the leader in water temperature controls and because that's all we do, no one offers more choices, more quality or more reliability.

All products are pre-assembled and pre-tested with Leonard's exclusive DURA-trol® solid bimetal thermostatic control, Automatic 7 Year Thermostat Warranty, CASPAK® sizing, and on-phone, on-line, on-site technical support. Visit our website for more information.

LEONARD®
WATER TEMPERATURE CONTROLS

Value Alliance Club®

1360 Elmwood Avenue, Cranston, RI 02910, 888-797-4456, fax 401-941-5310, www.leonardvalve.com, info@leonardvalve.com

and at 120°F (49°C), it takes 8 min to produce a first-degree burn.

The normal threshold of pain is approximately 118°F (48°C). A person exposed to 120°F (49°C) water would immediately experience discomfort, so it's unlikely that the person would be exposed for the 8 min required to produce a first-degree burn. People in some occupancies (e. g., hospitals), as well as those over the age of 65 and under the age of one, may not sense pain or move quickly enough to avoid a burn once pain is sensed. If such a possibility exists, scalding protection should be considered. It often is required by code. (For more information on skin damage caused by exposure to hot water, see Table 6-7.)

Table 6-7 Time/Water Temperature Combinations Producing Skin Damage

Water Temperature		
°F	°C	Time(s)
Over 140	Over 60	Less than 1
140	60	2.6
135	58	5.5
130	54	15
125	52	50
120	49	290

Source: Tom Byrley. 1979. "130 degrees F or 140 degrees F." Contractor Magazine (September). First published in American Journal of Pathology.
Note: The above data indicate conditions producing the first evidence of skin damage in adult males.

CODES AND STANDARDS

The need to conform to various codes and standards determines many aspects of the design of a domestic hot water system as well as the selection of components and equipment.

Some of the most often used codes and standards follow:

1. Regional, state, and local plumbing codes.
2. American Society of Heating, Refrigerating and Air-Conditioning Engineers ASHRAE/IES 90.1.
3. American Society of Mechanical Engineers (ASME) code for fired and unfired pressure vessels.
4. ASME and American Gas Association (AGA) codes for relief valves.
5. Underwriters' Laboratories (UL) listing for electrical components.
6. National Sanitation Foundation (NSF) listing.
7. AGA approval for gas-burning components.
8. National Fire Protection Association (NFPA) standards.
9. National Electrical Code (NEC).
10. Department of Health and Environmental Control (DHEC).

In addition, the federal government, agencies with jurisdiction over public schools and public housing, and many other agencies have specific requirements that must be observed when designing projects and selecting equipment for them.

REFERENCES

1. ASPE Research Foundation. 1989. "Temperature limits in service hot water systems." *Journal of Environmental Health* (June): 38-48.
2. Moritz, A. R., and F. C. Henriques, Jr. 1947. "The relative importance of time and surface temperature in the causation of cutaneous burns." *American Journal of Pathology* 23: 695-720.

7 Fuel-Gas Piping Systems

LOW AND MEDIUM-PRESSURE NG SYSTEMS

This chapter describes fuel-gas systems on consumer sites from the property line to the final connection with the most remote gas appliance or piece of equipment. The system is intended to provide sufficient pressure and volume for all uses. Since NG is a nonrenewable energy resource, the engineer should design for its efficient use. The direct utilization of NG is preferable to the use of electrical energy when electricity is obtained from the combustion of gas or oil. However, in many areas, the gas supplier and/or governmental agencies may impose regulations that restrict the use of natural gas. Refer to the chapter "Energy Conservation in Plumbing Systems" in *Plumbing Engineering Design Handbook* Volume 1 for information on appliance efficiencies and energy conservation recommendations.

The composition, specific gravity, and heating value of NG (NG) vary depending on the well (or field) from which the gas is gathered. NG is a mixture of gases, most of which are hydrocarbons, and the predominant hydrocarbon is methane. Some natural gases contain significant quantities of nitrogen, carbon dioxide, or sulfur (usually as H_2S). Natural gases containing sulfur or carbon dioxide are apt to be corrosive. These corrosive substances are usually eliminated by treatment of the NG before it is transmitted to the customers. Readily condensable petroleum gases also are usually extracted before the NG is put into the pipeline to prevent condensation during transmission. The physical properties of both NG and liquefied petroleum gas (LPG) are given in Table 7-1. NG and LPG are colorless and odorless, so an additive is added to the gases to detect a leak.

General

NG is obtained from a franchised public utility obligated to provide gas to all who request this service. There are different types of services a utility may provide, each with a different cost. They include the following:

1. Firm Service. This service provides constant supply of gas under all conditions.
2. Interruptible Service. This service allows the utility to stop gas supply under certain conditions and proper notification and to start service when the conditions no longer exist. The most common reason for this interruption is when the ambient temperature falls below a predetermined point.

Table 7-1 Average Physical Properties of Natural Gas and Propane

	Propane	Natural gas (methane)
Formula	C_3H_8	CH_4
Molecular weight	44.097	16.402
Melting (or freezing) point, °F	– 305.84	– 300.54
Boiling point, °F	– 44	– 258.70
Specific gravity of gas (air = 1.00)	1.52	0.60
Specific gravity of liquid 60°F/60°F (water = 1.00)	0.588	0.30
Latent heat of vaporization at normal boiling point, Btu/lb	183	245
Vapor pressure, lb/in^2, gauge at 60°F	92	
Pounds per gallon of liquid at 60°F	4.24	2.51
Gallons per pound of liquid at 60°F	0.237	
Btu per pound of gas (gross)	21591	23000
Btu per ft^3 gas at 60°F and 30 in mercury	2516	1050 ±
Btu per gallon of gas at 60°F	91547	
Cubic feet of gas (60°F, 30 in Hg)/gal of liquid	36.39	59.0
Cubic feet of gas (60°F, 30 in Hg)/lb of liquid	8.58	23.6
Cubic feet of air required to burn 1 ft^3 gas	23.87	9.53
Flame temperature, °F	3595	3416
Octane number (isooctane = 100)	125	
Flammability limit in air, upper	9.50	15.0
Flammability limit in air, lower	2.87	5.0

Table 7-2 Physical and Combustion Properties of Commonly Available Fuel Gases

No.	Gas	Heating value Btu/ft³ Gross	Heating value Btu/ft³ Net	Heating value Btu/lb Gross	Heating value Btu/lb Net	Heat release, Btu Per ft³ air	Heat release, Btu Per lb air	Specific gravity	Density, lb per ft³	Specific volume ft³/lb
1	Acetylene	1,498	1,447	21,569	20,837	125.8	1677	0.91	0.07	14.4
2	Blast furnace gas	92	92	1,178	1,178	135.3	1804	1.02	0.078	12.8
3	Butane	3,225	2,977	21,640	19,976	105.8	1411	1.95	0.149	6.71
4	Butylene (hutene)	3,077	2,876	20,780	19,420	107.6	1435	1.94	0.148	6.74
5	Carbon monoxide	323	323	4,368	4,368	135.7	1809	0.97	0.074	13.5
6	Carburetted water gas	550	508	11,440	10,566	119.6	1595	0.63	0.048	20.8
7	Coke oven gas	574	514	17,048	15,266	115.0	1533	0.44	0.034	29.7
8	Digester (sewage) gas	690	621	11,316	10,184	107.6	1407	0.80	0.062	16.3
9	Ethane	1,783	1,630	22,198	20,295	106.9	1425	1.05	0.080	12.5
10	Hydrogen	325	275	61,084	51,628	136.6	1821	0.07	0.0054	186.9
11	Methane	1,011	910	23,811	21,433	106.1	1415	0.55	0.042	23.8
12	Natural (Birmingham, AL)	1,002	904	21,844	19,707	106.5	1420	0.60	0.046	21.8
13	Natural (Pittsburgh, PA)	1,129	1,021	24,161	21,849	106.7	1423	0.61	0.047	21.4
14	Natural (Los Angeles, CA)	1,073	971	20,065	18,158	106.8	1424	0.70	0.054	18.7
15	Natural (Kansas City, MO)	974	879	20,259	18,283	106.7	1423	0.63	0.048	20.8
16	Natural (Groningen, Netherlands)	941	849	19,599	17,678	111.9	1492	0.64	0.048	20.7
17	Natural (Midlands Grid, U.K.)	1,035	902	22,500	19,609	105.6	1408	0.61.	0.046	21.8
18	Producer (Wellman-Galusha)	167	156	2,650	2,476	128.5	1713	0.84	0.065	15.4
19	Propane	2,572	2,365	21,500	19,770	108	1440	1.52	0.116	8.61
20	Propylene (Propane)	2,332	2,181	20,990	19,030	108.8	1451	1.45	0.111	9.02
21	Sasol (South Africa)	500	443	14,550	13,016	116.3	1551	0.42	0.032	31.3
22	Water gas (bituminous)	261	239	4,881	4,469	129.9	1732	0.71	0.054	18.7

3. Light or Heavy Process Service. This service is provided for process or other industrial use. The quantity of gas must meet utility company requirements.
4. Commercial or Industrial Service. This type of service is used for heating and cooling loads for this class of building.
5. Transportation Gas Service. This is used when the gas is purchased directly from the producer (or wellhead) and not directly from the utility company. The gas actually is carried in the utility company mains, and there is a charge for this use.

There are many gases used as a fuel gas. Where easily and cheaply available, two major fuel gases, NG and LPG, are preferred. Other gases are used because of availability. For properties of gases commonly available throughout the world, refer to Table 7-2.

Approvals

The American Gas Association, the National Fire Protection Association, and the American National Standards Association do not approve, inspect, or certify installations, procedures, equipment, or materials. The acceptability of all such items must comply with the authority having jurisdiction (AHJ).

System Operating Pressure

The gas pressure in the piping system downstream of the meter is usually 5 to 14 in. (125 to 356 mm) of water column (wc). Under these conditions, good engineering practice limits the pressure losses in the piping to a range between 0.2 to 0.5 in. (5 to 13 mm) wc. However, local codes may dictate a more stringent pressure drop maximum; these should be consulted before the system is sized. Most appliances require approximately 3.5 in. (89 mm) wc. The designer must be aware that large appliances, such as boilers, may require high gas pressures to operate properly. Where appliances require high pressures or where long distribution lines are involved, it may be necessary to use higher pressures at the meter outlet to satisfy the appliance requirements or provide for greater pressure losses in the piping system, thereby allowing economy of pipe size. Systems often are designed with meter outlet pressures of 3 to 5 psi (20.7 to 34.5 kPa) and with pressure regulators to reduce the pressure for appliances as required. A majority of times, the utility company will reduce the incoming pressure to a figure that is requested by the design engineer at the start of the project.

The maximum allowable operating pressure for NG piping systems inside a building is based on NFPA

54: *National Fuel Gas Code,* except when approved by the AHJ or when insurance carriers have more limiting requirements. NG systems are not permitted to have more than 5 psig (34.5 kPa) unless all the following are met:

1. The AHJ will allow a higher pressure.
2. The distribution piping is welded.
3. Pipe runs are enclosed for protection and located in a ventilated place that will not allow gas to accumulate.
4. The pipe is installed in areas only used for industrial processes, research, warehouse, or mechanical equipment rooms.

The maximum LPG pressure of 20 psig (138 kPa) is allowed, provided the building is used only for research or industrial purposes and is constructed in accordance with NFPA 58: *Liquefied Petroleum Gas Code,* Chapter 7.

Efficiency

The difference between the input and the output of any equipment is the heat lost in the burner, the heat exchanger, and the flue gases. Water heating and space heating equipment are usually 75 to 85% efficient, and ratings are given for both input and output. Cooking and laundry equipment also is usually 75 to 85% efficient, and ratings are given for the input that take into consideration the internal losses. When only the output required for the appliance is known, it will be necessary to increase the volume of gas to account for the loss of efficiency.

Codes and Standards

The local code in the area where the project is located is the primary code to be used. Often, this code refers to NFPA 54. Other codes and standards that may be applicable are ANSI/NFPA 30: *Flammable and Combustible Liquids Code,* ANSI/NFPA 58, ANSI Z83.3: *Gas Utilization Equipment for Large Boilers,* ANSI/UL 144: *Pressure Regulating Valves for LPG*, NFPA 88A: *Standard for Parking Structures,* and American Gas Association standards. Insurance carriers such as Industrial Risk Insurers and FM Global also have standards, which may be in many respects stricter than the applicable code.

Gas Meters

Meters are required in all services. To achieve greatest accuracy, the pressure into the meter must be regulated. Requirements for various utilities differ regarding the placement and arrangement of the meter assembly. The assembly could consist of filters, valves, regulators, and relief valves. It could be placed indoors, on a slab outdoors aboveground, or underground in an outdoor pit. The plumbing contractor is usually responsible for a pit, if required, a slab, telephone outlet, and electrical outlet adjacent to the meter. The utility company almost always supplies the meter. The utility company usually runs the service on the consumer's site up to the meter, terminating with a shutoff valve.

Pressure Regulating Valves

A pressure regulator is a device for reducing a variable high inlet pressure to a constant lower outlet pressure. The line regulator is used to reduce supply line pressure from generally 25–50 psig (170–345 kPa) to an intermediate pressure of about 3–5 psig (21–35 kPa). If used, it is usually placed outside before the meter and selected by the utility company. If installed inside the building, a relief vent will be necessary. An intermediate regulator is used to further reduce the pressure from 3–5 psig (21–35 kPa) to one that can be used by terminal equipment, which is approximately 7 in. (178 mm) wc. Different types of valves may require a relief vent. An appliance regulator connects the supply to the terminal equipment and may be provided by the equipment manufacturer, usually on gas trains where equipment has one. Types of appliance regulators are a zero governer, a backpressure regulator, and a differential regulator.

When regulators are installed inside a building and require a vent, these vents often must be routed to the atmosphere. The vents from individual regulators may not be combined. When bottled gas is used, the tank can have as much as 150 psi (1034.6 kPa) pressure to be reduced to the burner design pressure of 11 in. (279.4 mm) wc. The regulator normally is located at the tank for this pressure reduction.

Pressure Control Valves

An **excess flow valve** is a device that shuts off the flow of gas if there is a much larger flow through the pipe or service than designed for. In some parts of the country, particularly in areas where earthquakes may occur, excessive flow valves are necessary to guard against the possibility of a break during such an event. In other cases, where danger exists for equipment such as large boilers, installation should be considered.

A **low pressure cutoff** shall be installed between the meter and appliance where the operation of a device, such as a gas compressor, appliance, or a boiler, could produce a vacuum or dangerous vacuum condition in the piping system.

Appliance Control Valves

An **appliance shutoff valve** shall be installed at all gas appliances prior to any flexible hose used to connect the appliance to the building gas supply.

Interlocks

An automatic interlock, connected to the automatic fire extinguishing system, is required to shut off the

Table 7-3 Approximate Gas Demand for Common Appliances[a]

Appliance	Input, Btu/h	(mJ/h)
Commercial kitchen equipment		
Small broiler	30,000	(31.7)
Large broiler	60,000	(63.3)
Combination broiler and roaster	66,000	(69.6)
Coffee maker, 3-burner	18,000	(19)
Coffee maker, 4-burner	24,000	(25.3)
Deep fat fryer, 45 lb (20.4 kg) of fat	50,000	(52.8)
Deep fat fryer, 75 lb (34.1 kg) of fat	75,000	(79.1)
Doughnut fryer, 200 lb (90.8 kg) of fat	72,000	(76)
2-deck baking and roasting oven	100,000	(105.5)
3-deck baking oven	96,000	(101.3)
Revolving oven, 4 or 5 trays	210,000	(221.6)
Range with hot top and oven	90,000	(95)
Range with hot top	45,000	(47.5)
Range with fry top and oven	100,000	(105.5)
Range with fry top	50,000	(52.8)
Coffee urn, single, 5-gal (18.9 L)	28,000	(29.5)
Coffee urn, twin, 10-gal. (37.9 L)	56,000	(59.1)
Coffee urn, twin, 15-gal (56.8 L)	84,000	(88.6)
Stackable convection oven, per section of oven	60,000	(63.3)
Residential equipment		
Clothes dryer (Type I)	35,000	(36.9)
Range	65,000	(68.6)
Stove-top burners (each)	40,000	(42.2)
Oven	25,000	(26.4)
30-gal (113.6-L) water heater	30,000	(31.7)
40 to 50-gal (151.4 to 189.3-L) water heater	50,000	(52.8)
Log lighter	25,000	(26.4)
Barbecue	50,000	(52.8)
Miscellaneous equipment		
Commercial log lighter	50,000	(52.8)
Bunsen burner	5,000	(5.3)
Gas engine, per horsepower (745.7 W)	10,000	(10.6)
Steam boiler, per horsepower (745.7 W)	50,000	(52.8)
Commercial clothes dryer (Type 2)	See manufacturer's data.	

[a] The values given in this table should be used only when the manufacturer's data are not available.

gas supply to all equipment in a kitchen when there is a discharge in the event of a fire. In earthquake-prone areas, an interlock is required to shut off the supply of gas if the disturbance may rupture the pipe or separate pipe from any equipment.

Appliances

Appliances are listed by types and categories that shall be used in the design of vents. These vents shall be sized and located in accordance with NFPA 54.

Most manufacturers of gas appliances rate their equipment by the gas consumption values that are used to determine the maximum gas flow rate in the piping. Table 7-3 shows the approximate gas consumption for some common appliances. To find the flow rate of gas required, use the consumption from the manufacturer and divide by 1,000. If the equipment is a water heater, multiply the figure by the weight of water (8.48 lbs).

The products of combustion from an appliance must be safely exhausted to the outside. This is accomplished with a gas vent system in most cases. Where an appliance has a very low rate of gas consumption (e.g., Bunsen burner or countertop coffee maker) or where an appliance has an exhaust system associated with the appliance (e.g., gas clothes dryer or range) and the room size and ventilation are adequate, a separate gas vent system may not be required. Current practice usually dictates the use of factory-fabricated and listed vents for small to medium-size appliances. Large appliances and equipment may require specially designed venting or exhaust systems. It is not the plumbing engineer's responsibility to design and specify gas vents. This is done by either the HVAC department or the manufacturer.

Where the ratings of the appliances are not known, they shall comply with the typical demand of appliances by types as indicated in NFPA 54.

Allowable Gas Pressure

The gas outlet pressure in the piping system downstream of the meter that is supplied by the utility is mostly in the range of 4–14 in. (102–356 mm) wc, with approximately 7 in. (178 mm) wc being a common figure. Good engineering practice limits the pressure losses in the piping to approximately 0.2–0.5 in. (5–12.7 mm) wc depending on the outlet pressure, with 0.3 in. (7.6 mm) wc being the most commonly used number. However, local codes may dictate a more stringent pressure drop maximum. The AHJ should be consulted before the system is sized. Most appliances require approximately 3.5 in. (89 mm) wc; however, the designer must be aware that large appliances, such as boilers, may require higher gas pressures to operate properly. Where appliances require higher pressures or where long distribution lines are involved, it may be necessary to use higher pressures at the meter outlet to satisfy the appliance requirements or provide for greater pressure losses in the piping system. If greater pressure at the meter outlet can be attained, a greater pressure drop can be allowed in the piping system. If the greater pressure drop design can be used, a more economical piping system is possible.

Laboratory Usage

NG is the primary gas used in laboratories at lab benches for Bunsen burners. Where NG is not available, propane gas is used, but this generally requires the manufacturer to be advised due to the Bunsen burner requiring a smaller orifice. Typical Bunsen

burners consume either 5 cfh (0.15 m^3/h) (small burners) or 10 cfh (0.30 m^3/h) (large burners).The maximum pressure at the burner should not exceed 14 in. (355.6 mm) wc. 10 cfh (0.30 m^3/h) is more commonly used.

Some local codes require laboratory gas systems, especially those in schools or universities, to be supplied with emergency gas shutoff valves on the supply to each laboratory. The valve normally should be closed and opened only when the gas is being used. It should be located inside the laboratory and used in conjunction with shutoff valves at the benches or equipment, which may be required by other codes. The designer should ensure locations meet local code requirements.

The following diversities, found in Table 7-4, shall be applied where flow will be from Bunsen burners:

Table 7-4 Laboratory Diversity Factors

Number of Outlets	Laboratory Diversity Factor	Flow cfh (m^3/h)
1–8	100	9 (0.26)
9–16	90	15 (0.43)
17–29	80	24 (0.68)
30–79	60	48 (1.36)
80–162	50	82 (2.32)
163–325	45	107 (3.03)
326–742	40	131 (3.71)
743–1,570	30	260 (7.36)
1,571–2,900	25	472 (13.37)
2,901 and up	20	726 (20.56)

Branch piping that serves one or two laboratory classrooms should be sized for 100% usage regardless of the number of outlets. Use factors should be modified to suit special conditions and must be used with judgment after consultation with the owner and/or user.

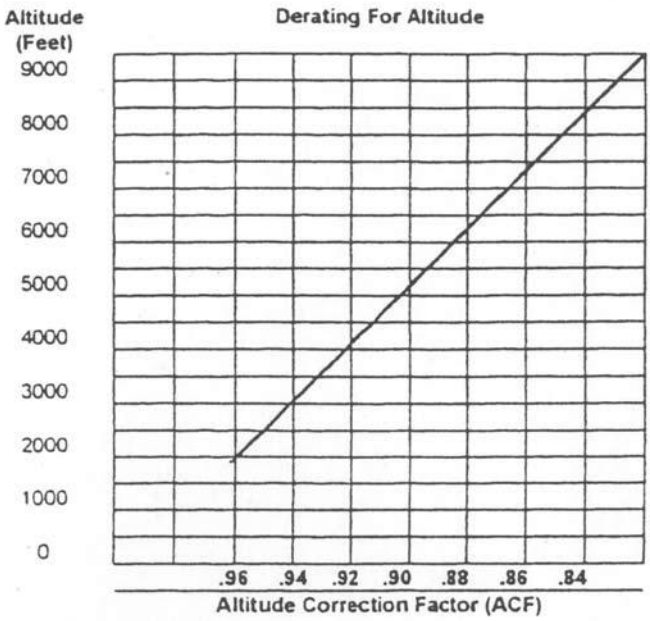
Gas Regulator Relief Vents

Guidelines for the use of relief vents from pressure regulators, also referred to as gas-train vents, can be found in the latest editions of NFPA 54 and *FM Global Loss Prevention Data Sheet 6-4: Oil- and Gas-Fired Single-Burner Boilers,* as well as in other publications of industry standards, such as those issued by Industrial Risk Insurers and the American Gas Association.

It should be noted that when the pressure regulators discharge, large amounts of fuel gas may be released. It is not uncommon for a local fire department to be summoned to investigate an odor of gas caused by a gas-train vent discharge. Every attempt should be made to locate the terminal point of the vents above the line of the roof and away from doors, windows, and fresh-air intakes. It also should be located on a side of the building that is not protected from the wind. Refer to NFPA 54 and local codes for vent locations.

Altitude Derating Factor

NG has a reduced density at a higher altitude that must be allowed for when the project location is more than 2,000 feet above sea level. This altitude correction factor shall be multiplied by the gas input at sea level to determine the correct input at full load capacity. Refer to Figure 7-1 to determining the derating factor for NG.



The Altitude Correction Factor (ACF) should be multiplied by the gas input at sea level to determine the corrected input. Sizing of the equipment is then performed utilizing this corrected input multiplied by the full load efficency.

Figure 7-1 Altitude Correction Factor

Piping System Materials

The following piping materials are the most often used for both NG and propane.

Pipe Steel (galvanized, plastic-wrapped, or black), brass, and copper. Black steel is the most commonly used pipe. Cast-iron pipe shall not be used.

Tubing Semi-rigid copper type K or L.

Plastic pipe and tubing (polyethylene) Plastic pipe may be used outside and underground only.

Flexible hose

Corrugated stainless steel tubing

Indoor Indoor gas hose connectors may be used with laboratory or shop and other equipment that requires mobility during operation or installation, if listed for this application. A shutoff valve must be installed where the connector is attached to the building pip-

ing. The connector must be of minimum length but shall not exceed 6 ft (1.8 m). The connector must not be concealed and must not extend from one room to another nor pass through wall partitions, ceilings, or floors.

Outdoor Outdoor gas hose connectors may be used to connect portable outdoor gas-fired appliances, if listed for this application. A shutoff valve or a listed quick-disconnect device must be installed where the connector is attached to the supply piping and in such a manner as to prevent the accumulation of water or foreign matter. This connection must be made only in the outdoor area where the appliance is to be used.

Fittings and joints for low-pressure piping, 3 psi (21 kPa) or less Steel pipe may be threaded, flanged, or welded. Cast or malleable iron threaded fittings are the most commonly used. Tubing may be soldered or brazed using wrought copper or copper alloy fittings and no flux. Brazing alloy must not contain phosphorous.

Fittings and joints for high pressure piping greater than 3 psi (21 kPa) Steel pipe and fittings 4 in. (100 mm) and larger shall be welded.

Tubing joints Tubing usually is needed for the flexible connections to equipment. For pressures normally encountered in the utilization of NG and LPG, the most often used joints are screwed.

Design Considerations

The fact that LPG vapors are heavier than air has a practical bearing on several items. For one thing, LPG systems are located in such a manner that the hazard of escaping gas is kept at a minimum.

Since the heavier-than-air gas tends to settle in low places, the vent termination of relief valves must be located at a safe distance from openings into buildings that are below the level of such valves. With many gas systems, both the gas pressure regulator and the fuel containers are installed adjacent to the building they serve. This distance must be a least 3 ft (0.91 m) measured horizontally. However, the required clearances vary according to the tank size and the adjacent activities. The designer should refer to the local code and NFPA 54 for these clearances.

When LPG piping is installed in crawl spaces or in pipe tunnels, the engineer may consider a sniffer system, which automatically shuts down the gas supply, sounds an alarm, and activates an exhaust system to purge the escaping gas from the area upon detection of gas in the space due to a breach in the piping system.

GAS BOOSTERS

A gas booster is a pump that increases the pressure of gas. It is used when there is insufficient pressure available from the gas utility or LPG storage device to supply the necessary pressure to the equipment at hand. It is important to note that the gas service must be capable of the volumetric flow rate required at the boosted level. A booster cannot overcome an inadequate volumetric supply.

Gas boosters for natural or liquefied petroleum gas Boosters for natural or utility-supplied gas are hermetically sealed and are equipped to deliver a volumetric flow rate (user defined but within the booster's rated capacity) to an elevated pressure beyond the supply pressure. The outlet pressure usually remains at a constant differential above the supply pressure within a reasonable range. The discharge pressure is the sum of the incoming gas pressure and the booster-added pressure at the chosen flow rate. The incoming gas pressure usually has an upper safety limit as stipulated by the hermetic gas booster manufacturer. Therefore, in the engineering literature from the manufacturer, the engineer may find cautions or warnings about the upper limits of incoming pressure, usually about 5 psi (34.5 kPa).

Materials of construction

Housing and rotor Boosters used for fuel gas must be Underwriters Laboratories (UL) listed for the specific duty intended and shall be hermetically sealed. Casings on standard boosters usually are constructed of carbon steel, depending on the equipment supplier. Booster casings are also available in stainless steel and aluminum. Inlet and outlet connections are threaded or flanged, depending on the pipe size connection and the manufacturer selected, and the casings are constructed leak tight. Drive impellers are contained within the casing and always manufactured of a spark-resistant material such as aluminum.

Discharge-type check valves are furnished on the booster inlet and on the booster bypass. It is important that these valves are listed and approved for use on the gas service at hand. The fan, control panel, valves, piping, and interelectrical connections can be specified as a skid-mounted package at the discretion of the designer. This allows for UL listing of the entire package rather than of individual components.

Electrical components Motor housings for gas booster systems are designed for explosion-proof (XP) construction and are rated per National Electrical Manufacturers Association (NEMA) Class 1, Division 1, Group D classification with thermal overload protection. A factory UL-listed junction box with a protected, sealed inlet is necessary for wiring connections.

Other electrical ancillary equipment Boosters are equipped with low pressure switches that monitor the incoming gas pressure. The switch is designed to shut down the booster should the utility-supplied

pressure fall below a preset limit. The set point is usually about 3 in. (76 mm) wc, but the designer should verify the limit with the local gas provider. The switch must be UL listed for use with the gas service at hand. When the switch opens, it de-energizes the motor control circuit and simultaneously outputs both audible and visual signals, which require manual resetting. The booster can be equipped with an optional high/low gas pressure switch. This feature equips the booster to run only when adequate supply pressure is available. The switch shuts the booster down at the maximum discharge setpoint pressure at the output line pressure.

Minimum gas flow Gas boosters normally require a minimum gas flow that serves as an internal cooling medium. For example, a booster sized at a flow rate of 10,000 cfh (283.2 m^3/h) has an inherent minimum turndown based on the minimum flow required to cool the unit. This rate, in the example, may be 2,000 cfh (566.3 m^3/h) (see Figure 7-2). Should the unit be required to run below this turndown rate, additional supplemental cooling systems must be incorporated into the booster design. The heat exchangers normally rated for this use are water cooled.

Intrinsic safety Electrical connections are made through a sealed, explosion-proof conduit to the XP junction box on the booster unit. Control panels are rated NEMA 4 for outdoor use and NEMA 12 for indoor use unless the booster system is to be located in a hazardous area, which may have additional requirements. The panel, as an assembly, must display a UL label specific for its intended use.

Gas laws for boosters

Pressure/volume relationships The gas laws apply to the relationship of the incoming gas supply and the boosted service. The standard law for compressed gas relationships is as follows:

Equation 7-4

$$PV = RT$$

where

P = Pressure, psi or in. wc (kPa or mm wc)
V = Volume, cfh (m^3/h)
R = Constant for the gas/air mixture used
T = Temperature, °F (°C)

Usually the temperature of the gas remains relatively constant and can be ignored in the relationship. Therefore, the pressure times the volume is proportional to a constant R. Further, the pressure/volume ratios before and after the booster are proportional, that is:

Equation 7-5

$$P_1V_1 = P_2V_2$$

where

P_1 = Pressure at a point prior to the booster
P_2 = Pressure at a point after the booster

For almost every case, the volumetric rating of gas-fired equipment is in Btu/h, which can readily be converted to cfh. In the booster application, sizing criteria should be approached from a standard cfh (scfh) not an actual cfh (acfh) rating.

Gas temperatures and density As stated, the temperature of the gas is usually constant. However, in the event that the gas is to be heated or cooled, the previously mentioned gas laws are affected by

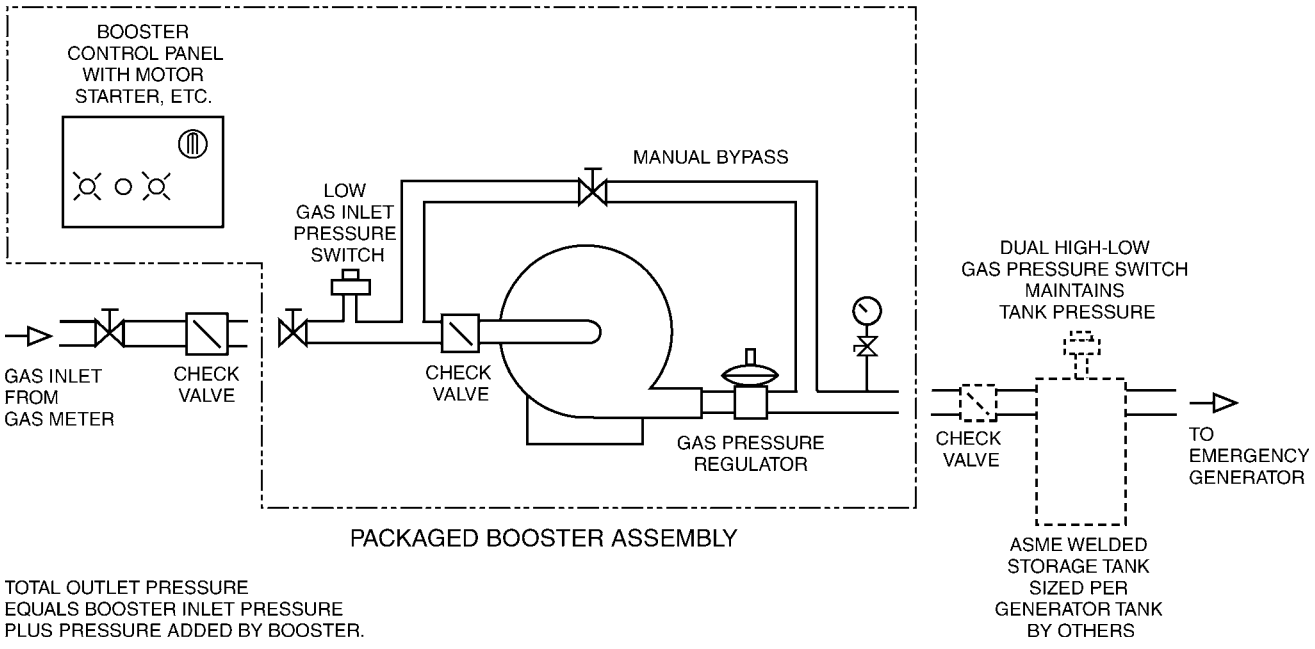


Figure 7-2 Variations of a Basic Simplex Booster System: (A) Standby Generator Application with Accumulator Tank Having a Limitation on Maximum Pressure

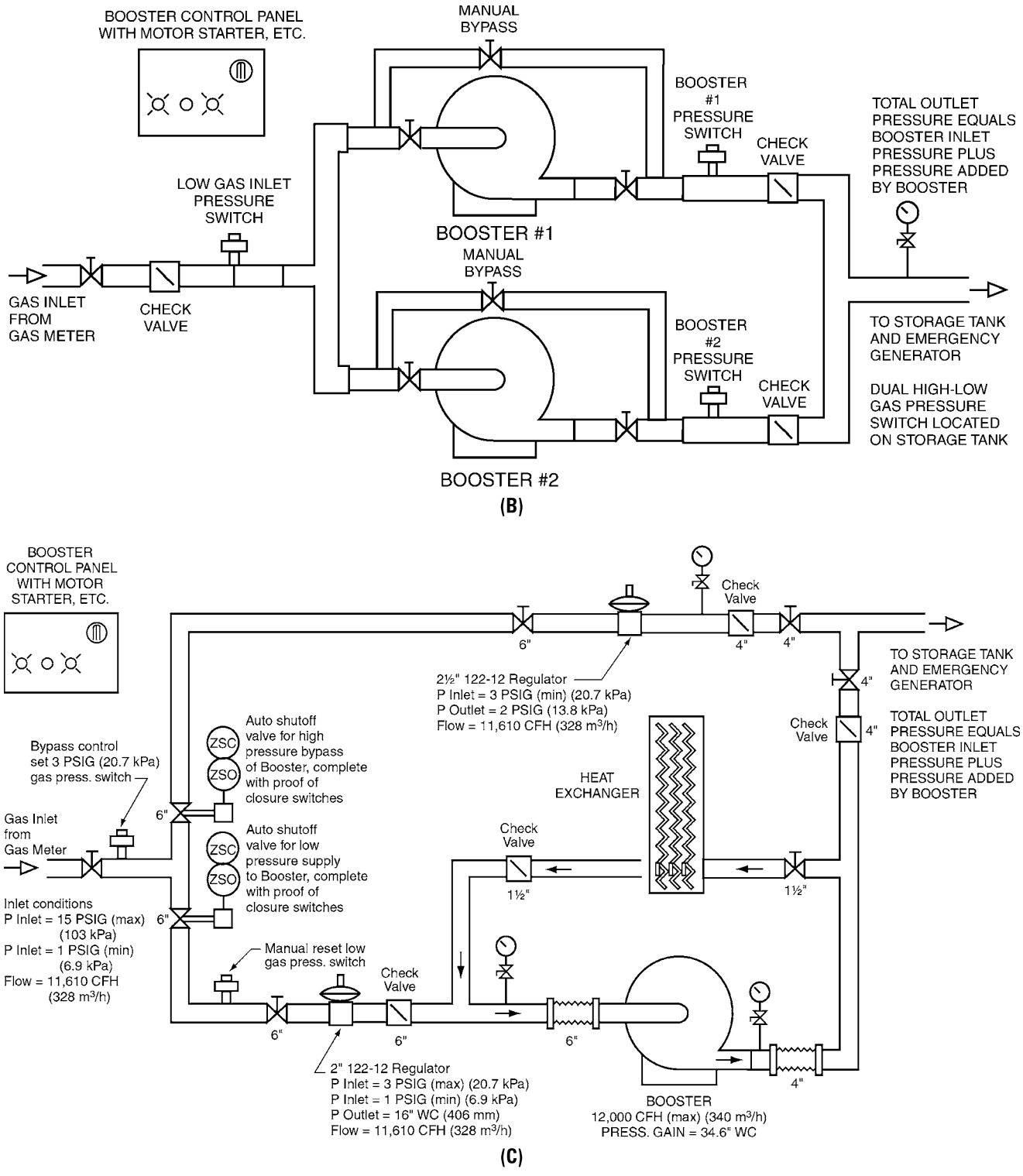


Figure 7-2 Variations of a Basic Simplex Booster System: (B) Dual Booster System for Critical Systems Like Those in Hospitals, (C) Heat Exchanger Loop Example—Required for High Flow Range with Low Minimum Flow.

temperature. Gas density changes affect the constant but usually do not affect the relationship since the same mixture is boosted across the fan.

High-rise building issues Consideration must be given to the rise effect in available gas pressure as gas rises in the piping through a high-rise building. Therefore, if the gas system supplies a kitchen on the first level and a boiler in the penthouse of a 50-story building, it may be necessary to boost the supply to the kitchen but not to the boiler. The gas rises to the penthouse through the piping system because of the density differential; its rising is dependent on this stack effect, which is directly related to the piping system layout.

Design considerations Although a gas booster is a basic mechanical piece of equipment, there are significant design considerations that should be taken into account when applying it:

1. *Indoor vs. outdoor location.* This may be driven by local code or the end user. An indoor location involves a lower initial cost and lower costs for long-term maintenance. Outdoor locations are inherently safer.
2. *Access.* The location should be accessible for installation, inspection, and maintenance. The unit should not be so accessible as to create a security issue. Keep the equipment out of traffic patterns and protect it from heavy equipment.
3. *Minimum and maximum flow rates.* Boosters usually have a minimum flow rate that must be maintained so that the booster's motor is kept cool. When specifying a booster, always indicate the minimum flow required in addition to other design parameters. Cooling devices and bypass loops may be required if the application requires a turndown in flow (lowest flow expected) that is higher than the booster's minimum flow.
4. *Controls and interlocking.* Determine how the application should be controlled and what demands the application will put on the system. The control philosophy, method of electrically interlocking the system to the gas-fired equipment, and physical hardware will vary based on the application.

For some specific examples, see the schematics in Figure 7-2, which shows variations of a basic simplex booster system for an emergency generator. In Figure 7-2(A), the regulator controls maximum delivered pressure, and a combination high/low pressure switch on the tank cycles the booster to ensure emergency startup pressure within a design deadband for the generator. Oversized piping, in this case, can be substituted for the tank itself. Provide adequate volume so that the generator can fire and deliver standby power back to the booster system to continue operation during main power interrupt. In Figure 7-2(B), a dual booster system, the booster is controlled in a lead/lag control scenario. Should one booster fail, the second is started automatically. Unit operation is rotated automatically via the control panel to share the duty and to keep both units in operating order. The booster with a heat exchanger loop shown in Figure 7-2(C) has a potential of up to 15 psi (103.4 kPa) and down to 28 in. (711.2 mm) wc supply pressure. The system automatically diverts gas around the booster if there is sufficient supply pressure. While these illustrations obviously do not cover all the potential applications, they are provided to give the system designer some guidance.

Sizing a gas booster A gas booster's main purpose is to elevate the pressure of a volume of gas to overcome a supply pressure deficiency. When sizing a booster, an engineer needs to understand the following terms and issues:

Maximum design flow (Q_{max}) The sum of all gas loads at the maximum capacity rating (MCR) for all equipment downstream of the booster that could possibly be required to operate simultaneously.

Minimum design flow (Q_{min}) The minimum volumetric flow that could exist while the booster is operating. This flow is not always associated with the smallest Btu/h-rated piece of equipment. For example, when evaluating a 75,000,000 Btu/h (22 MW) boiler with a 10:1 turndown ratio in comparison to a 1.0 Btu/h (0.3 W) hot water heater that is on/off in operation, the larger Btu/h (W)-rated boiler has the smaller flow of 0.75 Btu/h (0.2 W) at its minimum firing rate.

Turndown (TD) ratio The ratio of the MCR input to the equipment's minimum, or low-fire, input. For example, a 100 Btu/h (29.3 W) burner that can fire at a minimum rate of 20 Btu/h (5.9 W) has a TD ratio of 5:1.

Pressure droop and peak consumption Pressure droop is the inability of a supply system to maintain a steady or consistent inlet pressure as an increase in volumetric flow is demanded. Often, in areas where boosters are applied, the supply pressure in off-peak months when gas is not in such demand can be sufficient to run a system. As the local demand for gas increases, the supply system no longer can provide the gas efficiently and the pressure falls off or droops. It is the booster's function to overcome the droop (or excessive pressure drop) of the supply system during such times.

Flow rate relationships Do your flows for separate pieces of equipment relate to each other? In other words, do the three boilers always operate in unison while another process machine always operates off peak and alone? Relationships among the equipment can significantly affect both maximum and minimum flow rates.

Test block A factor of safety added to design criteria. Typically, a minimum of 5% added volume and 10% added static pressure should be applied to the design criteria. When specifying the equipment, ensure that you note both the design and test block conditions. This makes other people working on the system aware and ensures that safety factors are not applied to criteria that already include safety factors.

Minimum inlet pressure ($P_{I\text{-}min}$) What is the minimum supply pressure in in. (mm) wc gauge? This must be evaluated during peak flow demands both for the equipment and for the local area. Always evaluate during flow, not static, conditions. It is also important to know how high the inlet pressure is expected to rise during off-peak periods. A booster is typically rated to about 5 psi (34.5 kPa). It may be possible to exceed this rating during off-peak demand periods; therefore, a bypass system or other means of protection is required. Often this pressure can be specified by the local gas company as the minimum guaranteed gas pressure from their supply system. Also, the maximum inlet pressure ($P_{I\text{-}max}$) must be determined.

Maximum outlet pressure ($P_{O\text{-}max}$) List all maximum and required supply pressures for the various pieces of equipment being supplied gas from the booster. Determine the differential between the highest expected gas pressure supply to the booster (e.g., 8 in. [203.2 mm] wc) and the lowest maximum supply pressure rating to a piece of equipment (e.g., 18 in. [457.2 mm] wc). The booster's pressure gain should not exceed this differential (for the above example, 18 – 8 = 10 in. [457.2 – 203.2 = 254 mm] wc) unless other means of protecting the downstream equipment are provided.

Outlet pressure protection There are several ways to protect equipment downstream of a booster should it be necessary due to potential over-pressurization during off-peak periods. If all the equipment being serviced operates at nominally the same pressure, install a regulator on the inlet or outlet of the booster to maintain a controlled maximum outlet pressure. If the equipment being serviced operates at various inlet pressures, it may be best to supply a regulator for each piece of equipment. Most often, packaged equipment is supplied with its own regulator. If this is the case, review the equipment regulator's maximum inlet pressure.

To perform an evaluation of system requirements, do the following:

1. Establish design Q_{min} and Q_{max} per the previously discussed definitions while evaluating TD requirements.
2. Establish $P_{I\text{-}min}$ and $P_{I\text{-}max}$ per the previously discussed definitions.
3. Define maximum inlet pressure requirements to equipment ($P_{I\text{-}eq}$).
4. Define piping pressure losses (P_{PL}) from the gas booster location to each piece of equipment.
5. Design flow rate (Q_D) = Q_{min} to Q_{max}, cfh (m^3/h).
6. Design pressure boost (ΔP) = $P_{I\text{-}eq} + P_{PL} - P_{I\text{-}min}$.
7. Test block flow (Q_{TB}) = ($1.05 \times Q_{min}$) to ($1.05 \times Q_{max}$).
8. Test block pressure boost: $1.10 \times \Delta P = P_{I\text{-}eq} + P_{PL} - P_{I\text{-}min}$.

where

P_{PL} = Pressure losses, psi (kPa)

Interior NG Pipe Sizing

To accurately size all elements of the piping system, calculate or obtain the following information:

1. The information needed by both the utility company and the engineer.
2. The gas pressure available after the meter assembly.
3. The allowable friction loss through the piping system.
4. A piping layout that shows all the connected equipment, allowing determination of the measured length of piping to the furthest connection. This, in turn, gives the equivalent length of piping.
5. The maximum probable demand.
6. A pipe sizing method acceptable to the AHJ or local code.

The information needed by both the utility company and the engineer The following are intended to be complete lists of items. Not all items will be necessary for all projects.

The following criteria and information shall be obtained in writing from the public utility company and given to the engineer:

1. BTU content of the gas provided.
2. Minimum pressure of the gas at the outlet of the meter.
3. Extent of the installation work done by the utility company and the point of connection to the meter by the facility construction contractor.
4. The location of the utility supply main and the proposed run of pipe on the site by the utility company. This shall be in the form of a marked-up plan or description of the work. Include the expected date of installation if no gas is available.
5. Acceptable location of the meter and/or regulator assembly or a request to locate the meter at a particular location.

Table 7-5 Equivalent Lengths for Various Valve and Fitting Sizes

Fitting	Pipe Size, in. (mm)									
	¾ (19.1)	1 (25.4)	1½ (38.1)	2 (50.8)	2½ (63.5)	3 (76.2)	4 (101.6)	5 (127)	6 (152.4)	8 (203.2)
	Equivalent Lengths, ft (m)									
90° elbow	1.00 (0.3)	2.00 (0.61)	2.50 (0.76)	3.00 (0.91)	4.00 (1.22)	5.50 (1.68)	6.50 (1.98)	9.00 (2.74)	12.0 (3.66)	15.0 (4.57)
Tee (run)	0.50 (0.15)	0.75 (0.23)	1.00 (0.3)	1.50 (0.46)	2.00 (0.61)	3.00 (0.91)	3.50 (1.07)	4.50 (1.37)	6.00 (1.83)	7.00 (2.13)
Tee (branch)	2.50 (0.76)	3.50 (1.07)	4.50 (1.37)	5.00 (1.52)	6.00 (1.83)	11.0 (3.35)	13.0 (3.96)	18.0 (5.49)	24.0 (7.32)	30.0 (9.14)
Gas cock (approx.)	4.00 (1.22)	5.00 (1.52)	7.50 (2.29)	9.00 (2.74)	12.0 (3.66)	17.0 (5.18)	20.0 (6.1)	28.0 (8.53)	37.0 (11.28)	46.0 (14.02)

Note: The pressure drop through valves should be taken from manufacturers' published data rather than using the equivalent lengths, since the various patterns of gas cocks can vary greatly.

6. Any work required by the owner to allow the meter assembly to be installed (such as a meter pit or slab on grade).
7. Types of gas service available and the cost of each.

For the utility company to provide this data, the following information must be provided to them:

1. The total connected load. The utility will use its own diversity factor to calculate the size of the service line. For the design of the project's interior piping, the design engineer will select the diversity factor involved.
2. Minimum pressure requirements for the most demanding device.
3. Site plan indicating the location of the proposed building on the site and the specific area of the building where the proposed NG service will enter the building.
4. Preferred location of the meter/regulator assembly
5. Expected date of the start of construction.
6. Different requirements for pressure.
7. Two site plans, one to be marked up and returned to the engineer.
8. If any equipment has pilot lights.
9. The hours of operation for the different types of equipment.

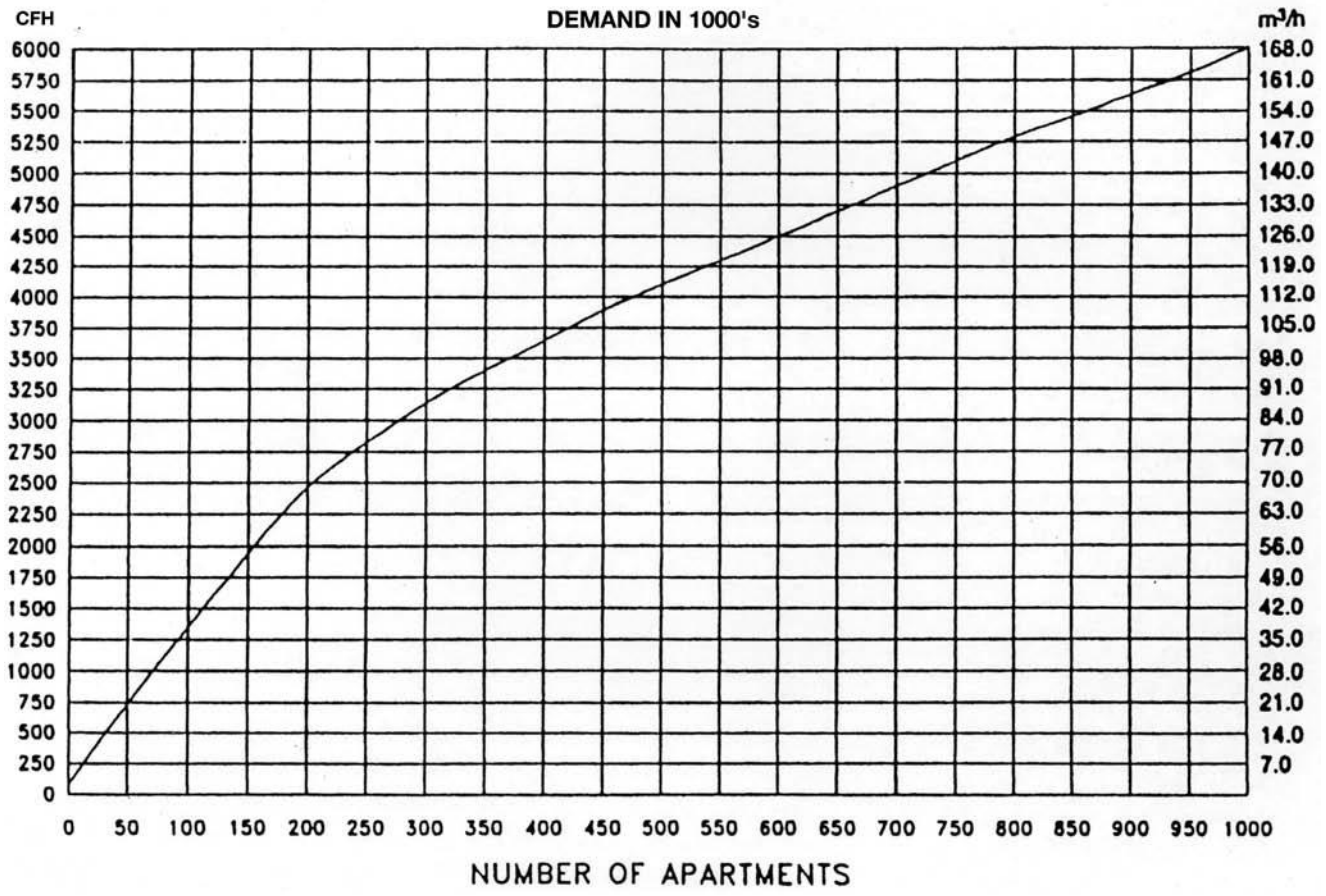


Figure 7-3 Gas Demand for Multiple-unit Dwellings with More Than 50 Apartments

10. Future equipment and capacities, if any, known at this time.

The pressure available after the meter shall be established in writing from the utility at the start of the project. If boilers or other major equipment is being used, the pressure requirements and the flow rate for that equipment must be provided to the utility.

The allowable friction loss through the entire piping system shall be established by the engineer. This value depends on the pressure provided by the utility company. The most often selected value under average conditions is 0.3 in. (7.6 mm) wc, with a range of 0.2–0.5 in. (5–13 mm) wc. The residential appliances (range and dryer) require a pressure of 3.5 in. (89 mm) wc. If the pressure from the utility company is around 7 in. (178 mm) wc, a higher friction loss allowance could be used for economy in pipe sizing. If the pressure from the utility company is 4 in. (102 mm) wc, a 0.2 in. (5 mm) wc is recommended.

A piping layout and the equivalent length of piping A piping layout is necessary to show the run of the whole piping system and all the connected appliances and equipment. The equivalent length of piping is calculated by measuring the actual length of proposed piping from the meter to the furthest connection and then adding 50% of the measured length to find the equivalent length. If a very accurate determination of the equivalent length is necessary, it will be necessary to count the fittings and valves and then add those to the measured length. Refer to Table 7-5 for the equivalent amount of pipe to be added for various valves and fittings.

It is common practice not to use the vertical length in either calculation because NG is lighter than air. It expands at the rate of 1 in. (25.4 mm) wc for each 15 ft of elevation as the gas rises. The increase in pressure due to the height will offset any friction loss in the piping.

The maximum probable demand is calculated by the engineer with input from the owner if necessary. The primary usage of gas is for cooking and clothes drying at residences, for Bunsen burners or heating (boilers) in laboratories, or cooling equipment in industrial projects. For residential usage, Figure 7-3 for large residences and Figure 7-4 for smaller projects give a direct reading of the usage in cfh (m^3/hr). These direct reading tables give flow rate usage by using the number of apartments. Figure 7-5 is a riser diagram of multiple dwellings that gives the size of gas risers used for cooking and drying for both single and back-to-back installations. For laboratories, use Table 7-5 for the diversity factor. For schools, use no diversity factor for individual classrooms. Use no diversity factor for groups of classrooms if information of proposed usage is not conclusive or available from the owner. For industrial usage, a diversity factor generally is not used because of the possibility that all equipment may be in use at one time.

For a listing of input requirements for common appliances, refer to Table 7-3.

NG Pipe Sizing Methods

A number of formulas can be used to calculate the capacity of NG piping based on such variables as delivery pressure, pressure drop through the piping system, pipe size, pipe material, and length of piping. These formulas are referenced in numerous current model codes as well as in NFPA 54. The most commonly referenced formula for gas pressures under

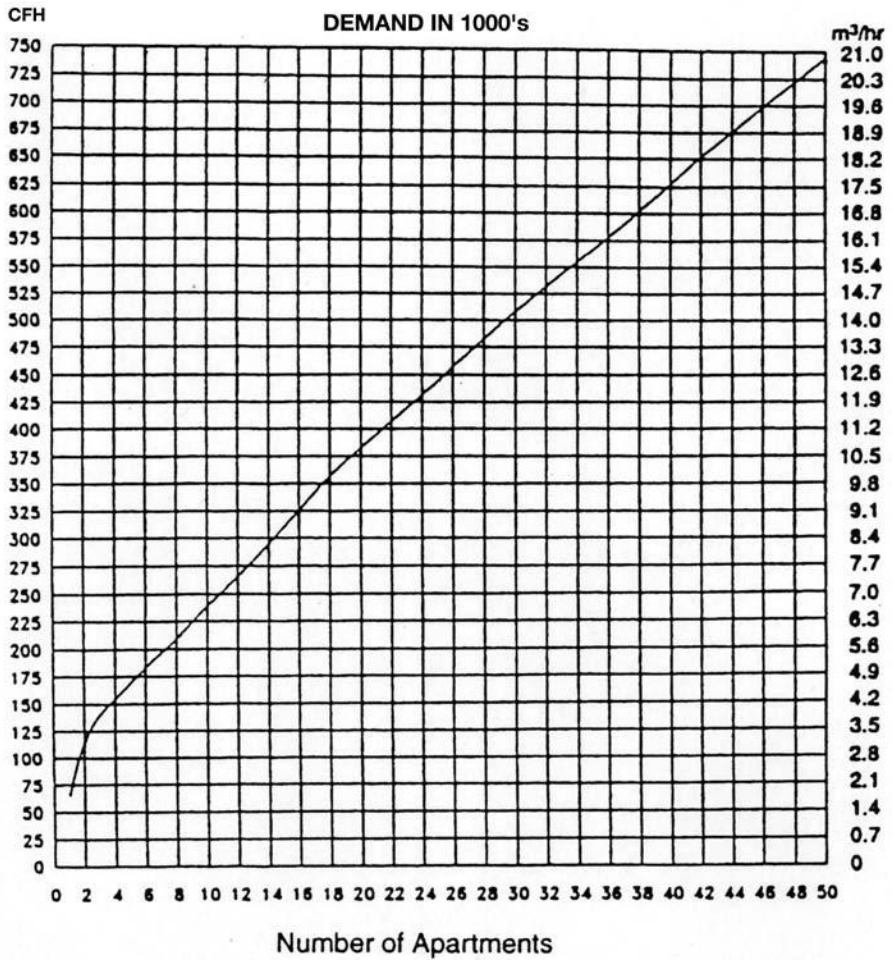


Figure 7-4 Gas Demand for Multiple-unit Dwellings with Less than 50 Apartments

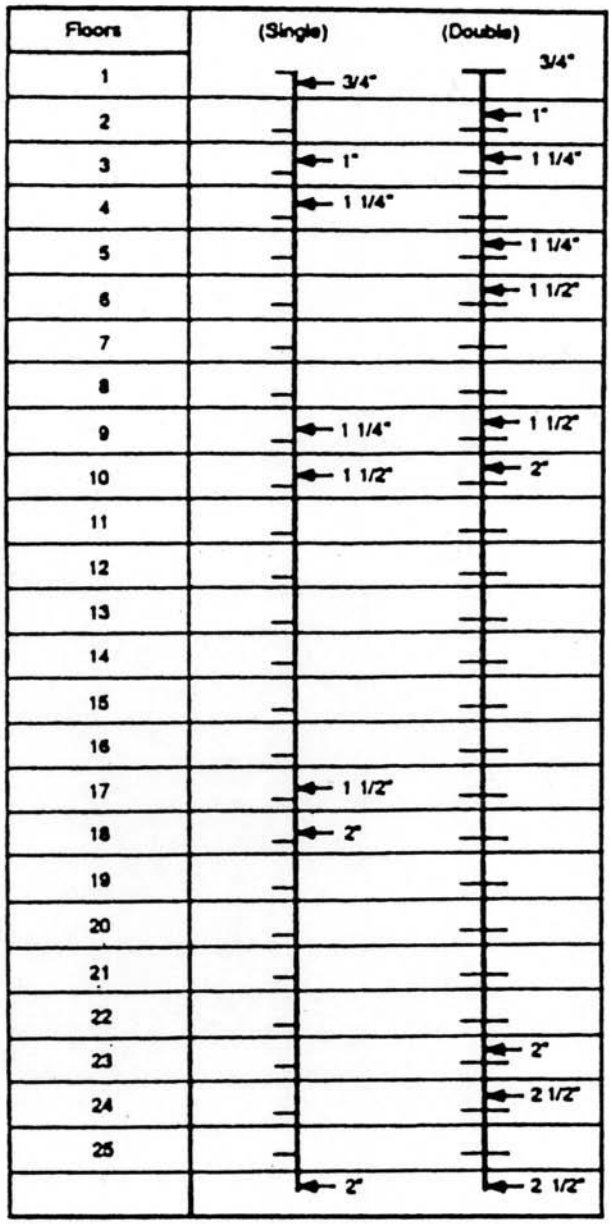


Figure 7-5 Gas Riser Pipe Sizing for Multiple Dwellings

1½ psi (10.3 kPa) is the Spitzglass formula. The other commonly referenced equation for pressures of 1½ psi (10.3 kPa) and more is the Weymouth formula. Using these formulas for sizing is a very cumbersome task, so they are rarely, if ever, used. However, they were used as a basis for the sizing tables that are included in this chapter and reproduced with permission from the NFPA. These tables are regarded as the most conservative method for sizing NG pipe. Proprietary tables and calculators are available from various organizations and are considered more accurate than those shown here.

The tables are based on Schedule 40 steel pipe, cfh of gas, and a specific gravity of 0.60. The initial pressures are different, and the friction loss allowable is indicated. The following tables are provided:

Table 7-6 pressure less than 2 psi (14 kPa), loss of 0.3 in. (7.5 mm) wc

Table 7-7 pressure less than 2 psi (14 kPa), loss of 0.5 in. (12.5 mm) wc

Table 7-8 pressure of 5 psi (35 kPa), loss of 10 percent

Table 7-9 pressure 10 psi (70 kPa), loss of 10 percent

Table 7-10 pressure 20 psi (140 kPa), loss of 10 percent

Table 7-11 pressure 50 psi (350 kPa), loss of 10 percent

Note 1 cfh gas = 0.3 m^3/hr

To determine the size of each section of pipe in a gas supply system using the gas pipe sizing tables, the following method should be used:

1. Measure the length of the pipe from the gas meter location to the most remote outlet on the system. Add a fitting allowance of 50% of the measured length. This now gives you the equivalent length of pipe. For natural gas, the vertical portion of piping is not considered due to the pressure gained as the gas rises. This very closely approximates the friction loss in the piping.
2. Select the column showing the distance that is equal to or more than the equivalent length just calculated.
3. Use the vertical column to locate all gas demand figures for this particular system. This is the *only* column to use. Starting at the most remote outlet, find in the vertical column the calculated gas demand for that design point. If the exact figure is not shown, choose the figure closest to or more than the calculated demand.
4. Opposite this demand figure selected, in the column at the left, find the correct size of pipe.
5. Proceed for each design point and each section of pipe. For each section of pipe, determine the total gas demand supplied by that section.

If the gas used for the system has a different specific gravity than natural gas, obtain that figure from Table 7-12 and use this as a multiplier for the specific gas selected.

To convert gas pressure to various designations, refer to Table 7-13.

LIQUEFIED PETROLEUM GAS

Liquefied petroleum gas (LPG) is a refined NG developed mainly for use beyond the utilities' gas mains, but it has proven to be competitive in areas not covered by mains in rural areas. It is chiefly a blend of propane and butane with traces of other hydrocarbons remaining from the various production methods. The exact

Table 7-6 Pressure less than 2 psi (14 kPa), loss of 0.3 in. (7.5 mm) wc

Pipe Size (in.)														
Nominal	½	¾	**1**	**1¼**	**1½**	**2**	**2½**	**3**	**4**	**5**	**6**	**8**	**10**	**12**
Actual ID	**0.622**	**0.824**	**1.049**	**1.380**	**1.610**	**2.067**	**2.469**	**3.068**	**4.026**	**5.047**	**6.065**	**7.981**	**10.020**	**11.938**
Length (ft)	**Capacity in Cubic Feet of Gas per Hour**													
10	131	273	514	1,060	1,580	3,050	4,860	8,580	17,500	31,700	51,300	105,000	191,000	303,000
20	90	188	353	726	1,090	2,090	3,340	5,900	12,000	21,800	35,300	72,400	132,000	208,000
30	72	151	284	583	873	1,680	2,680	4,740	9,660	17,500	28,300	58,200	106,000	167,000
40	62	129	243	499	747	1,440	2,290	4,050	8,270	15,000	24,200	49,800	90,400	143,000
50	55	114	215	442	662	1,280	2,030	3,590	7,330	13,300	21,500	44,100	80,100	127,000
60	50	104	195	400	600	1,160	1,840	3,260	6,640	12,000	19,500	40,000	72,600	115,000
70	46	95	179	368	552	1,060	1,690	3,000	6,110	11,100	17,900	36,800	66,800	106,000
80	42	89	167	343	514	989	1,580	2,790	5,680	10,300	16,700	34,200	62,100	98,400
90	40	83	157	322	482	928	1,480	2,610	5,330	9,650	15,600	32,100	58,300	92,300
100	38	79	148	304	455	877	1,400	2,470	5,040	9,110	14,800	30,300	55,100	87,200
125	33	70	131	269	403	777	1,240	2,190	4,460	8,080	13,100	26,900	48,800	77,300
150	30	63	119	244	366	704	1,120	1,980	4,050	7,320	11,900	24,300	44,200	70,000
175	28	58	109	224	336	648	1,030	1,820	3,720	6,730	10,900	22,400	40,700	64,400
200	26	54	102	209	313	602	960	1,700	3,460	6,260	10,100	20,800	37,900	59,900
250	23	48	90	185	277	534	851	1,500	3,070	5,550	8,990	18,500	33,500	53,100
300	21	43	82	168	251	484	771	1,360	2,780	5,030	8,150	16,700	30,400	48,100
350	19	40	75	154	231	445	709	1,250	2,560	4,630	7,490	15,400	28,000	44,300
400	18	37	70	143	215	414	660	1,170	2,380	4,310	6,970	14,300	26,000	41,200
450	17	35	66	135	202	389	619	1,090	2,230	4,040	6,540	13,400	24,400	38,600
500	16	33	62	127	191	367	585	1,030	2,110	3,820	6,180	12,700	23,100	36,500
550	15	31	59	121	181	349	556	982	2,000	3,620	5,870	12,100	21,900	34,700
600	14	30	56	115	173	333	530	937	1,910	3,460	5,600	11,500	20,900	33,100
650	14	29	54	110	165	318	508	897	1,830	3,310	5,360	11,000	20,000	31,700
700	13	27	52	106	159	306	488	862	1,760	3,180	5,150	10,600	19,200	30,400
750	13	26	50	102	153	295	470	830	1,690	3,060	4,960	10,200	18,500	29,300
800	12	26	48	99	148	285	454	802	1,640	2,960	4,790	9,840	17,900	28,300
850	12	25	46	95	143	275	439	776	1,580	2,860	4,640	9,530	17,300	27,400
900	11	24	45	93	139	267	426	752	1,530	2,780	4,500	9,240	16,800	26,600
950	11	23	44	90	135	259	413	731	1,490	2,700	4,370	8,970	16,300	25,800
1,000	11	23	43	87	131	252	402	711	1,450	2,620	4,250	8,720	15,800	25,100
1,100	10	21	40	83	124	240	382	675	1,380	2,490	4,030	8,290	15,100	23,800
1,200	NA	20	39	79	119	229	364	644	1,310	2,380	3,850	7,910	14,400	22,700
1,300	NA	20	37	76	114	219	349	617	1,260	2,280	3,680	7,570	13,700	21,800
1,400	NA	19	35	73	109	210	335	592	1,210	2,190	3,540	7,270	13,200	20,900
1,500	NA	18	34	70	105	203	323	571	1,160	2,110	3,410	7,010	12,700	20,100
1,600	NA	18	33	68	102	196	312	551	1,120	2,030	3,290	6,770	12,300	19,500
1,700	NA	17	32	66	98	189	302	533	1,090	1,970	3,190	6,550	11,900	18,800
1,800	NA	16	31	64	95	184	293	517	1,050	1,910	3,090	6,350	11,500	18,300
1,900	NA	16	30	62	93	178	284	502	1,020	1,850	3,000	6,170	11,200	17,700
2,000	NA	16	29	60	90	173	276	488	1,000	1,800	2,920	6,000	10,900	17,200

Table 7-7 pressure less than 2 psi (14 kPa), loss of 0.5 in. (12.5 mm) wc

Pipe Size (in.)														
Nominal	½	¾	1	1¼	1½	2	2½	3	4	5	6	8	10	12
Actual ID	**0.622**	**0.824**	**1.049**	**1.380**	**1.610**	**2.067**	**2.469**	**3.068**	**4.026**	**5.047**	**6.065**	**7.981**	**10.020**	**11.938**
Length (ft)	**Capacity in Cubic Feet of Gas per Hour**													
10	172	360	678	1,390	2,090	4,020	6,400	11,300	23,100	41,800	67,600	139,000	252,000	399,000
20	118	247	466	957	1,430	2,760	4,400	7,780	15,900	28,700	46,500	95,500	173,000	275,000
30	95	199	374	768	1150	2,220	3,530	6,250	12,700	23,000	37,300	76,700	139,000	220,000
40	81	170	320	657	985	1,900	3,020	5,350	10,900	19,700	31,900	65,600	119,000	189,000
50	72	151	284	583	873	1,680	2,680	4,740	9,660	17,500	28,300	58,200	106,000	167,000
60	65	137	257	528	791	1,520	2,430	4,290	8,760	15,800	25,600	52,700	95,700	152,000
70	60	126	237	486	728	1,400	2,230	3,950	8,050	14,600	23,600	48,500	88,100	13,900
80	56	117	220	452	677	1300	2,080	3,670	7,490	13,600	22,000	45,100	81,900	130,000
90	52	110	207	424	635	1220	1,950	3,450	7,030	12,700	20,600	42,300	76,900	122,000
100	50	104	195	400	600	1160	1,840	3,260	6,640	12,000	19,500	40,000	72,600	115,000
125	44	92	173	355	532	1020	1,630	2,890	5,890	10,600	17,200	35,400	64,300	102,000
150	40	83	157	322	482	928	1,480	2,610	5,330	9,650	15,600	32,100	58,300	92,300
175	37	77	144	296	443	854	1,360	2,410	4,910	8,880	14,400	29,500	53,600	84,900
200	34	71	134	275	412	794	1270	2,240	4,560	8,260	13,400	27,500	49,900	79,000
250	30	63	119	244	366	704	1120	1,980	4,050	7,320	11,900	24,300	44,200	70,000
300	27	57	108	221	331	638	1020	1,800	3,670	6,630	10,700	22,100	40,100	63,400
350	25	53	99	203	305	587	935	1,650	3,370	6,100	9,880	20,300	36,900	58,400
400	23	49	92	189	283	546	870	1,540	3,140	5,680	9,190	18,900	34,300	54,300
450	22	46	83	177	266	512	816	1,440	2,940	5,330	8,620	17,700	32,200	50,900
500	21	43	82	168	251	484	771	1,360	2,780	5,030	8,150	16,700	30,400	48,100
550	20	41	78	159	239	459	732	1290	2,640	4,780	7,740	15,900	28,900	45,700
600	19	39	74	152	228	438	699	1240	2,520	4,560	7,380	15,200	27,500	43,600
650	18	38	71	145	218	420	669	1180	2,410	4,360	7,070	14,500	26,400	41,800
700	17	36	68	140	209	403	643	1140	2,320	4,190	6,790	14,000	25,300	40,100
750	17	35	66	135	202	389	619	1090	2,230	4,040	6,540	13,400	24,400	38,600
800	16	34	63	130	195	375	598	1060	2,160	3,900	6,320	13,000	23,600	37,300
850	16	33	61	126	189	363	579	1020	2,090	3,780	6,110	12,600	22,800	36,100
900	15	32	59	122	183	352	561	992	2,020	3,660	5,930	12,200	22,100	35,000
950	15	31	58	118	178	342	545	963	1,960	3,550	5,760	11,800	21,500	34,000
1,000	14	30	56	115	173	333	530	937	1,910	3,460	5,600	11,500	20,900	33,100
1,100	14	28	53	109	164	316	503	890	1,810	3,280	5,320	10,900	19,800	31,400
1,200	13	27	51	104	156	301	480	849	1,730	3,130	5,070	10,400	18,900	30,000
1,300	12	26	49	100	150	289	460	813	1,660	3,000	4,860	9,980	18,100	28,700
1,400	12	25	47	96	144	277	442	781	1,590	2,880	4,670	9,590	17,400	27,600
1,500	11	24	45	93	139	267	426	752	1,530	2,780	4,500	9,240	16,800	26,600
1,600	11	23	44	89	134	258	411	727	1,480	2,680	4,340	8,920	16,200	25,600
1,700	11	22	42	86	130	250	398	703	1,430	2,590	4,200	8,630	15,700	24,800
1,800	10	22	41	84	126	242	386	682	1,390	2,520	4,070	8,370	15,200	24,100
1,900	10	21	40	81	122	235	375	662	1,350	2,440	3,960	8,130	14,800	23,400
2,000	NA	20	39	79	119	229	364	644	1,310	2,380	3,850	7,910	14,400	22,700

Table 7-8 Pressure of 5 psi (35 kPa), loss of 10 percent

Pipe Size of Schedule 40 Standard Pipe (in.)	Internal Diameter (in.)	Total Equivalent Length of Pipe (ft)										
		50	100	150	200	250	300	400	500	1000	1500	2000
1.00	1.049	1,989	1,367	1,098	940	833	755	646	572	393	316	270
1.25	1.380	4,084	2,807	2,254	1,929	1,710	1,549	1,326	1,175	808	649	555
1.50	1.610	6,120	4,206	3,378	2,891	2,562	2,321	1,987	1,761	1,210	972	832
2.00	2.067	11,786	8,101	6,505	5,567	4,934	4,471	3,827	3,391	2,331	1,872	1,602
2.50	2.469	18,785	12,911	10,368	8,874	7,865	7,126	6,099	5,405	3,715	2,983	2,553
3.00	3.068	33,209	22,824	18,329	15,687	13,903	12,597	10,782	9,559	6,568	5,274	4,514
3.50	3.548	48,623	33,418	26,836	22,968	20,356	18,444	15,786	13,991	9,616	7,722	6,609
4.00	4.026	67,736	46,555	37,385	31,997	28,358	25,694	21,991	19,490	13,396	10,757	9,207
5.00	5.047	122,544	84,224	67,635	57,887	51,304	46,485	39,785	35,261	24,235	19,461	16,656
6.00	6.065	198,427	136,378	109,516	93,732	83,073	75,270	64,421	57,095	39,241	31,512	26,970
8.00	7.981	407,692	280,204	225,014	192,583	170,683	154,651	132,361	117,309	80,626	64,745	55,414
10.00	10.020	740,477	508,926	408,686	349,782	310,005	280,887	240,403	213,065	146,438	117,595	100,646
12.00	11.938	1,172,269	805,694	647,001	553,749	490,777	444,680	380,588	337,309	231,830	186,168	159,336

Pressure 5.0 PSI (35 kPa)
Pressure Drop of 10%

Table 7-9 Pressure 10 psi (70 kPa), loss of 10 percent

Pipe Size of Schedule 40 Standard Pipe (in.)	Internal Diameter (in.)	Total Equivalent Length of Pipe (ft)										
		50	100	150	200	250	300	400	500	1000	1500	2000
1.00	1.049	3,259	2,240	1,789	1,539	1,364	1,236	1,058	938	644	517	443
1.25	1.380	6,690	4,598	3,692	3,160	2,801	2,538	2,172	1,925	1,323	1,062	909
1.50	1.610	10,024	6,889	5,532	4,735	4,197	3,802	3,254	2,884	1,982	1,592	1,362
2.00	2.067	19,305	13,268	10,655	9,119	8,082	7,323	6,268	5,555	3,818	3,066	2,624
2.50	2.469	30,769	21,148	16,982	14,535	12,882	11,672	9,990	8,854	6,085	4,886	4,182
3.00	3.068	54,395	37,385	30,022	25,695	22,773	20,634	17,660	15,652	10,757	8,638	7,393
3.50	3.548	79,642	54,737	43,956	37,621	33,343	30,211	25,857	22,916	15,750	12,648	10,825
4.00	4.026	110,948	76,254	61,235	52,409	46,449	42,086	36,020	31,924	21,941	17,620	15,080
5.00	5.047	200,720	137,954	110,782	94,815	84,033	76,140	65,166	57,755	39,695	31,876	27,282
6.00	6.065	325,013	223,379	179,382	153,527	136,068	123,288	105,518	93,519	64,275	51,615	44,176
8.00	7.981	667,777	458,959	368,561	315,440	279,569	253,310	216,800	192,146	132,061	106,050	90,765
10.00	10.020	1,212,861	833,593	669,404	572,924	507,772	460,078	393,767	348,988	239,858	192,614	164,853
12.00	11.938	1,920,112	1,319,682	1,059,751	907,010	803,866	728,361	623,383	552,493	379,725	304,933	260,983

Pressure 10.0 PSI (70 kPa)
Pressure Drop of 10%

Table 7-10 Pressure 20 psi (140 kPa), loss of 10 percent

Pipe Size of Schedule 40 Standard Pipe (in.)	Internal Diameter (in.)	Total Equivalent Length of Pipe (ft)										
		50	100	150	200	250	300	400	500	1000	1500	2000
1.00	1.049	5,674	3,900	3,132	2,680	2,375	2,152	1,842	1,633	1,122	901	771
1.25	1.380	11,649	8,006	6,429	5,503	4,877	4,419	3,782	3,352	2,304	1,850	1,583
1.50	1.610	17,454	11,996	9,633	8,245	7,307	6,621	5,667	5,022	3,452	2,772	2,372
2.00	2.067	33,615	23,103	18,553	15,879	14,073	12,751	10,913	9,672	6,648	5,338	4,569
2.50	2.469	53,577	36,823	29,570	25,308	22,430	20,323	17,394	15,416	10,595	8,509	7,282
3.00	3.068	94,714	65,097	52,275	44,741	39,653	35,928	30,750	27,253	18,731	15,042	12,874
3.50	3.548	138,676	95,311	76,538	65,507	58,058	52,604	45,023	39,903	27,425	22,023	18,849
4.00	4.026	193,187	132,777	106,624	91,257	80,879	73,282	62,720	55,538	38,205	30,680	26,258
5.00	5.047	349,503	240,211	192,898	165,096	146,322	132,578	113,370	100,566	69,118	55,505	47,505
6.00	6.065	565,926	388,958	312,347	267,329	236,928	214,674	183,733	162,840	111,919	89,875	76,921
8.00	7.981	1,162,762	799,160	641,754	549,258	486,797	441,074	377,502	334,573	229,950	184,658	158,043
10.00	10.020	2,111,887	1,451,488	1,165,596	997,600	884,154	801,108	685,645	607,674	417,651	335,388	287,049
12.00	11.938	3,343,383	2,297,888	1,845,285	1,579,326	1,399,727	1,268,254	1,085,462	962,025	661,194	530,962	454,435

Pressure 20.0 PSI (140 kPa)
Pressure Drop of 10%

Table 7-11 pressure 50 psi (350 kPa), loss of 10 percent

Pipe Size of Schedule 40 Standard Pipe (in.)	Internal Diameter (in.)	Total Equivalent Length of Pipe (ft)										
		50	100	150	200	250	300	400	500	1000	1500	2000
1.00	1.049	12,993	8,930	7,171	6,138	5,440	4,929	4,218	3,739	2,570	2,063	1,766
1.25	1.380	26,676	18,335	14,723	12,601	11,168	10,119	8,661	7,676	5,276	4,236	3,626
1.50	1.610	39,970	27,471	22,060	18,881	16,733	15,162	12,976	11,501	7,904	6,348	5,433
2.00	2.067	76,977	52,906	42,485	36,362	32,227	29,200	24,991	22,149	15,223	12,225	10,463
2.50	2.469	122,690	84,324	67,715	57,955	51,365	46,540	39,832	35,303	24,263	19,484	16,676
3.00	3.068	216,893	149,070	119,708	102,455	90,804	82,275	70,417	62,409	42,893	34,445	29,480
3.50	3.548	317,564	218,260	175,271	150,009	132,950	120,463	103,100	91,376	62,802	50,432	43,164
4.00	4.026	442,393	304,054	244,166	208,975	185,211	167,814	143,627	127,294	87,489	70,256	60,130
5.00	5.047	800,352	550,077	441,732	378,065	335,072	303,600	259,842	230,293	158,279	127,104	108,784
6.00	6.065	1,295,955	890,703	715,266	612,175	542,559	491,598	420,744	372,898	256,291	205,810	176,147
8.00	7.981	2,662,693	1,830,054	1,469,598	1,257,785	1,114,752	1,010,046	864,469	766,163	526,579	422,862	361,915
10.00	10.020	4,836,161	3,323,866	2,669,182	2,284,474	2,024,687	1,834,514	1,570,106	1,391,556	956,409	768,030	657,334
12.00	11.938	7,656,252	5,262,099	4,225,651	3,616,611	3,205,335	2,904,266	2,485,676	2,203,009	1,514,115	1,215,888	1,040,643

Table 7-12 Specific Gravity Multipliers

Specific Gravity	Capacity Multiplier	Specific Gravity	Capacity Multiplier	Specific Gravity	Capacity Multiplier
0.35	1.310	0.75	0.895	1.40	0.655
0.40	1.230	0.80	0.867	1.50	0.633
0.45	1.160	0.85	0.841	1.60	0.612
0.50	1.100	0.90	0.817	1.70	0.594
0.55	1.040	1.00	0.775	1.80	0.577
0.60	1.000	1.10	0.740	1.90	0.565
0.65	0.962	1.20	0.707	2.00	0.547
0.70	0.926	1.30	0.680	2.10	0.535

Table 7-13 Conversion of Gas Prcssurc to Various Designations

	Equivalent inches		Pressure per square inch		Equivalent inches		Pressure per square inch		
kP	Water	Mercury	Pounds	Ounces	Water	Mercury	Pounds	Ounces	kP
0.002	0.01	0.007	0.0036	0.0577	8.0	0.588	0.289	4.62	2.0
0.05	0.20	0.015	0.0072	0.115	9.0	0.662	0.325	5.20	2.2
0.07	0.30	0.022	0.0108	0.173					
0.10	0.40	0.029	0.0145	0.231	10.0	0.74	0.361	5.77	2.5
					11.0	0.81	0.397	6.34	2.7
0.12	0.50	0.037	0.0181	0.239	12.0	0.88	0.433		3.0
0.15	0.60	0.044	0.0217	0.346	13.0	0.96	0.469	7.50	3.2
0.17	0.70	0.051	0.0253	0.404					
0.19	0.80	0.059	0.0289	0.462	13.6	1.00	0.491	7.86	3.37
0.22	0.90	0.066	0.0325	0.520	13.9	1.02	0.500	8.00	3.4
					14.0	1.06	0.505	8.08	3.5
0.25	1.00	0.074	0.036	0.577					
0.3	1.36	0.100	0.049	0.785	15.0	1.10	0.542	8.7	3.7
0.4	1.74	0.128	0.067	1.00	16.0	1.18	0.578	9.2	4.0
0.5	2.00	0.147	0.072	1.15	17.0	1.25	0.614	9.8	4.2
0.72	2.77	0.203	0.100	1.60	18.0	1.33	0.650	10.4	4.5
0.76	3.00	0.221	0.109	1.73	19.0	1.40	0.686	10.9	4.7
1.0	4.00	0.294	0.144	2.31					
					20.0	1.47	0.722	11.5	5.0
1.2	5.0	0.368	0.181	2.89			0.903	14.4	6.2
1.5	6.0	0.442	0.217	3.46	25.0	1.84	0.975	15.7	6.7
1.7	7.0	0.515	0.253	4.04	27.2	2.00	1.00	16.0	6.9
					27.7	2.03			

blend is controlled by the LPG distributor to match the climatic conditions of the area served. For this reason, the engineer must confirm the heat value of the supplied gas. Unlike natural gas, 100 percent propane has a specific gravity of 1.53 and a rating of 2,500 Btu/cf (93 MJ/cm^3).

Easy storage for relatively large quantities of energy has led to widespread acceptance and usage of LPG in all areas previously served by utilities providing NG to users, including automotive purposes. In addition, a principal use is for the heating of industrial projects. It does not take the place of NG but provides an alternative energy source when the owners want to use a low, interruptible rate for heating purposes. When used for this purpose, experience has shown that the mixing with air should produce a gas with the heating value of 1,500 Btu/cf (a specific gravity of 1.30) for ease of burning and ignition. Use Table 7-12 for the factor to be used for sizing.

Storage

LPG storage tanks can be provided by the vendor or the customer and are subject to the regulations of the U.S. Department of Transportation (DOT) and the local authority, as well as NFPA standards, so the plumbing designer has little opportunity to design storage tanks and piping, per se. Normally, the designer starts at the storage supply outlet, and the piping system is generally in a low pressure range of 20 psig to 11 in wc.

LPG SIZING

The pressure of LPG is set by the supplier or the engineer. If the piping is to be run on the site, the pressure would be set higher for economy of pipe sizing, and a regulator would be provided to lower the pressure to a value that would be compatible with equipment served. A lower pressure would be used within a building.

Propane gas shall be sized in accordance with. Tables 7-14 and 7-15 that have been developed by the NFPA. Table 7-14 is based on an outlet pressure of 11 in. wc.(280 mm) that would be suitable for interior piping. Table 7-15 is based on a higher outlet pressure more suitable for site mains. The engineer shall obtain or request the pressure provided by the supplier and decide upon the pressure drop in the piping system that would be appropriate. The AHJ shall be consulted regarding acceptance of any pressure selected.

STORAGE TANKS

Small tanks (for example, those for residential cooking and heating) are allowed to be located in close proximity to buildings. Large tanks (e.g., for industrial or multiple building use), however, have strict requirements governing their locations in relation to buildings, public use areas, and property lines. If large leaks occur, the heavier-than-air gas will hug the ground and form a fog. The potential for a hazardous condition could exist. Proper safety precautions and equipment, as well as good judgment, must be utilized when locating large LPG storage tanks. The lines also have to be purged of air prior to the startup of the facility.

Table 7-14 100% Propane for Interior Piping

Nominal Inside	½	¾	1	1¼	1½	2	2½	3	4
Actual	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	4.026
Lenth (ft)	Capacity in Thousands of Btu per Hour								
10	291	608	1,150	2,350	3,520	6,790	10,800	19,100	39,000
20	200	418	787	1,620	2,420	4,660	7,430	13,100	26,800
30	160	336	632	1,300	1,940	3,750	5,970	10,600	21,500
40	137	287	541	1,110	1,660	3,210	5,110	9,030	18,400
50	122	255	480	985	1,480	2,840	4,530	8,000	16,300
60	110	231	434	892	1,340	2,570	4,100	7,250	14,800
80	101	212	400	821	1,230	2,370	3,770	6,670	13,600
100	94	197	372	763	1,140	2,200	3,510	6,210	12,700
125	89	185	349	716	1,070	2,070	3,290	5,820	11,900
150	84	175	330	677	1,010	1,950	3,110	5,500	11,200
175	74	155	292	600	899	1,730	2,760	4,880	9,950
200	67	140	265	543	814	1,570	2,500	4,420	9,010
250	62	129	243	500	749	1,440	2,300	4,060	8,290
300	58	120	227	465	697	1,340	2,140	3,780	7,710
350	51	107	201	412	618	1,190	1,900	3,350	6,840
400	46	97	182	373	560	1,080	1,720	3,040	6,190
450	42	89	167	344	515	991	1,580	2,790	5,700
500	40	83	156	320	479	922	1,470	2,600	5,300
550	37	78	146	300	449	865	1,380	2,440	4,970
600	35	73	138	283	424	817	1,300	2,300	4,700
650	33	70	131	269	403	776	1,240	2,190	4,460
700	32	66	125	257	385	741	1,180	2,090	4,260
750	30	64	120	246	368	709	1,130	2,000	4,080
800	29	61	115	236	354	681	1,090	1,920	3,920
850	28	59	111	227	341	656	1,050	1,850	3,770
900	27	57	107	220	329	634	1,010	1,790	3,640
950	26	55	104	213	319	613	978	1,730	3,530
1,000	25	53	100	206	309	595	948	1,680	3,420
1,100	25	52	97	200	300	578	921	1,630	3,320
1,200	24	50	95	195	292	562	895	1,580	3,230
1,300	23	48	90	185	277	534	850	1,500	3,070
1,400	22	46	86	176	264	509	811	1,430	2,930
1,500	21	44	82	169	253	487	777	1,370	2,800
1,600	20	42	79	162	243	468	746	1,320	2,690
1,700	19	40	76	156	234	451	719	1,270	2,590
1,800	19	39	74	151	226	436	694	1,230	2,500
1,900	18	38	71	146	219	422	672	1,190	2,420
2,000	18	37	69	142	212	409	652	1,150	2,350

100% Propane, Pressure 11 in wc, Pressure Drop 0.5 in wc

GLOSSARY

Btu Abbreviation for British thermal unit, the quantity of heat required to raise the temperature of one pound of water by one degree Fahrenheit.

Boiling point The temperature of a liquid at which the internal vapor pressure is equal to the external pressure exerted on the surface of the liquid.

Burner A device for the final conveyance of gas, or a mixture of gas and air, to the combustion zone.

Table 7-15 100% Propane for Site Mains

Nominal Inside	½	¾	1	1¼	1½	2	2½	3	4
Actual	0.622	0.824	1.049	1.380	1.610	2.067	2.469	3.068	4.026
Lenth (ft)	Capacity in Thousands of Btu per Hour								
10	5,890	12,300	23,200	47,600	71,300	137,000	219,000	387,000	789,000
20	4,050	8,460	15,900	32,700	49,000	94,400	150,000	266,000	543,000
30	3,250	6,790	12,800	26,300	39,400	75,800	121,000	214,000	436,000
40	2,780	5,810	11,000	22,500	33,700	64,900	103,000	183,000	373,000
50	2,460	5,150	9,710	19,900	29,900	57,500	91,600	162,000	330,000
60	2,230	4,670	8,790	18,100	27,100	52,100	83,000	147,000	299,000
70	2,050	4,300	8,090	16,600	24,900	47,900	76,400	135,000	275,000
80	1,910	4,000	7,530	15,500	23,200	44,600	71,100	126,000	256,000
90	1,790	3,750	7,060	14,500	21,700	41,800	66,700	118,000	240,000
100	1,690	3,540	6,670	13,700	20,500	39,500	63,000	111,000	227,000
125	1,500	3,140	5,910	12,100	18,200	35,000	55,800	98,700	201,000
150	1,360	2,840	5,360	11,000	16,500	31,700	50,600	89,400	182,000
175	1,250	2.620	4,930	10,100	15,200	29,200	46,500	82,300	167,800
200	1,160	2,430	4,580	9,410	14,100	27,200	43,300	76,500	156,100
250	1,030	2,160	4,060	8,340	12,500	24,100	38,400	67,800	138,400
300	935	1,950	3,680	7,560	11,300	21,800	34,800	61,500	125,400
350	860	1,800	3,390	6,950	10,400	20,100	32,000	56,500	115,300
400	800	1,670	3,150	6,470	9,690	18,700	29,800	52,600	107,300
450	751	1,570	2,960	6,070	9,090	17,500	27,900	49,400	100,700
500	709	1,480	2,790	5,730	8,590	16,500	26,400	46,600	95,100
550	673	1,410	2,650	5,450	8,160	15,700	25,000	44,300	90,300
600	642	1,340	2,530	5,200	7,780	15,000	23,900	42,200	86,200
650	615	1,290	2,420	4,980	7,450	14,400	22,900	40,500	82,500
700	591	1,240	2,330	4,780	7,160	13,800	22,000	38,900	79,300
750	569	1,190	2,240	4,600	6,900	13,300	21,200	37,400	76,400
800	550	1,50	2,170	4,450	6,660	12,800	20,500	36,200	73,700
850	532	1,110	2,100	4,300	6,450	12,400	19,800	35,000	71,400
900	516	1,080	2,030	4,170	6,250	12,000	19,200	33,900	69,200
950	501	1,050	1,970	4,050	6,070	11,700	18,600	32,900	67,200
1,000	487	1,020	1,920	3,940	5,900	11,400	18,100	32,000	65,400
1,100	463	968	1,820	3,740	5,610	10,800	17,200	30,400	62,100
1,200	442	923	1,740	3,570	5,350	10,300	16,400	29,000	59,200
1,300	423	884	1,670	3,420	5,120	9,870	15,700	27,800	56,700
1,400	406	849	1,600	3,280	4,920	9,480	15,100	26,700	54,500
1,500	391	818	1,540	3,160	4,740	9,130	14,600	25,700	52,500
1,600	378	790	1,490	3,060	4,580	8,820	14,100	24,800	50,700
1,700	366	765	1,440	2,960	4,430	8,530	13,600	24,000	49,000
1,800	355	741	1,400	2,870	4,300	8,270	13,200	23,300	47,600
1,900	344	720	1,360	2,780	4,170	8,040	12,800	22,600	46,200
2,000	335	700	1,320	2,710	4,060	7,820	12,500	22,000	44,900

100% Propane
Pressure 10 PSI (70 kPa)
Pressure Loss 3.0 PSI (21 kPa)

Butane (C_4H_{10}) A saturated aliphatic hydrocarbon existing in two isomeric forms and used as a fuel and a chemical intermediate.

Caloric value See heating value.

Chimney A vertical shaft enclosing one or more flues for conveying flue gases to the outside atmosphere.

Condensate The liquid that separates from a gas (including flue gas) due to a reduction in temperature.

Cubic foot (meter) of gas The amount of gas that would occupy 1 cubic foot (cubic meter) when at a temperature of 60°F (15.6°C), saturated with water vapor, and under a pressure equivalent to that of 30 in. of mercury (101.3 kPa).

Demand The maximum amount of gas per unit time, usually expressed in cubic feet per hour (liters per minute) or Btu (watts) per hour, required for the operation of the appliance(s) supplied.

Dilution air Air that enters a draft hood or draft regulator and mixes with the flue gases.

Diversity factor The ratio of the maximum probable demand to the maximum possible demand.

Draft hood A device built into an appliance, or made a part of the vent connector from an appliance, that is designed to:

1. Provide for the ready escape of the flue gases from the appliance in the event of no draft, backdraft, or stoppage beyond the draft hood.
2. Prevent a backdraft from entering the appliance.
3. Neutralize the effect of stack action of the chimney or gas vent upon the operation of the appliance.

Excess air Air that passes through the combustion chamber and the appliance flues in excess of that which is theoretically required for complete combustion.

Flue gases The products of combustion plus the excess air in appliance flues or heat exchangers (before the draft hood or draft regulator).

Fuel gas A gaseous compound used as fuel to generate heat. It may be known variously as utility gas, natural gas, liquefied peteroleum gas, propane, butane, methane, or a combination of the above. It has a caloric value that corresponds to the specific compound or combination of compounds. Care must be exercised in determining the caloric value for design purposes.

Gas log An unvented, open-flame-type room heater consisting of a metal frame or base supporting simulated logs designed for installation in a fireplace.

Gas train A series of devices pertaining to a fuel gas appliance located on the upstream side of the unit. Typically, it consists of a combination of devices and may include pipe, fittings, fuel, air-supervisory switches (e.g., pressure regulators), and safety shutoff valves.

Gas-train vent A piped vent to atmosphere from a device on a gas train.

Gas vents Factory-built vent piping and vent fittings listed by a nationally recognized testing agency, assembled and used in accordance with the terms of their listings, used for conveying flue gases to the outside atmosphere.

1. *Type B gas vent.* A gas vent for venting gas appliances with draft hoods and other gas appliances listed for use with type B gas vents.
2. *Type B-W gas vent.* A gas vent for venting listed gas-fired vented wall furnaces.
3. *Type L vent.* A gas vent for venting gas appliances listed for use with type L vents.

Heating value (total) The number of British thermal units produced by the combustion, at constant pressure, of 1 cubic foot (cubic meter) of gas when the products of combustion are cooled to the initial temperature of the gas and air; the water vapor formed during combustion is condensed; and all the necessary corrections have been applied.

LPG Liquefied petroleum gas, a mixture of propane and butane.

Loads, connected The sum of the rated Btu input to individual gas utilization equipment connected to a piping system. May be expressed in cubic feet (cubic meters) per hour.

Meter set assembly The piping and fittings installed by the serving gas supplier to connect the inlet side of the meter to the gas service and the outlet side of the meter to the customer's building or yard piping.

Pipe, equivalent length The resistance of valves, controls, and fittings to gas flow, expressed as equivalent length of straight pipe.

Pressure drop The loss in static pressure due to friction or obstruction during flow through pipe, valves, fittings, regulators, and burners.

Propane (C_3H_8) A gaseous hydrocarbon of the methane series, found in petroleum.

Regulator, gas pressure A device for controlling and maintaining a uniform gas pressure. This pressure is always lower than the supply pressure at the inlet of the regulator.

Safety shutoff device A device that is designed to shut off the gas supply to the controlled burner(s) or appliance(s) in the event that the source of ignition fails. This device may interrupt the flow of gas to the main burner(s) only or to the pilot(s) and main burner(s) under its supervision.

Specific gravity The ratio of the weight of a given volume of gas to that of the same volume of air, both measured under the same conditions.

Vent connector That portion of the venting system that connects the gas appliance to the gas vent, chimney, or single-wall metal pipe.

Vent gases The products of combustion from a gas appliance plus the excess air and the dilution air in the venting system above the draft hood or draft regulator.

REFERENCES

1. American Society of Heating, Refrigerating and Air Conditioning Engineers. *Handbooks*. Fundamentals and Equipment Vols. Latest ed. New York.
2. American Society of Mechanical Engineers (ASME). *Fuel gas piping.* ASME B31.2.
3. Ingersoll-Rand Company. 1969. *Compressed air and gas data*. New York.
4. International Association of Plumbing and Mechanical Officials (IAPMO) Code.
5. n.a. 1994. *Mechanical engineering reference manual.* 9th ed. Professional Publications.
6. Mohinder Nayer ed, . 1998. *Piping handbook*. New York: McGraw-Hill.
7. National Fire Protection Association. *Cutting and welding processes*. NFPA 51B. Boston, Mass.
8. National Fire Protection Association (NFPA). *LP-gases at utility gas plants.* NFPA 59. Boston Mass.
9. National Fire Protection Association. *National fuel gas code.* NFPA 54. Boston, Mass.
10. National Fire Protection Association. *Oxygen-fuel gas systems for weldings and cuttings*. NFPA 51. Boston.
11. National Fire Protection Association. *Powered industrial trucks*. NFPA 505. Boston.
12. *U.S. Army Corps of Engineers manual*. EM-1110-34-166.
13. Frankel, M., Facility Piping Systems Handbook, 2002, McGraw Hill, New York City

The material reproduced from the NFPA is not the official and complete position of the NFPA on the referenced subject which is presented only by the standard in its entirety.

REAL AMERICAN VALUES: APOLLO® VALVES

Apollo® Plumbing And Heating Products

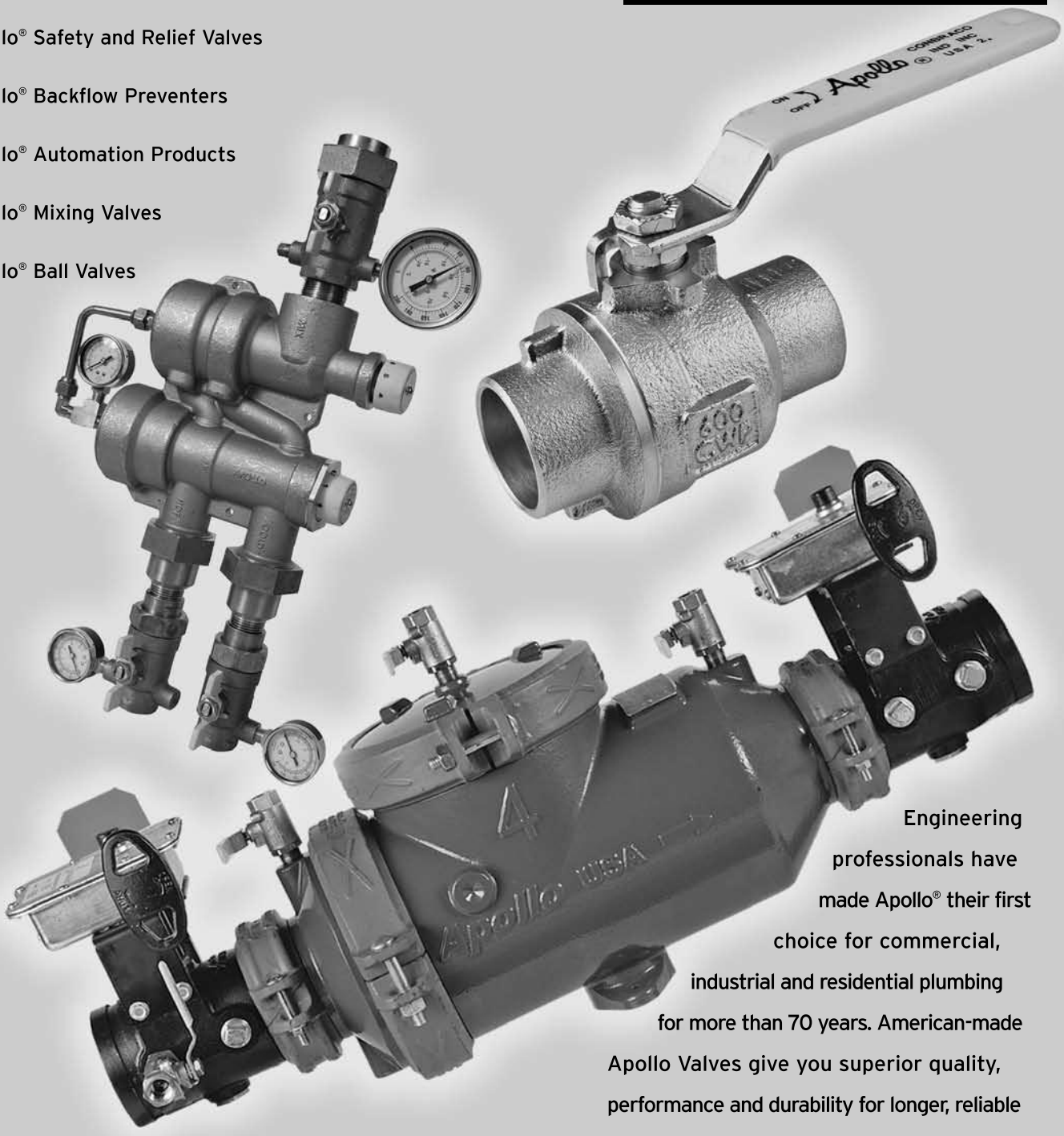
Apollo® Safety and Relief Valves

Apollo® Backflow Preventers

Apollo® Automation Products

Apollo® Mixing Valves

Apollo® Ball Valves



Engineering professionals have made Apollo® their first choice for commercial, industrial and residential plumbing for more than 70 years. American-made Apollo Valves give you superior quality, performance and durability for longer, reliable service in any plumbing system. For real American values, always specify Apollo Valves.

COPH 0411

MADE IN THE USA

"Apollo®" Valves
Manufactured by Conbraco Industries Inc.

Conway, SC • Matthews, NC • Pageland, SC • Customer Service 1-704-841-6000 • www.conbraco.com/info/ASPE0411.html

Chapitre de Québec

Quebec chapter

American Society of Plumbing Engineers

1937, rue Delisle, Saint-Nicolas (Québec) G7A 2E3

8 Private Onsite Wastewater Treatment Systems (POWTS)

INTRODUCTION

This chapter discusses private onsite wastewater treatment systems (POWTS), which provide an alternative to public sewers. The primary emphasis of this chapter is on residential, anaerobic treatment (septic) tanks; effluent and gravity-soil absorption systems; soil evaluation; anaerobic treatment tank selection; and the design of the dispersal cell.

Most areas of the country have local regulations, which must be followed, regarding the design of sewage treatment and dispersal systems. Most areas have extension offices that may provide valuable information, including soil surveys and soil maps of the region. The examples given in this chapter are only general guidelines and illustrations of criteria and methods and are not to be used for actual project design purposes.

The wastewater discharge to POWTS must be controlled. These systems are not designed to handle solids, such as disposable diapers, feminine products, food disposal wastes, or excessive oils, fats, and greases.

Primary Treatment

Two types of primary treatment generally are used in residential onsite treatment: aerobic and anaerobic. The purpose of both is to collect sewage effluent, decompose organic matter, and separate other solids from the effluent stream. The effluent from either process is a liquid, and variations in the effluent quality directly affect the design of the soil absorption component.

SOIL ABSORPTION SYSTEMS

The soil absorption system receives the effluent from the primary treatment tank by means of gravity or via a pump system.

Inground soil absorption component operation is a two-stage process involving both wastewater treatment and dispersal. Treatment is accomplished predominately by physical and biochemical processes within the treatment/dispersal zone. The physical characteristics of the influent wastewater, influent application rate, temperature, and the nature of the receiving soil affect these processes.

Physical entrapment, increased retention time, and conversion of pollutants in the wastewater are important treatment objectives accomplished under unsaturated soil conditions. Pathogens contained in the wastewater eventually are deactivated through filtering, retention, and adsorption by in situ soil.

Dispersal primarily is affected by the depth of the unsaturated receiving soil, the soil's hydraulic conductivity, influent application rate, land slope, and the area available for dispersal.

The inground soil absorption component consists of a distribution cell. Influent is discharged to the distribution cell, where it flows through the void area formed by stone aggregate and perforated pipe or leaching chambers and then passes into the underlying in situ soil for treatment and dispersal to the environment. The soil, to the prescribed depth, beneath the distribution cell is considered part of the cell known as the treatment/dispersal zone.

Cover material over the geotextile fabric or leaching chamber provides frost protection and a barrier to excess precipitation or runoff infiltration, prevents erosion protection, and allows oxygen transfer.

The in situ soil within the treatment/dispersal zone provides the physical and biochemical treatment for the influent.

The successful operation of a soil absorption system requires a comprehensive site evaluation, good design criteria, and careful installation.

Every inground soil absorption component design ultimately is matched to the given soil and site.

When evaluating a site, the designer must consider the lot size, soil characteristics, slope, topography, surface water, and the seasonal high-water table. Residential lots must be large enough to accommodate the projected area of the dispersal cell and primary treatment device while maintaining minimum setbacks from surface waters, wells, and property lines as mandated by local codes. In the absence of code

specifications, Table 8-1 may be used as a guide when using the morphological evaluation of the soil, while Table 8-2 may be used for the percolation test.

Guide for Estimating Soil Application Rates

Soil maps The capacity of a soil to absorb and transmit water is an important consideration in agriculture, particularly in relation to irrigation, drainage, and other land management practices. Through careful studies in these fields, a variety of aids have been developed for determining the absorption and water-transmission properties of soil that could be helpful in the sewage field. Considerable information on the relative absorption capacities of specific soils in many areas has been accumulated. Much of this information is included in soil survey reports and maps published by the U.S. Department of Agriculture. Although the soil maps may be used for initial discussion, the suitability of a soil for effluent treatment and dispersal should not be assigned based on these maps.

Clues to infiltrative capacity Information about relative absorption capacities of soils also may be obtained by a close visual inspection of the soil. This is known as a soil profile description. The value of such an inspection depends on the interpreter's knowledge of the pertinent soil properties. The main properties indicative of infiltrative capacity are soil texture, structure, color, depth, consistence, boundary characteristics, and redoximorphic features of the profile.

Texture Soil texture generally is defined as the relative proportion of sand, silt, and clay in the soil. It is the first clue to the soil's infiltrative capacity. Generally large soil particles create large pores and a faster infiltration rate.

Soil texture best can be judged by feeling. Lighter or sandier soils have a gritty feel when rubbed between the thumb and forefinger. Silty soils have a floury feel and, when wet, have no cohesion. Heavier, clay-type soils are dense and hard when dry and have a slick, greasy feel when wet.

The use of soil texture in determining infiltrative capacity has its limitations. It is usually reliable in the lighter soils. However, in the heavier soils (including sandy soils containing appreciable amounts of silt

Table 8-1 Maximum Soil Application Rates Based on Morphological Soil Evaluation (in gals./sq.ft./day)

Soil Characteristics			Maximum Monthly Average			
Texture	Structure		BOD_5 30-≤220mg/L TSS>30≤150mg/L		BOD_5≤30mg/L TSS≤30mg/L[c]	
COS, S, LCOS, LS	—	0	0.7[a]	0.5[b,c]	1.6[a]	0.5[b]
FS, LFS	—	0	0.5		1.0	
VFS, LVFS	—	0	0.4		0.6	
	—	OM	0.2		0.6	
		1	0.4		0.6	
	PL	2,3	0.0		0.2	
		1	0.4		0.7	
COSL, SL	PR, BK, GR	2,3	0.6		1.0	
	—	OM	0.2		0.5	
	PL	2,3	0.0		0.2	
	PL, PR, BK, GR	1	0.2		0.6	
FSL, VFSL	PR, BK, GR	2,3	0.6		0.8	
	—	OM	0.0		0.2	
	PL	1	0.4		0.6	
	PL,PR,BK,GR	1	0.4		0.6	
L	PR, BK, GR	2,3	0.6		0.8	
	—	OM	0.0		0.2	
	PL	2,3	0.0		0.2	
	PL,PR,BK,GR	1	0.4[c]		0.6	
SIL	PR, BK, GR	2,3	0.6		0.8	
SI	—	—	0.0		0.0	
	—	OM	0.0		0.0	
	PL	1,2,3	0.0		0.2	
		1	0.2		0.3	
SCL, CL SICL	PR, BK, GR	2,3	0.4		0.6	
	—	OM	0.0		0.0	
	PL	1,2,3	0.0		0.0	
		1	0.0		0.0	
SC, C, SIC	PR, BK, GR	2,3	0.2		0.3	

Note a: With ≤ 60% rock fragments
Notes b: With > 60 < 90% rock fragments
Note c: Requires pressure distribution
Note d: **C** – Clay, **COS** – Coarse Sand, **COSL** – Coarse Sandy Loam, **FS** – Fine Sand, **FSL** – Fine Sandy Loam, **LFS** – Loamy Fine Sand, **LVFS** – Loamy Very Fine Sand, **LS** – Loamy Sand, **S** – Sand, **SC** – Sandy Clay, **SCL** – Sandy Clay Loam, **SI** – Silt, **SICL** – Silty Clay Loam, **SIL** – Silt Loam, **VFSL** – Very Fine Sandy Loam , **VFS** – Very Fine Sand, **VFSL** – Very Fine Sandy Loam
Note e: **BK** – Blocky, **GR** – Granular, **M** – Massive, **PL** – Platy, **PR** – Prismatic, 0 – Structureless, 1– Weak, 2 – Moderate, 3 – Strong

Table 8-2 Maximum Soil Application Rates Based on Percolation Rates

Percolation Rate (minutes per inch)	Maximum Monthly Average	
	BOD_5 > 30 mg/L < 220 mg/L TSS > 30 mg/L < 150 mg/L (gals/sq ft/day)	BOD5 < 30 mg/L TSS < 30 mg/L (gals/sq ft/day)
0 to less than 10	0.7	1.2
10 to less than 30	0.6	0.9
30 to less than 45	0.5	0.7
45 to less than 60	0.3	0.5
60 to 120	0.2	0.3
Greater than 120	0.0	0.0

or clay) one must look for additional clues, such as structure and soil color.

Structure Soil structure is characterized by the aggregation (or grouping together) of the textural particles to form secondary particles of a larger size. The structure easily can be recognized by the manner in which a clod, or lump, breaks apart. If a soil has well defined structure, a clod will break with very little force, along well-defined cleavage planes, into uniformly sized units. If a soil has no structure, or is structureless, it may flow like beach sand or hold together like a massive block of clay.

In general, there are four fundamental structural types, named according to the shape of the aggregate particles: platy, prism-like, block-like, and spherical. Spherical structure tends to provide the most favorable infiltrative properties, and platy structure tends to provide the least favorable. Although other factors, such as the size and stability of the aggregates in water, also influence the infiltrative capacity of the soil, recognition of the type of structure is probably sufficient for a general appraisal.

Color One of the clues to the infiltrative capacity of the soil is color.

Most soils contain some iron compounds. This iron (like iron in a tool or piece of machinery), if alternately exposed to air and water, oxidizes and takes on a reddish-brown or yellow color. Thus, if the soil has a uniform reddish-brown to yellow oxidized color, it indicates that there has been a free alternating movement of air and water in and through the soil. Such a soil has some desirable infiltrative characteristics. At the other extreme, if the soil is dull gray or has mottled coloring, this indicates a lack of oxidizing conditions or a very restricted movement of air and water through the soil. Mottled soils may indicate poor infiltrative characteristics.

Depth (or thickness) of permeable strata The quantity of water that may be infiltrated into the soil is frequently proportional to the thickness (or volume) of the soil horizon. With a soil having 1 ft (0.3 m) or more of permeable material above tight clay, the infiltrative capacity is far greater than it is in a soil having the same kind of material lying within 2 in. (50.8 mm) of tight clay.

Procedure for percolation tests[1] Although the requirement for the percolation test rapidly is being replaced by the soil evaluation report, the engineer should consult the authority having jurisdiction (AHJ) to ascertain whether the perc test is required.

Several types (procedures) of percolation test may be acceptable to the AHJ or there may be no standards. In the absence of standards, the following method of conducting percolation tests may be used.

Number and location of tests Six or more tests should be made in separate test holes, spaced uniformly over the proposed absorption field site.

Type of test hole Dig or bore a hole, with horizontal dimensions varying from 4 to 12 in. (101.6 to 304.8 mm) and vertical sides to the depth of the proposed absorption trench. To save time, labor, and water per test, the holes can be bored with a 4-in. (101.6-mm) auger.

Preparation of the test hole Carefully scratch the bottom and sides of the hole with a knife blade or sharp-pointed instrument to remove any smeared soil surfaces and provide a natural soil interface into which water may percolate. Remove all loose material from the hole. Add 2 in. (50.8 mm) of coarse sand or fine gravel to protect the bottom from scouring and sediment.

Saturation and swelling of the soil It is important to distinguish between saturation and swelling. Saturation means that the void spaces between soil particles are full of water. This can be accomplished in a short period. Swelling is caused by the intrusion of water into individual soil particles. This is a slow process, especially in clay-type soils, and is the reason that a prolonged soaking period is required.

To conduct the test, carefully fill the hole with clear water to a minimum depth of 12 in. (304.8 mm) over the gravel.

In most soils, it is necessary to refill the hole by supplying a surplus reservoir of water, possibly by means of an automatic siphon, to keep water in the hole for at least four hours and preferably overnight. This procedure ensures that the soil is given ample opportunity to swell and to approach the condition it will have during the wettest season of the year. Thus, tests of the same soil give comparable results, whether they are made in a dry or wet season.

In sandy soils containing little or no clay, the swelling procedure is not essential. Therefore, in these soils there is no need to refill the hole with water.

Percolation rate measurement With the exception of sandy soils, the percolation rate measurement should be made on the day following the procedure described above, 24 hours after water is first added to the hole. For sandy soils, the percolation rate measurement may be taken after the water from one filling of the hole has completely seeped away.

1. If the water remains in the test hole after the overnight swelling period, adjust the depth to approximately 6 in. (152.4 mm) over the gravel. From a fixed reference point, measure the drop in the water level over a 30-minute period. This drop is used to calculate the percolation rate.
2. If no water remains in the hole after the overnight swelling period, add clear water to bring the depth of the water in the hole to approximately

[1] The procedure for percolation tests described in this chapter was developed at the Robert A. Taft Co.

6 in. (152.4 mm) over the gravel. From a fixed reference point, measure the drop in the water level at approximately 30-minute intervals for four hours, refilling to 6 in. (152.4 mm) over the gravel as necessary. The drop that occurs during the final 30-minute period is used to calculate the percolation rate of the soil. Any drop during the prior period provides the information for a possible modification of the procedure to suit any local circumstances.

3. In sandy soils—and in types of soil in which the first 6 in. (152.4 mm) of water seep away in fewer than 30 minutes after the overnight swelling period—the time interval between the measurements should be 10 minutes and the test should be run for 1 hour. The drop that occurs during the final 10 minutes is used to calculate the percolation rate.

Soil Absorption System Selection

For areas where the percolation rates and/or soil characteristics are acceptable, the next step after conducting a soil and site evaluation is to determine the absorption system suitable for the site.

For unsuitable sites, the installation of a traditional soil absorption system is impossible; the designer should consider alternative types of absorption systems, such as mounds, at-grades or shallow subsurface irrigation. If none of these alternatives is acceptable, the engineer may have to consider the use of a sewage lift station to pump the wastewater to a public sewer system or wastewater treatment plant, a holding tank, or a private wastewater treatment plant.

Selection of the appropriate absorption system is dependent to some extent on the location of the system in the area under consideration. A safe distance should be maintained between the system site and any water supply source or other physical feature that may be impacted by the POWTS or may impact the operation of the POWTS. Since the distance that pollution may travel underground depends upon numerous factors, including the characteristics of subsoil formations and the quality of the sewage discharged, no specified distance is absolutely safe in all localities. Ordinarily, a greater distance means greater safety provided. The location of the components of sewage disposal systems shall be as required by local codes. In their absence, Table 8-3 may be used as a guide.

Table 8-3 Recommended Setbacks for Soil Absorption Systems

Physical Feature	POWTS Soil Absorption System	Exterior Subsurface Treatment Tank or Holding Tank	Servicing, Suction Lines and Pump Discharge Lines
Building	10 feet	5 feet	None
Property Line	5 feet	2 feet	2 feet
Swimming Pool	15 feet	None	None
High Water Mark of Navigable Water	50 feet	10 feet	10 feet
Water Service or Private Water Main	10 feet	10 feet	10 feet
Public Water Main	8 feet	8 feet	8 feet
Public Well	400 feet	400 feet	200 feet
Private Well	50 feet	25 feet	25 feet

Details pertaining to the local water wells—such as depth, type of construction, and vertical zone of influence—together with data on geological formations and the porosity of the subsoil strata, should be considered when determining the safe allowable distance between wells and subsurface disposal systems.

Inground Conventional Soil Absorption System

An inground soil absorption system routinely consists of a bed constructed of aggregate or placed within a chamber. In either installation, a void is created to allow for storage of the partially treated effluent. Piping may be installed within the void to serve as a distribution system for the effluent. Perforated plastic is the piping material that typically is used.

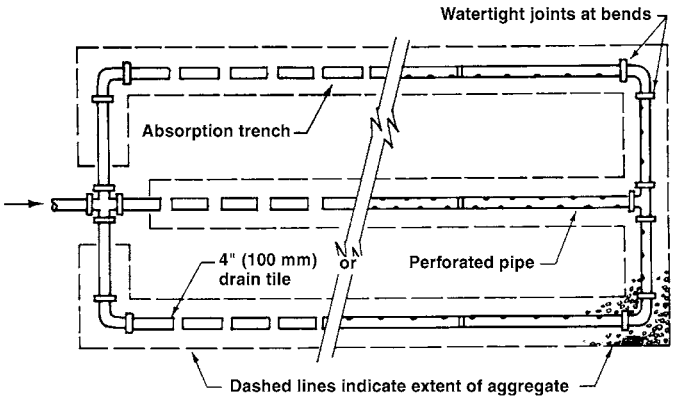


Figure 8-1 Three Legs of Disposal Field Fed from Cross Fitting Laid on Its Side

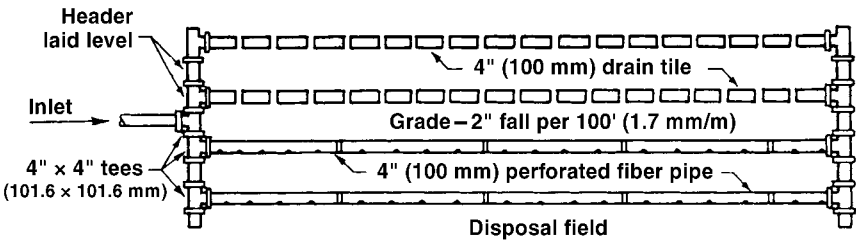


Figure 8-2 Disposal Lines Connected by Headers to Circumvent Stoppages

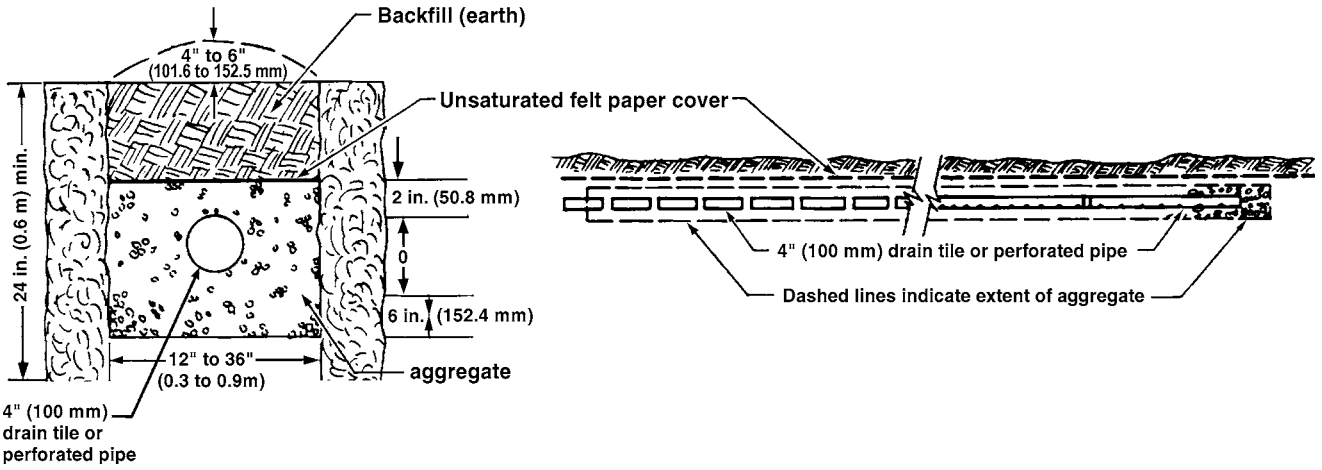


Figure 8-3 Transverse and Lineal Sections of Drain Field Showing Rock and Earth Backfill around Drain Tile

Many different designs may be used when laying out the subsurface absorption fields. Typical layouts of absorption trenches are shown in Figures 8-1, 8-2, and 8-3. The designer's choice may depend on the size and shape of the available disposal area, the capacity required, or the topography of the installation site.

Absorption trench depths are based on the suitable soil depth on the site. A minimum depth of 12 in. (304.8 mm) from original grade will help reduce the ponding of partially treated wastewater near the system.

The required absorption area is predicated on the results of the soil profile description or the percolation tests and may be obtained from Table 8-1 or 8-2. The wastewater discharged from a home may be calculated using the following equation:

100 gal × Number of bedrooms = Estimated flow per day

The estimated flow per day is multiplied by a 150% safety factor and that design flow is used for calculating soil application rates.

The area of the lot on which the system is to be constructed should be large enough to allow room for a replacement system. For example, for a three-bedroom house the design flow is 150 gal/bedroom/day × 3 bedrooms or 450 gal/day. If the soil application rate is 0.5, the size of the system is calculated by dividing the design flow by the application rate or:

450 gal/day ÷ 0.5 gal/sq ft/day = 900 sq ft

The spacing of the trenches is generally governed by local regulations or practical construction considerations such as the type of equipment and safety. For serial distribution on sloping ground, the trenches should be separated by at least 3 ft (0.9 m) to allow for maximum infiltration area. Table 8-3 gives the recommended distances to be kept between the disposal system and various site features, such as wells and dwellings.

The width of the trenches on sloping sites is governed by two factors: the depth of suitable soil and the vertical separation distance required between the bottom of the absorption system and the limiting condition and the minimum depth of the system in in situ soil. On a flat site, limiting the width of the trenches to 6 ft (1.8 m) allows for a conservative use of surface area and reduces groundwater mounding caused by excessively wide systems.

For the example, on a site that would permit a system to be 100 ft (30.5 m) in length:

900 sq ft ÷ 100 ft = 9 ft

2 trenches, each 4.5 ft wide and 100 ft long

6 ft separating the trenches to allow for machine access

15-ft width required for the system

3 ft between the system and the replacement of equal dimension

15 ft + 3 ft + 15 ft = 33 ft required for width

With width replacement area: 33 ft + 33 ft + 3 ft separation = 69 ft for width

CONSTRUCTION CONSIDERATIONS

Site Preparation and Construction

Procedures used in the construction of an inground soil absorption component are just as critical as the design of the component. A good design with poor construction results in component failure. The soil shall be worked only when the moisture content is low to avoid compaction and smearing. Consequently, installations are to be made only when the soil is dry enough to prevent compaction and smearing of the infiltrative surface. Proper equipment includes tractors or other equipment that will not compact the infiltrative surface. Minimize foot traffic on infiltrative surface and avoid equipment traffic on or over infiltrative surface. The construction plan to be followed includes the following construction procedures:

1. Check the moisture content and condition of the soil. If the soil at the infiltrative surface can be rolled into a ¼-in. wire, the site is too wet. Smearing and compaction will result, thus reducing the infiltrative capacity of the soil. If the site is too wet, do not proceed until it dries out. If the soil at or below the infiltrative surface is frozen, do not proceed.
2. Set up a construction level or similar device and determine all relative elevations in relationship to the benchmark. It is necessary to determine the bottom elevation of the distribution cell, land surface contour lines, and approximate component elevations critical to the installation.
3. Lay out the absorption area within the tested designated area. Where possible lay out the absorption areas(s) on the site so that the distribution cell runs parallel with the land surface contours. Reference stakes offset from the corner stakes are recommended in case corner stakes are disturbed during construction.
4. Excavate the distribution cell(s) to the correct bottom elevation(s), taking care not to smear the infiltrative surface. If the infiltrative surface or sidewalls are smeared, loosen them with the use of a rake or similar device. The infiltration surface can be left rough and should not be raked smooth.
5. Install observation pipes with the bottom 6 in. (152.4 mm) of the pipe slotted for components using stone aggregate. When leaching chambers are installed, the observation pipe connects to the top of the leaching chamber. The observation pipes are located at opposite ends of the distribution cell. Each observation pipe is located 1/5 to 1/10 the length of the distribution cell measured from the end of the cell. Installation of the observation pipe includes a suitable means of anchoring so the pipes are not dislodged during inspections.
6. If stone aggregate is used, place it into the excavated area until the top of the stone aggregate is at the elevation of the distribution piping. Placement of the stone aggregate is done in such a manner as not to compact the infiltrative surface. If leaching chambers are used, install the leaching chambers in accordance with the manufacturer's installation instructions.
7. Place the distribution pipes, as determined from the design, on the stone aggregate. Connect the distribution box, drop box, or manifold to the pipe from the treatment or dosing chamber.
8. Install vent pipe, if one is to be installed.
9. If stone aggregate is used, place stone aggregate over the distribution pipe and the entire distribution cell until the elevation of the stone aggregate is at least 2 in. (50.8 mm) above the top of the distribution pipe.
10. If stone aggregate is used, place geotextile fabric over the stone aggregate.
11. Place the cover material on top of the geotextile fabric and/or leaching chamber. Avoid backfilling the first 12 in. (304.8 mm) with cobbles, stones, or frozen material that could damage pipe, chamber, or fabric.

Alternative Soil Absorption Components

In some situations, the area surrounding a facility is not suitable for an underground soil absorption component, and an alternative design may be possible. Alternatives include mounds, at-grades, and shallow subsurface irrigation designs.

Several jurisdictions have requirements for these alternative components. Examples can be found at www.commerce.state.wi.us/sb/sb-PowtsProgram.htm.

COLLECTION AND TREATMENT ALTERNATIVES

Alternatives to Gravity Collection and Distribution

If a gravity piping system is not possible, pumped systems are used. Alternatives to the typical gravity collection and distribution system that should be evaluated include small-diameter gravity sewers, pressure sewers, and vacuum sewers. If the septic tank receives effluent other than raw wastes, small-diameter pipe (4 in. [101.6 mm] nominal) may be used to reduce the cost of conventional gravity sewers. The individual septic tanks should partially treat the wastewater by decomposition of the larger particles and permit sand and grit to settle. The 4-in. (101.6-mm) mains should be installed at a minimum gradient of 0.67% based on a minimum velocity of 1.5 ft/s (0.5 m/s) at half-pipe flow capacity. Under these conditions, using the Manning Formula, a 4-in. (101.6-mm) pipe can carry over 2,000 gph (2.1 L/s), sufficient to serve 670 persons (assuming a peak flow of 3 gph [3.2 mL/s] per person).

Pressure sewer systems generally consist of septic tanks at each facility, a small submersible pump, and small-diameter plastic mains. Grinder pumps may be placed in the septic tank. Construction costs are reduced because the sewer main can follow the contour of the land just below the frost line.

Vacuum transport systems consist of a vacuum pump, a receiving tank (held at approximately 7.5 psia [51.7 kPa]), and a vacuum valve. When there is sufficient sewage in the lateral and the vacuum is at the proper level, the valve will open, and the sewage will enter as a slug. The slug of wastewater will move toward the receiving tank until the dispersal

of the slug results in a break in the seal, thus ending the vacuum effect. Traps should be placed at regular intervals in the mains to reshape the slugs. When the trap fills, the vacuum effect is reestablished, causing the slug to continue toward the receiving tank with the next operation of the valve. Vacuum sewers flow full and provide many of the advantages of pressure sewers.

Alternatives to Conventional Primary and Secondary Treatment

The alternatives to conventional primary and secondary treatment include sand filtration and evapotranspiration. Sand filters have been used in sewage treatment for many years. More recently, standard systems have been modified to recirculating sand filter systems, which have demonstrated that, if properly designed, installed, and operated, they can produce effluents that meet stringent effluent and stream-quality standards.

Evapotranspiration as a means of disposing of domestic wastes has been researched at several locations, and its use has been accepted by various local jurisdictions. However, this type of system is rarely used.

The use of self-contained sewage treatment plants, particularly the tertiary treatment type, has found wide acceptance for facilities. Though this method is outside the scope of this chapter, it is discussed briefly in the section on individual aerobic wastewater treatment plants.

SEPTIC (ANAEROBIC TREATMENT) TANKS

If the lot is large enough to accommodate one of the previously discussed types of absorption system, and construction of the system is permitted by the AHJ, the next step is the selection of a suitable septic tank. The criteria for selection are as follows:

Functions of the Septic Tank

Untreated liquid household effluent consists of both solids and liquids. If both were discharged directly into the seepage beds or trenches, the beds or trenches eventually would clog. The septic tank is a device that protects the beds by separating solids from liquids. The solids are retained in the septic tank so that only liquid is discharged to be percolated into the ground.

To provide this protection, two functions take place within the septic tank:

Biological treatment Sewage effluent (fecal matter) is subjected to decomposition by natural, bacterial processes. The bacteria present in the liquid are anaerobic (i.e., they thrive in the absence of free oxygen). This decomposition, or treatment, of the sewage under anaerobic conditions is termed *septic,* hence the name of the tank.

Solids removal Sludge is defined as an accumulation of solids at the bottom of the septic tank. Scum is a partially submerged mat of floating solids that forms at the surface of the fluid in the septic tank. Some sludge and scum are decomposed. The residual material, composed of inert solid material, remains. After a period of time, these solids, including all types of grease, must be pumped out. Space must be provided in the septic tank to store this residue between cleanings; otherwise, sludge and scum eventually will be scoured from the septic tank and may clog the disposal field.

If adequately designed, constructed, maintained, and operated, septic tanks accomplish their purpose very efficiently.

The heavier sewage solids settle to the bottom of the septic tank, forming a blanket of sludge. The lighter solids, including fat and grease, rise to the surface and form a layer of scum. A considerable amount of the sludge and scum is liquefied through decomposition or digestion. During this process, gas is liberated from the sludge and carries some solids to the surface, where they accumulate with the scum. Ordinarily, they undergo further digestion in the scum layer, and a portion settles again to the sludge blanket at the bottom. This action is retarded if a considerable amount of grease is in the scum layer. The settling also is retarded in small septic tanks because of the gasification due to fluctuations of flow, which are relatively wider in smaller septic tanks than in larger ones. This effect is reflected in Table 8-4, which shows the recommended minimum liquid capacities of household septic tanks.

Table 8-4 Liquid Capacity of Tank[a]

Number of Bedrooms[b]	Recommended Minimum Tank Capacity, gal (L)	Equivalent Capacity per Bedroom, gal (L)
2 or fewer	1000 (3785.0)	300 (1135.6)
3	1000 (3785.0)	375 (1419.5)
4	1500 (5678.1)	350 (1324.9)

[a] Provides for use of garbage grinders, automatic clothes washers, and other household appliances.

[b] For each additional bedroom beyond 4, add 350 gal (1324.9 L).

As wastewater enters the septic tank, effluent is forced out of the tank into the drain field. Although the effluent is liquid, some solids remain in suspension. These solids are digested further by the soil as the liquid effluent trickles out of the drain piping into trenches and the surrounding absorption field.

Septic Tank Specifications

Materials Septic tanks should be watertight and constructed of materials not subject to excessive corrosion or decay. Concrete, fiberglass, and coated metal commonly are used. Properly cured, precast,

and cast-in-place, reinforced-concrete septic tanks are acceptable by most jurisdictions. Special attention should be given to job-built septic tanks to ensure their watertightness. Heavyweight concrete block should be laid on a solid concrete foundation. Mortar joints should be surfaced with two ¼-in. (6.4-mm) coats of portland cement/sand plaster.

Precast septic tanks should have a minimum wall thickness of 3 in. (76.2 mm) and should be adequately reinforced to facilitate their handling. When precast slabs are used as covers, they should be watertight, have a thickness of at least 4 in. (101.6 mm), and be adequately reinforced. All concrete surfaces should be coated with an acceptable compound to minimize corrosion, as approved by the AHJ.

General Backfill around septic tanks should be made in thin layers thoroughly tamped in a manner that will not produce undue strain on the septic tank. Settlement of the backfill may be done with the use of water, provided the material is thoroughly wetted from the bottom upwards and the septic tank is first filled with water to prevent floating.

Adequate access to each compartment of the septic tank should be provided for inspection and cleaning. Both the inlet and the outlet devices should be accessible. Access to each tank compartment should be provided by means of a removable cover or a 20-in. (0.5-m) manhole. Where the top of the septic tank is located more than 18 in. (0.46 m) below the finished grade, manholes and inspection holes should extend to the finished grade. In most instances, the extension can be made using a clay or concrete pipe, but proper attention must be given to any potential hazard involved (such as yard maintenance equipment) when manholes are extended close to the ground surface.

Invert The inlet invert should enter the septic tank at least 3 in. (76.2 mm) above its liquid level to allow for any momentary rises in the liquid level during the discharges to the unit. This free drop prevents backwater and stranding of solid material in the house sewer leading to the septic tank.

A vented inlet tee or baffle should be provided to divert the incoming sewage downward. This device should penetrate at least 6 in. (152.4 mm) below the liquid level of the septic tank, but in no case should the penetration be greater than that allowed for the outlet device.

Outlet It is very important that the outlet device penetrate just far enough below the liquid level of the septic tank to provide balance between the sludge and scum storage volume; otherwise, part of the advantage of the capacity is lost. A vertical section of a properly operating septic tank would show it divided into three distinct layers: scum at the top, a middle zone free of solids (called clear space), and a bottom layer of sludge. The outlet device retains scum in the septic tank, but at the same time it limits the amount of sludge that can be accommodated without scouring (which results in the sludge discharging in the effluent from the septic tank). Observations of sludge accumulations in the field indicate that the outlet device should be extended to a distance below the surface equal to 40% of the liquid depth. For horizontal, cylindrical septic tanks, this distance should be reduced to 35%. For example, in a horizontal, cylindrical septic tank having a liquid depth of 42 in. (1.1 m), the outlet device should penetrate $42 \times 0.35 = 14.7$ in. (0.4 m) below the liquid level.

The outlet device should be extended above the liquid line to approximately 1 in. (25.4 mm) from the top of the septic tank. The space between the top of the septic tank and the baffle will allow any gas to pass through the septic tank into the house vent.

Tank proportions The available data indicate that, for septic tanks of a given capacity, shallow units function as well as deep ones. Also, for septic tanks of a given capacity and depth, the shape of the unit is not important. However, it is recommended that the smallest plan dimension be a minimum of 2 ft (0.6 m) in length. Liquid depths may range between 30 and 60 in. (0.8 and 1.5 m).

Storage above liquid level Capacity is required above the septic tank liquid line to provide for that portion of the scum that floats above the liquid. Although some variation is to be expected, on average about 30% of the total scum accumulates above the liquid line. In addition to the provision for scum storage, 1 in. (25.4 mm) usually is provided at the top of the septic tank to permit free passage of gas back to the inlet and house vent pipe.

For septic tanks having straight, vertical sides, the distance between the top of the septic tank and the liquid line should be equal to approximately 20% of the liquid depth. In horizontal, cylindrical tanks, approximately 15% of the total circle should be provided above the liquid level. This condition is met if the liquid depth (distance from outlet invert to bottom of tank) is equal to 79% of the diameter of the septic tank.

Use of compartments Although a number of arrangements is possible, *compartments* refers to the number of units in series. These compartments can be separate units linked together or sections enclosed in one continuous shell, with watertight portions separating the individual compartments.

A single-compartment septic tank provides acceptable performance. The available data indicate, however, that a two-compartment septic tank (with the first compartment equal to one-half to two-thirds of the total volume) provides better suspended-solids removal, which may be especially valuable for the protection of the soil absorption system. Septic tanks with

three or more equal compartments give performances that are at least as good as those of single-compartment septic tanks of the same total capacity. Each tank compartment should have a minimum length of 2 ft (0.6 m) with a liquid depth ranging from 30 to 60 in. (0.8 to 1.5 m).

An access manhole to each tank compartment shall be provided. Venting between the tank compartments should be provided to allow for the free passage of gas. Inlet and outlet fittings in the septic tank should be proportioned (as they are for a single tank). The same allowance should be made for storage above the liquid line (as is made for a single tank).

An allowance should be made for sludge and scum accumulation as indicated in Table 8-5.

General Information on Septic Tanks

Cleaning Septic tanks should be cleaned before too much sludge or scum accumulates. If the sludge or scum approaches the bottom of the outlet pipe too closely, solids will be discharged through the outlet device into the sewage disposal field and will clog the system. When this condition occurs, eventually the liquid may break through to the ground surface, and the sewage may back up the plumbing fixtures. When a disposal field is clogged in this manner, not only is it necessary to clean the septic tank, but also it may be necessary to construct a new disposal field.

With the tank capacities recommended in Table 8-4, there is a reasonable period of good operation before cleaning becomes necessary. From one septic tank to the next, there are wide differences in the rates at which sludge and scum accumulate. In general, the tank should be inspected at least once per year and cleaned as necessary.

Although it is a difficult task for most homeowners, actual inspection of the sludge and scum accumulations is the only way to determine definitely when a given septic tank needs to be pumped. When a septic tank is inspected, the depth of the sludge and scum should be measured in the vicinity of the outlet baffle. The septic tank should be cleaned if (a) the bottom of the scum mat is within 3 in. (76.2 mm) of the bottom of the outlet device or (b) the sludge comes within the limits specified in Table 8-5.

Scum can be measured with a stick to which a weighted flap has been hinged or with a device used to feel the bottom of the scum mat. The stick is forced through the scum mat, and the hinged flap falls into a horizontal position. The stick then is raised until resistance from the bottom of the scum is felt. With the same tool, the distance to the bottom of the outlet device can be determined.

A long stick wrapped with rough, white toweling and lowered to the bottom of the septic tank will show the depth of sludge and the liquid level of the septic tank. The stick should be lowered behind the outlet device to avoid scum particles. After several minutes, if the stick is carefully removed, the sludge line can be distinguished by the sludge particles clinging to the toweling.

In most communities where septic tanks are used, companies are engaged in cleaning septic tanks. The local health department can make suggestions on how to obtain this service. (In some communities, the service is offered on a limited basis and paid for by property taxes.) Cleaning is usually accomplished by pumping the contents of the septic tank into a truck. Septic tanks should not be washed or disinfected after pumping. A small residue of sludge should be left in the septic tank for seeding purposes. The material removed from the septic tank is a regulated waste requiring proper handling according to laws and rules imposed by federal or state agencies. The tank never should be emptied into storm drains or discharged directly into any stream or watercourse. All methods of sewage disposal should first be approved by the local health authority.

When a large septic tank is cleaned, care should be taken not to enter the septic tank until it has been ventilated thoroughly and all gases have been removed to prevent the creation of an explosion hazard and the asphyxiation of workers. Anyone entering the septic tank should wear a self-contained breathing apparatus and have one end of a stout rope tied around the waist with the other end held aboveground by another person in case of an accident or the person being overcome by gas remaining in the septic tank.

Grease interceptors Grease interceptors (grease traps) ordinarily are not considered necessary on household sewage disposal systems. The discharge from a garbage grinder should not be passed through these units. With the capacities recommended in this chapter, septic tanks can receive the grease normally discharged from a residence.

Chemicals The operation of a septic tank is not improved by the addition of disinfectants or other chemicals. In general, the addition of chemicals to a septic tank is not recommended and actually may have an adverse effect on the bacterial processes necessary for digestion. Use of commercial products containing sodium hydroxide or po-

Table 8-5 Allowable Sludge Accumulation

Liquid Capacity of Tank,[a] gal (L)	Liquid Depth, ft (m)			
	2½ (0.8)	3 (0.9)	4 (1.2)	5 (1.5)
	Distance from bottom of outlet device to top of sludge, in. (mm)			
750 (2838.8)	5 (127)	6 (152.4)	10 (254)	13 (330.2)
900 (3406.5)	4 (101.6)	4 (101.6)	7 (177.8)	10 (254)
1000 (3785.0)	4 (101.6)	4 (101.6)	6 (152.4)	8 (203.2)

[a] Tanks smaller than the capacities listed require more frequent cleaning.

tassium hydroxide as the active agent may result in the sludge bulking. A large increase in the alkalinity may interfere with digestion. The resulting effluent may damage the soil structure severely and cause accelerated clogging, though temporary relief may be experienced immediately after application of the product.

Frequently, however, the harmful effects of ordinary household chemicals are overemphasized. Small amounts of chlorine bleaches, added ahead of the septic tank, may be used for odor control and will have no adverse effects on the system. Small quantities of lye or caustics commonly used in the home, added to the plumbing fixtures, are not objectionable as far as the operation of the septic tank is concerned. If the septic tanks are as large as is recommended, the dilution of the lye or caustics in the unit will offset any of the harmful effects that otherwise might occur.

Many commercial products containing enzymes have been placed on the market for use in septic tanks. As far as is known, none has been proved, in properly controlled tests, to have an advantage.

Soaps, detergents, bleaches, drain cleaners, or other materials, as commonly used in households, will have no appreciable adverse effects on the sewage system. However, both the soil and essential organisms might be susceptible to large doses of chemicals, resulting from a hobby or an industry, discharged into the sewage system.

Bulk quantities of chemicals (paints, varnishes, pesticides, herbicides, etc.) should not be introduced to the system as these may cause significant problems by overloading the system, interrupting the digestion process, or placing harmful or toxic chemicals into the soil or waterways.

Miscellaneous It is advisable to have all sanitary wastes from a household discharge into a single septic tank and disposal system. For household installations, it is usually more economical to provide a single disposal system rather than two (or more) with the same total capacity. Normal household waste, including that from the laundry, bath, and kitchen, should pass into a single system.

Roof drains, foundation drains, and drainage from other sources producing large intermittent or constant volumes of clear water should not be piped into the septic tank or absorption area. Such large volumes of water will exceed the tank capacity, stir up the contents of the septic tank, and carry some of the solids into the outlet line. The disposal system following the septic tank likewise will become flooded or clogged, or both, and may fail. Drainage from garage floors or other sources of oily waste also should be excluded from the septic tank.

Toilet paper substitutes should not be flushed into a septic tank. Paper towels, newspaper, wrapping paper, rags, and sticks may not decompose in the septic tank and are likely to lead to clogging of the plumbing and disposal systems.

Waste brines from household water softener units may have adverse effects on the action of the septic tank, causing a slight shortening of the life of a sewage disposal field installed in a structured clay-type soil.

Adequate venting is obtained through the building plumbing system if the septic tank and the plumbing system are designed and installed properly. A separate vent on a septic tank is not necessary.

A chart showing the location of the septic tank and disposal system should be placed in a suitable location in the building(s) served by the system. Whether furnished by the builder, septic tank installer, or local health department, the chart should contain instructions as to the inspection and maintenance required for the septic tank. This chart will help acquaint homeowners with the necessary maintenance procedures septic tanks require, thus forestalling failures of the unit by ensuring satisfactory operation. Extension of the septic tank's manholes or inspection holes to within 8 in. (203.2 mm) of the ground surface will simplify maintenance and cleaning. Records must be retained, including all performed maintenance.

Abandoned tanks should be filled with earth or rock.

Distribution Boxes

It is recommended that distribution boxes not be used for individual sewage disposal systems for the following reasons:

1. The distribution boxes may be eliminated from septic tank soil absorption systems for other methods of distribution without inducing an increased possibility of failure of the disposal field. Evidence indicates that distribution boxes may be harmful to a system.
2. Data indicate that, on level ground, equal distribution is unnecessary if the system is designed so that an overloaded trench drains back to other trenches before a failure occurs.
3. On sloping ground, a method of distribution is needed to prevent an excessive buildup of head and the failure of any one trench before the capacity of the entire system is reached. It is doubtful that distribution boxes can provide an equal distribution.

SEPTIC TANK/SOIL ABSORPTION SYSTEMS FOR INSTITUTIONS AND RECREATIONAL AND OTHER ESTABLISHMENTS

Septic tank systems are utilized for providing sewage treatment and disposal in many types of small establishments—such as schools, small institutions, motels,

small hotels, small restaurants, trailer parks, housing projects, large private estates, and camps—where the quantities of sewage involved are larger than those discharged from an individual home. In general, the usefulness of a septic tank system decreases as the size of the facility served increases. The lack of sanitary engineering advice during the design of such a system generally leads to failures, excessive costs, and a multitude of other problems. Anyone contemplating the use of such a system should employ an engineer qualified to design it. The first item to be determined from the AHJ is whether or not this method of sewage disposal is suitable for the type of establishment under consideration.

Any institutional septic tank system should incorporate appurtenances and supplemental design features to meet the requirements of the establishment and the varying site conditions. Such systems can be successful when appropriate experience, study, and planning are employed in their choice and development. This section describes the most generally successful procedures and practices as a guide for engineers designing institutional systems. For occupancies covered by this section, under the Federal Clean Water Act and related state water-quality regulations, it is common that applications must be made for discharge requirements in addition to obtaining the normal approvals. For instance, for restaurants, supermarkets, and other establishments producing appreciable amounts of grease, grease interceptors commonly are required, either as a central grease trap located outside the building or, preferably, as separate grease interceptors located at each grease-producing fixture. Because regulations at all levels are changing rapidly, requiring greater clarity of effluent, engineers should be sure they have contacted all agencies that may be involved.

Water Conservation

In most institutional systems, an important factor in preventing overload of wastewater disposal systems is water conservation. Means of conserving water include automatically closing faucets on all public wash basins; flow restrictors, where applicable; water closet and urinal fixtures designed to minimize water consumption; preventive maintenance; and user education programs aimed at wastewater reduction. The use of 1.6-gal (6.1-L)-per-flush water closets is certainly a major factor in wastewater reduction.

Numerous states and localities are implementing, or studying the implementation of, water (gray and/or black) recycling programs.

Special Fixtures

A number of failing septic tank systems at highway safety rest stops, parks, and service stations have been corrected by installing water closets that use 2 qt (2.3 L) per flush or less. This option should be evaluated in system design, especially for occupancies where water closets and urinals produce the majority of wastewater at sites where soil porosity is limited.

Some service stations and similar occupancies utilize specially designed units to effectively recycle wastewater so health officials permit its reuse for toilet flushing.

Alternative Systems

Institutional wastewater management for sites without sewers presents unusual challenges. Jurisdictional authorities should develop policies whereby innovative, alternative systems can be evaluated to determine the conditions under which such systems may be accepted, based upon the various factors involved.

Special Design

Special design features are desirable for large institutional-type systems. Consideration should be given to providing larger-than-required tanks. Often two or more properly designed baffles are desirable rather than a dual-tank system.

Openings should be conveniently accessible for tank cleaning and maintenance.

Seepage systems also must be properly designed. For gravity flow, each seepage trench normally should not exceed 100 ft (30.5 m) in length. For systems designed for more than 2,000 gal (7,570 L) per day, automatic dosing by siphon or pump is desirable to ensure that the whole system is effectively used. Special dosing normally should be designed to fill the entire seepage trench piping to about three-fourths capacity.

Allowing for 100% expansion or having two separate absorption areas for alternating between seepage systems is a consideration for institutions.

Individual Aerobic Wastewater Treatment Plants

Where surface discharge is authorized by the AHJ, individual treatment plants can be used. Approval under National Sanitation Foundation (NSF) Standard No. 40 may be required. This standard requires compliance with Class 1 effluent standards to meet EPA secondary treatment guidelines. Septic tanks may require the installation of intermittent, conventional, or recirculating sand filters. Stabilization ponds or lagoons, either conventional or aerated, may be accepted by some jurisdictions when soil absorption systems are contemplated. It is essential to determine the characteristics and suitability of the area reserved for the subsurface disposal system, including, as required, room for future expansion. This includes checking the required separation from wells and surface waters, the topography, data on groundwater levels and impermeable layers, and the soil evalua-

tion and percolation tests, as required. The design engineer should explore fully all technical and legal aspects of securing approval of an acceptable method of sewage disposal before the site is developed. To do so, it is necessary to make a somewhat detailed plan of the total contemplated site occupancy to determine the size and capacities of the disposal units.

When soil absorption systems are contemplated, it is essential to determine the characteristics and suitability of the soil as a first step toward design. The builder of the establishment should explore this feature of a proposed site before the site is purchased. After the percolation tests are completed, the quantity of the sewage to be discharged should be estimated to determine the size and capacity of the disposal units.

ESTIMATING SEWAGE QUANTITIES

Normally, disposal systems are designed prior to the actual construction of a facility. In estimating the quantity of sewage, the first consideration must be given to local code requirements. These requirements usually result in design flows that are considerably above average. If there are no code requirements, the most reliable criteria are readings from water meters at similar existing buildings. These usually can be obtained from the water utility company. It is recommended that a safety factor of 10% be added to the quantity of water obtained to account for any additional unknown requirements. However, water flows that do not pass through the sewage system (e.g., irrigation) should be excluded.

Where codes and actual usage data are not available, it is necessary to use other methods of estimating the amount of sewage to be discharged. For residential facilities refer to Table 8-6 for average daily wastewater flows, including minimum and maximum flow and frequency distribution. These data are useful for the design of systems for apartments, mobile home parks, and similar residential facilities. Refer to Tables 8-7 through 8-9 for typical wastewater flows from commercial, institutional, and recreational sources.

Where measurements of water consumption are not possible, it is necessary to use other methods of estimating the amount of sewage to be discharged. One method is to base the estimated flow on the number of bedrooms. A second method is to calculate the flow on the basis of the number and kinds of plumbing fixture. If the building is used as a restaurant, the number of meals served may be the best criterion. The design engineer must use judgment and base an estimate upon a combination of the various influencing factors. Refer to Table 8-10 for general establishments to estimate sewage quantities. The quantities given in the table are merely the best averages available at this time; they should be modified in localities or establishments where experience indicates a need to do so.

It is sometimes economically wise to construct separate disposal systems for different types of waste at a given establishment. The decision regarding the number of disposal systems may be influenced by topography, conditions of terrain, and the locations of

Table 8-6 Average Waste-Water Flows from Residential Sources

Source	Unit	Flow, gal (L) / unit / day	
		Range	Typical
Apartment	Person	53–90 (200–340)	69 (260)
Hotel, residential	Resident	40–58 (150–220)	50 (190)
Individual dwelling			
Average home	Person	50–92 (190–350)	74 (280)
Better home	Person	66–106 (250–400)	82 (310)
Luxury home	Person	79–145 (300–550)	100 (380)
Semi-modern home	Person	26–66 (100–250)	53 (200)
Trailer park	Person	32–53 (120–200)	40 (150)

Table 8-7 Typical Waste-Water Flows from Commercial Sources

Source	Unit	Waste-Water Flow, gpd/unit (L/d/unit)	
		Range	Typical
Airport	Passenger	2.1–4.0 (8–15)	2.6 (10)
Automobile service station	Vehicle serviced	7.9–13.2 (30–50)	10.6 (40)
	Employee	9.2–15.8 (35–60)	13.2 (50)
Bar	Customer	1.3–5.3 (5–20)	2.1 (8)
	Employee	10.6–15.8 (40–60)	13.2 (50)
Hotel	Guest	39.6–58.0 (150–220)	50.1 (190)
	Employee	7.9–13.2 (30–50)	10.6 (40)
Industrial building	Employee	7.9–17.2 (3–65)	14.5 (55) [excluding industry and cafeteria]
Laundry (self-service)	Machine	475.0–686.0 (1800–2595)	580.0 (2195)
	Wash	47.5–52.8 (180–200)	50.1 (190)
Motel	Person	23.8–39.6 (90–150)	31.7 (120)
Motel with kitchen	Person	50.2–58.1 (190–220)	52.8 (200)
Office	Employee	7.9–17.2 (30–65)	14.5 (55)
Restaurant	Meal	2.1–4.0 (8–15)	2.6 (10)
Rooming house	Resident	23.8-50.1 (90–190)	39.6 (150)
Store, department	Toilet room	423.0–634.0 (1600–2400)	528.0 (2000)
	Employee	7.9–13.2 (30–50)	10.6 (40)
Shopping center	Parking space	0.5–2.1 (2–8)	1.1 (4)
	Employee	7.9–13.2 (30–50)	10.6 (40)

Table 8-8 Typical Waste-Water Flows from Institutional Sources

Source	Unit	Waste-Water Flow, gpd/unit (L/d/unit)	
		Range	Typical
Hospital, medical	Bed	132.0–251.0 (500–950)	172.0 (650)
	Employee	5.3–15.9 (20–60)	10.6 (40)
Hospital, mental	Bed	79.3–172.0 (300–650)	106.0 (400)
	Employee	5.3–15.9 (20–60)	10.6 (40)
Prison	Inmate	79.3–159.0 (300–600)	119.0 (450)
	Employee	5.3–15.9 (20–60)	10.6 (40)
Rest home	Resident	52.8–119.0 (200–450)	92.5 (350)
	Employee	5.3–15.9 (20–60)	10.6 (40)
School, day			
With cafeteria, gym, showers	Student	15.9–30.4 (60–115)	21.1 (80)
With cafeteria only	Student	10.6–21.1 (40–80)	15.9 (60)
Without cafeteria, gym, showers	Student	5.3–17.2 (20–65)	10.6 (40)
School, boarding	Student	52.8–106.0 (200–400)	74.0 (280)

Table 8-9 Typical Waste-Water Flows from Recreational Sources

Source	Unit	Waste-Water Flow, gpd/unit (L/d/unit)	
		Range	Typical
Apartment, resort	Person	52.8–74.0 (200–280)	58.1 (220)
Cabin, resort	Person	34.3–50.2 (130–190)	42.3 (160)
Cafeteria	Customer	1.1–2.6 (4–10)	1.6 (6)
	Employee	7.9–13.2 (30–50)	10.6 (40)
Campground (developed)	Person	21.1–39.6 (80–150)	31.7 (120)
Cocktail lounge	Seat	13.2–26.4 (50–100)	19.8 (75)
Coffee shop	Customer	4.0–7.9 (15–30)	5.3 (20)
	Employee	7.9–13.2 (30–50)	10.6 (40)
Country club	Member present	66.0–132.0 (250–500)	106.0 (400)
	Employee	10.6–15.9 (40–60)	13.2 (50)
Day camp (no meals)	Person	10.6–15.9 (40–60)	13.2 (50)
Dining hall	Meal served	4.0–13.2 (15–50)	7.9 (30)
Dormitory, bunkhouse	Person	19.8–46.2 (75–175)	39.6 (150)
Hotel, resort	Person	39.6–63.4 (150–240)	52.8 (200)
Laundromat	Machine	476.0–687.0 (1800–2600)	581.0 (2200)
Store resort	Customer	1.3–5.3 (5–20)	2.6 (10)
	Employee	7.9–13.2 (30–50)	10.6 (40)
Swimming pool	Customer	5.3–13.2 (20–50)	10.6 (40)
	Employee	7.9–13.2 (30–50)	10.6 (40)
Theater	Seat	2.6–4.0 (10–15)	2.6 (10)
Visitor center	Visitor	4.0–7.9 (15–30)	5.3 (20)

the buildings contributing to the waste. For example, at large camps and some resorts, the kitchen and central dining facilities may be located at appreciable distances from the living quarters, cottages, and cabins. Under such circumstances, the kitchens may be provided with separate disposal systems designed especially for kitchen waste. A major factor is grease interception. Also, while many authorities discourage use of garbage disposal units or disposals for occupancies served by onsite disposal sytems, such disposers are still used. For such occupancies where disposers are used, and for food processing and poultry or animal slaughtering establishments and other units producing special types of liquid waste, separate interceptors and pretreatment should be designed to meet the particular requirements of the establishment.

Some authorities favor placing limits on the size and capacity of septic tank-type disposal systems. Under such circumstances, it may be desirable to provide separate systems for groups of a limited number of dwellings, apartments, mobile homes, or other occupancies. Some favor limits approaching (not to exceed) 10 apartments per system. This has the advantage of limiting the number of units affected by temporary system malfunctioning as by overloading due to plumbing fixture malfunctioning (constantly running water closets, for instance).

Separate systems also may be used for community bathhouses. When this is done, the total per capita flow must be broken down into its component parts, and some allowance should be made for the amount of sewage tributary from the different disposal systems. Table 8-11 illustrates how this may be done where there are no definite data regarding exact distribution flow.

For a certain number of new establishments, the design engineer may be unable to obtain from the client accurate estimates of the number of patrons to be served by the disposal system. This is particularly true in the case of restaurants and recreational facilities, such as picnic areas, country clubs, and the like. In such cases, the following data should be considered. For restaurants, seating capacity, type of menu, hours to be open per day and all available data can be considered in calculating wastewater quantities and characteristics. For recreational facilities like picnic areas, country clubs, and similar occupancies, a review of all proposed buildings, campsites, and methods of operation can provide valuable data. Computations and estimates can be made from the number and types of fixture installed, together with data from experience with similar facilities elsewhere.

Estimates of sewage quantities from golf clubs should be checked and calculations based on the

Table 8-10 Quantities of Sewage Flows

Type of Establishment	GPD/Person (L/D/Person)[a]
Airports (per passenger)	5 (20)
Apartments—multifamily (per resident)	60 (225)
Bathhouses and swimming pools	10 (40)
Camps	
Campground with central comfort stations	35 (130)
With flush toilets, no showers	25 (95)
Construction camps (semipermanent)	50 (190)
Day camps (no meals served)	15 (60)
Resort camps (night and day) with limited plumbing	50 (190)
Luxury camps	100 (380)
Cottages and small dwellings with seasonal occupancy	50 (190)
Country clubs (per resident member)	100 (380)
Country clubs (per nonresident member present)	25 (95)
Dwellings	
Boarding houses	50 (190)
additional for nonresident boarders	10 (40)
Luxury residences and estates	150 (570)
Multifamily dwellings (apartments)	60 (225)
Rooming houses	40 (150)
Single-family dwellings	75 (285)
Factories (gal [L] per person, per shift, exclusive of industrial wastes)	35 (130)
Hospitals (per bed space)	250 (945)[b]
Hotels with private baths (2 persons per room)	60 (225)
Hotels without private baths	50 (190)
Institutions other than hospitals (per bed space)	125 (475)
Laundries, self-service (gal [L] per wash, i.e., per customer)	50 (190)
Mobile home parks (per space)	250 (945)
Motels with bath, toilet, and kitchen wastes (per bed space)	50 (190)
Motels (per bed space)	40 (150)
Picnic parks (toilet wastes only) (per picnicker)	5 (20)
Picnic parks with bathhouses, showers, and flush toilets	10 (40)
Restaurants (toilet and kitchen wastes per patron)	10 (40)
Restaurants (kitchen wastes per meal served)	3 (10)
Restaurants, additional for bars and cocktail lounges	2 (8)
Schools	
Boarding	100 (380)
Day, without gyms, cafeterias, or showers	15 (60)
Day, with gyms, cafeteria, and showers	25 (95)
Day, with cafeteria, but without gyms or showers	20 (80)
Service stations (per vehicle served)	10 (40)
Swimming pools and bathhouses	10 (40)
Theaters	
Movie (per auditorium seat)	5 (20)
Drive-in (per car space)	5 (20)
Travel trailer parks without individual water and sewer hookups (per space)	50 (190)
Travel trailer parks with individual water and sewer hookups (per space)	100 (380)
Workers	
Construction (at semipermanent camps)	50 (190)
Day, at schools and offices (per shift)	15 (60)

[a] Unless otherwise noted.
[b] Includes cafeteria.

weekend population. Allowances of 10 gal (37.9 L) per person for showers and 7 gal (26.5 L) per person for toilet and kitchen wastes, both for the average weekend population, have been found reasonable.

Figure 8-4 from the *Manual of Septic Tank Practice* has long been used. However, modified wording is suggested:

"Where all pertinent factors are suitable for conventional soil absorption systems, Figure 8-4 and Table 8-11 may be used for sizing systems where the percolation test is selected. However, where local experience, soil analysis results, and other data are available, such data should be taken into consideration in the final design."

Table 8-12 and Figure 8-4 do not allow for waste from garbage grinders and automatic washing machines. Discharges from these appliances to an institutional waste disposal system call for special design considerations.

Generally, garbage disposal units are not recommended for institutional occupancies that have central kitchens. It is usually more efficient and economical to handle garbage through conventional garbage cans and disposal methods. However, where it is decided to use garbage disposal units in central kitchens or food-processing plants, the system designer should design the grease interceptor or a separate garbage separation tank especially on the basis of anticipated quantities of garbage to be produced between normal tank cleanings. Then, special provisions should be made for removal and disposal of garbage and grease at sufficiently frequent intervals based upon actual periodic inspection of such receptacles.

The amount of additional flow of wastewater from garbage grinding can be estimated by determining the nature of the operation. Interpolating from data in the *Manual*, an average design flow of about 1 gal (3.8 L) per meal per day is estimated when garbage grinders are used.

For residential automatic laundries, the *Manual* gives about 40 gal (151.4 L) per wash. An estimate of the average number of wash loads per day multiplied by 40 (151.4) would, therefore, give the wastewater flow to attribute to an institutional laundry.

INSPECTION

After a soil absorption system has been completely installed and before it is used, the entire system should be tested and inspected. The septic tank should be filled with water and allowed to stand overnight to check for leaks. If any leaks occur, they should be repaired immediately. The soil absorption system should be inspected before it is covered to be sure that the disposal system is installed properly. Prompt inspection before backfilling usually is required by local regulations, even where approval of plans for

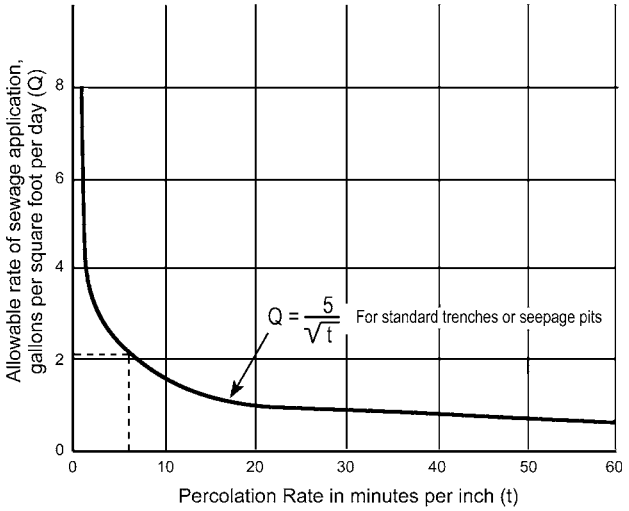


Figure 8-4 Graph Showing Relation Between Percolation Rate and Allowable Rate at Sewage Application

Source: *Manual of Septic Tank Practice.*

the subsurface sewage disposal system is required before issuance of a permit. Backfill material should be free of large stones and other deleterious material and should be over-filled a few inches (millimeters) to allow for settling.

REFERENCES

1. MacHatton, J.G. 1972. *Vacuum sewage collection*. Mishawaka, IN: Joseph MacHatton Assoc.
2. Otis, Richard J. 1976. "On site waste-water facilities for small communities and subdivisions." *Proceedings of the Third National Conferece on Individual On Site Waste-Water Systems*. Ann Arbor: Ann Arbor Science.
3. US Environmental Protection Agency. *Pressure sewer demonstration at the borough of Phoenixville, Pennsylvania*. Report EPA 2-73-270. Washington, DC.
4. US Public Health Service. *Manual of septic tank practice.* Washington, DC.
5. "What future role for pressure sewers?" *Civil Engineering* 44: 52-3, 1974.

BIBLIOGRAPHY

1. Bennett, E.R., and K.C. Linstedt. *Individual home waste-water characterization and treatment.* Fort Collins, CO: Environmental Resources Center, Colorado State University.
2. Boegly, W. J., et al. *MIUS technology evaluation: collection, treatment and disposal of liquid wastes*. ORNL-MIUS-16. Springfield, VA: National Technical Information Service.
3. McClelland, Nina I., Ed. 1976. *Proceedings of the third national conference on individual on site waste-water systems*. Ann Arbor: Ann Arbor Science.
4. Metcalf and Eddy, Inc. 1979. *Waste-water engineering: Treatment/disposal/reuse.* 2nd ed. New York: McGraw-Hill.

Table 8-11 Estimated Distribution of Sewage Flows

Type of Waste	Volume, gpd/person (L/d/person)				
	30 (115)	40 (150)	50 (190)	75 (285)	100 (380)
Kitchen wastes	0[a]	7 (26)	10 (40)	10 (40)	15 (60)
Toilet wastes	15 (60)	15 (60)	20 (80)	25 (95)	30 (115)
Showers, washbasins, etc.	15 (60)	18 (70)	20 (80)	25 (95)	35 (135)
Laundry wastes	0[a]	0[a]	0[a]	15 (60)	20 (80)

[a] No waste from these uses.

Table 8-12 Allowable Rate of Sewage Application to a Soil-Absorption System

Percolation Rate (time in min for water to fall 1 in. [25.4 mm])	Maximum Rate of Sewage Application for Absorption Trenches,[a] Seepage Beds, and Seepage Pits[b], g/ft²/d (L/m²/d)[c]	Percolation Rate (time in min for water to fall 1 in. [25.4 mm])	Maximum Rate of Sewage Application for Absorption Trenches, Seepage Beds, and Seepage Pits[b], g/ft²/d (L/m²/d)[c]
1 or less	5.0 (244.3)	10	1.6 (78.2)
2	3.5 (171.0)	15	1.3 (63.5)
3	2.9 (141.7)	30[d]	0.9 (44.0)
4	2.5 (122.2)	45[d]	0.8 (39.1)
5	2.2 (107.5)	60[d,e]	0.6 (29.3)

[a] Absorption area is figured as trench bottom area and includes a statistical allowance for vertical sidewall area.
[b] Absorption area for seepage pits is effective sidewall area.
[c] Not including effluents from septic tanks that receive wastes from garbage grinders and automatic washing machines.
[d] More than 30 is unsuitable for seepage pits.
[e] More than 60 is unsuitable for absorption systems.

5. U.S. Environmental Protection Agency. *Alternatives for small waste-water treatment systems: Cost-effectiveness analysis*. EPA Publication 625/4-77-011 (US Government Printing Office: 1977-757-140/6602). Washington, DC: US Government Printing Office.
6. U.S. Environmental Protection Agency. *Alternatives for small waste-water treatment systems: On-site disposal/seepage treatment and disposal*. EPA publication 625/4-77-011. (US Government Printing Office: 1977-757-140/6604). Washington, DC: US Government Printing Office.
7. U.S. Environmental Protection Agency. *Alternatives for small waste-water treatment systems: Pressure sewers/vacuum sewers*. EPA Publication 625/4-77-011 (US Government Printing Office: 1977-757-140/6603). Washington, DC: US Government Printing Office.

9 Private Water Wells

INTRODUCTION

This chapter will discuss the design and installation of private water well systems. Private water wells are considered a type of private water supply, since they are designed to provide potable water for a single building or facility of either residential or commercial construction. Normally, a water well that provides potable water to multiple buildings or facilities is considered a community water supply. Community water supply systems require more stringent design, a greater volume of reserve storage capacity, redundant pumping systems, a highly scrutinized permit process, and, for the most part, a full-time licensed water system operator. Conversely, a private water well system is installed, controlled, operated, and maintained by the user. Safe drinking water is the ultimate goal, and the methods described in this chapter are a means to that goal.

Engineering considerations in the design of private water wells include the following: the geology of the area, required demand, potential water quality, system elements, equipment, construction, initial operation, and maintenance procedures. In addition to addressing each of these areas, the engineer should seek sources of local information and references, including drilling logs of previously constructed wells and their respective water quality test results. The regional governmental agency or health department responsible for water quality and protection is the preferred source of information for the quality of the water supply and approximate location of aquifers. These agencies should be contacted as soon as possible to determine the adequacy and quality of the supply and any local regulations governing the construction of private water wells.

Wells often are classified as deep or shallow. A shallow well is considered to be about 50 to 100 feet (15 to 30 m) deep. A deep well generally is considered to be a superior source of water because the water is less susceptible to contamination and the depth of the aquifer usually fluctuates less than the water in a shallow well.

Codes and Standards

1. The Safe Drinking Water Act governs the quality of water from the wells.
2. U.S. Environmental Protection Agency manuals include standards establishing maximum contamination levels.
3. The Association of State Drinking Water Administrators provide potable water information.
4. State, local, and regional regulations provide minimum construction standards.

Sources of Supply

The source of water for private water well systems is groundwater, which by definition is subsurface water stored in a saturated state within certain types of geological formations beneath the Earth's surface. The Earth's crust is comprised of multiple layers of various geological formations of different minerals and many different substrates. Water-filled voids occur in both bedrock and regolith formations. The glacial drift (sand and gravel) and sandstone regions are examples of shallow water bearing zones, whereas shale and dolomite regions do not contain any saturated water properties. The water-saturated voids or regions are considered aquifers, and it is possible to find multiple aquifers at various elevations at the same location. Aquifers store subsurface water that can be yielded in an usable quality and quantity through the use of water wells. The water quality and volume that can be obtained from aquifers substantially changes from region to region and elevation to elevation. Groundwater supply is recharged through surface runoff that soaks into the ground and not absorbed by surface agriculture. Commercial development and drought have an impact on reducing the available recharge water for applicable aquifers. Aquifer recharge is necessary to preserve the well's water source; therefore,

protecting our environment from pollution is critical to the quality of future groundwater supplies.

A further explanation of subsurface water is given in Chapter 4, "Storm Water Drainage," in this volume.

WELLS

A water well is a cased hole (usually vertical) that is drilled through the Earth's substrate to access water that is stored within the Earth's aquifers. Modern wells generally are drilled using a machine that advances a bore hole to an aquifer, where a casing is installed to prevent collapse of the boring. This casing also prevents the well's aquifer from being contaminated by surface water or other sources of surface pollution at or near the surface of the ground.

The size of the well is determined by the building's water demand, equipment size (pump and pipe), and static pumping elevation. Deeper wells typically require larger diameter pumps/impellers, thus requiring larger diameter casings. Residential wells providing water for a single dwelling generally range from 2 to 6 in. (5 to 15 cm) in diameter and produce several hundred gallons of water per day. High-capacity wells, such as wells for industry or municipal water supplies, may range from 6 to 36 in. (15 to 91 cm) in diameter or larger and may produce several million gallons of water per day. Shallow wells of 50 to 100 ft (15 to 30 m) or less can be installed in loose formations of sand by driving or jetting (a high-pressure jet of water) a 2-in. (5-cm) pipe into the ground until an adequate depth is reached to provide the required water. Shallow wells more than 50 ft (15 m) in depth generally are drilled using mud or air rotary. These techniques use a fluid, such as water, drilling mud, or compressed air, to clean the soil cuttings from the bore hole as the well is drilled. Water or drilling mud is used in loose formations of sand and gravel to stabilize the bore hole, whereas deeper wells through clay and bedrock formations generally are drilled using air and water to clean the bore hole since these formations are fairly stable.

The bore hole is advanced until either adequate water is encountered or bedrock is reached. In either case, the bore hole must be of a significant depth to isolate the well so that it is not contaminated from surface water and pollutants. In porous formations of sand or gravel, casing is installed with a well screen to allow the water to easily enter the well from the aquifer. If bedrock is encountered before water, the bore hole is advanced into bedrock a few feet; a casing is installed; and the well is advanced into bedrock until water is encountered. The annulus between the casing and bore hole must be sealed with an impervious material to prevent infiltration of surface water into the aquifer. Specific state, local, and regional regulations provide minimum construction standards for the well with regard to potential sources of contamination, structures, surface features, and property lines. Additionally, state regulations may specify a minimum depth of the well, a minimum amount of casing, the type of casing, and grouting specifications for the annulus of the casing to prevent surface contamination. Typically, well permits are required before actual drilling can begin, with follow-up jurisdictional inspections.

Dug and Augered Wells

Depths can be 65 ft (20 m) or more, depending on the position of the water table, while diameters are usually 3 to 30 ft (1 to 9 m). Dug and augered wells can yield relatively large quantities of water from shallow sources. They are the most common kind of well used for individual water supplies. Their large diameters permit storage of considerable quantities of water if the wells extend some distance below the water table. Some large municipal wells called collectors are dug wells with lateral screened horizontal pipes.

In the past, all dug wells were excavated by hand; today, the auger method is becoming more widely utilized. The auger pulls loose material to the surface for distribution as fill. Large dug wells can be constructed rapidly with portable excavating and augering equipment. For safety and to prevent caving, a lining of shoring or sheet piling should be placed in the hole to brace the walls.

A dug well needs to be permanently lined with a casing of wood staves, brick, rock, concrete, or metal to support it from cave-in. A properly constructed dug well penetrating a permeable aquifer can yield approximately 200 to 1000 gpm (757 to 3,785 L/min), although most domestic dug wells yield less than 18,000 ft^3/day (510 m^3/day). It is difficult to provide a proper sanitary seal on a dug well, whereas augering allows the installation of welded steel casing to prevent ground source contamination. Construction of dug wells is prohibited or at least discouraged in some areas because of the increased possibility of surface contamination compared to deeper wells constructed by other means.

Bored Wells

Bored wells are constructed with hand-operated (shallow depths) or power-driven earth augers similar to those previously described. Augers are available in several shapes and sizes, all operating with cutting blades at the bottom that bore through the Earth's substrate in a rotary motion. Hand-boring operations rarely exceed 50 ft (15 m) in depth, whereas power drilling/augering equipment can exceed 1,000-ft (305-m) depths. Deep well construction requires casing pipe insulation to contain and prevent contamination but also to protect the well shaft from collapsing. The

drilling operation may pass through loose gravel or unstable strata before it reaches an aquifer to support the necessary water quality and quantity required for the project under design. It is important to specify a proper compound of portland cement and bentonite to grout and seal the well casing respective to its penetration through the various geological formations. This prevents surface contamination and prohibits contamination between the various layers between the Earth's geological formations.

Driven Wells

A driven well consists of a series of connected lengths of pipe driven by repeated impacts into the ground to below the water table. Water enters the well through a drive (or sand) point at the lower end of the well. This consists of a screened cylindrical section protected during driving by a steel cone at the bottom. Diameters of driven wells are small, most falling in the range of 2 to 4 in. (5 to 10 cm). Standard-weight steel and galvanized steel pipe having threaded couplings serve as casing. Most depths are less than 50 ft (15 m), although a few exceed 65 ft (20 m). As suction-type or jet pumps extract water from driven wells, the water table must be near the ground surface if a continuous water supply is to be obtained. The practical suction limit (that is, the vertical distance between the suction intake of the pump and the pumping level in the well) for a single pipe installation is about 25 ft (7.6 m). However, two-pipe venturi suction designs or multistaged turbine pumps can remove water from deeper depths.

Driven wells are best applied for single home, residential water supplies, for temporary water supplies (such as those required on a remotely located construction project), and for exploration and observation. Driven wells are limited to unconsolidated formations containing no large gravel or rocks that might damage the drive point. Driving can be done with a manual sledge, ram driver, drop hammer, or air hammer. The important advantages of driven wells are that they can be constructed in a short time, at minimum cost, and by just one person.

Jetted Wells

Jetted wells are constructed by the cutting action of a downward-directed stream of water. The high-velocity stream washes the earth away, while the casing, which is lowered into the deepening hole, conducts the water and cuttings up and out of the well. Small-diameter holes of 2 to 4 in. (5 to 10 cm) to depths greater than 50 ft (15 m) can be formed in this manner. Jetted wells typically have only small yields of water and are best suited to unconsolidated formations. During the jetting operation, the drill pipe is turned slowly to ensure a straight hole. To complete a shallow jetted well after the casing extends below the water table, the well pipe with screen attached is lowered to the bottom of the hole inside the casing. The outer casing then is pulled; gravel is inserted between the interior casing and the bore hole; and the well is ready for pumping.

The above procedure can be simplified by the use of a self-jetting well point. This consists of a tube of brass screen ending in a jetting nozzle, which is screwed to the well pipe. As soon as the well point is jetted to the required depth, the well is completed and ready for pumping. Gravel should be added around the drill pipe for permanent installation. Construction of jetted wells is prohibited in some areas because of the inability to grout the annular space and the consequent exposure of the well to surface contamination.

Hydraulics of Wells

Figure 9-1 shows a well under two conditions: (A) static, or nonpumping, and (B) pumping. Once the pumping of the well starts, the water table (or, in the case of a confined aquifer, the potentiometric surface) is lowered in the vicinity of the well, and the resulting water table surface is known as the cone of depression. The decrease in the water level at and in the vicinity of the well is known as the drawdown.

The basic equilibrium equation for an unconfined aquifer can be derived using the notations indicated in Figure 9-1. In this case, the flow is assumed to be radial; the original water table is considered to be horizontal; the well is considered to fully penetrate the aquifer, which has an infinite area; and steady-state conditions must prevail. Using Darcy's law, this becomes:

Equation 9-1

$$Q = \frac{K_f (h_2^2 - h_1^2)}{1{,}055 \, \mathrm{Log_e}\left(\frac{r_2}{r_1}\right)}$$

where

- Q = Discharge, gpm (L/min)
- K_f = Permeability (flow velocity), gal/day/ft^2 (L/day/m^2)
- h_2 = Static head measured from the bottom of the aquifer, ft (m)
- h_1 = Depth of water in the well while pumping, ft (m)
- r_2 = Radius of the cone of depression, ft (m)
- r_1 = Radius of the well, ft (m)

This equation then may be solved for K_f, yielding:

Equation 9-2

$$K_f = \frac{1{,}055 Q \mathrm{Log_{10}}\left(\frac{r_2}{r_1}\right)}{(h_2^2 - h_1^2)}$$

Where $\mathrm{Log_e}$ has been converted to $\mathrm{Log_{10}}$, K_f (flow velocity) is in gal/day/ft^2 (L/day/m^2); Q (discharge) is in gpm (L/min); and r and h are measured in ft (m). If

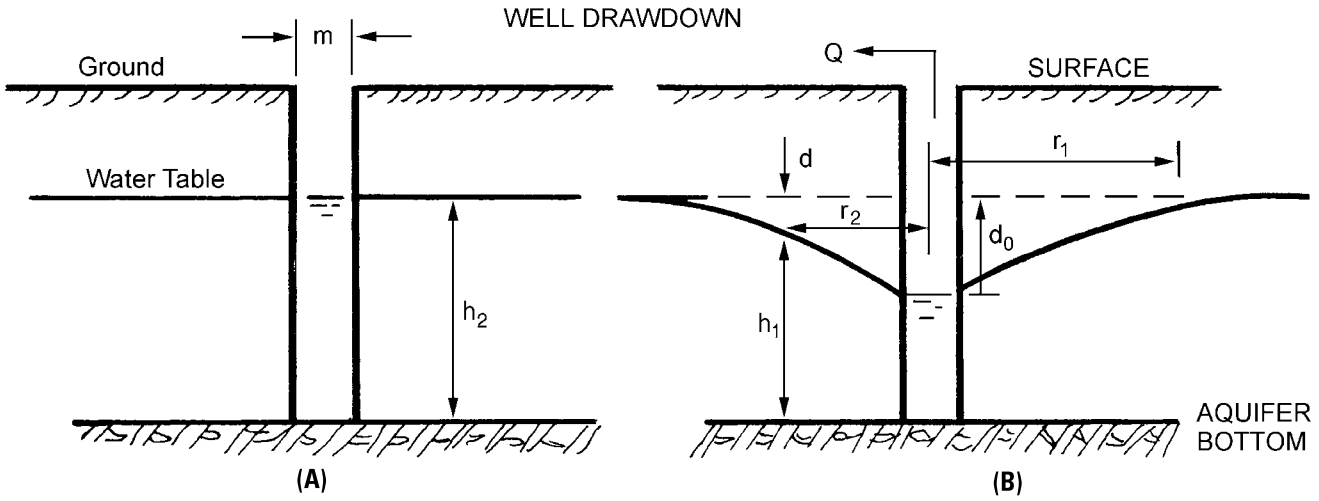


Figure 9-1 Well under (A) Static and (B) Pumping Conditions

the drawdown is small compared to the total aquifer thickness, an approximate formula for the discharge of the pumped well can be obtained by inserting wall height (h_w) for h_1 and the height of the aquifer for h_2 in Equation 9-1.

The basic equilibrium equation for a confined aquifer can be obtained in a similar manner, using the notation indicated in Figure 9-1. The same assumptions apply. Mathematically, the flow in ft^3/s (m^3/s) may be determined as follows:

Equation 9-3

$$Q = \frac{2K_f m\,(h_2 - h_1)}{\mathrm{Log_e}\left(\frac{r_2}{r_1}\right)}$$

where

m = Inside diameter of the well shaft, ft (m)

The coefficient of permeability may be determined by rearranging Equation 9-3 as follows:

Equation 9-4

$$K_f = \frac{528Q\mathrm{Log_{10}}\left(\frac{r_2}{r_1}\right)}{m(h_2^{\,2} - h_1^{\,2})}$$

Protection of Wells

Whenever groundwater pumped from a well is intended for human consumption, proper sanitary precautions must be taken to protect the water quality. (See discussion of water quality following.) Pollution sources may exist either above or below the ground surface. Submersible pump installations often are equipped with a pitless adapter, which provides an excellent sanitary seal as well as frost protection for the discharge piping. A cross-section of a typical pitless adaptor is illustrated in Figure 9-2.

Surface pollution can enter wells through either the annular space outside the casing or the top of the well itself. To close avenues of access outside the casing, the annular space should be filled with a sealing grout—either a cement, bentonite, or combination thereof. Entry through the top of the well can be prevented by the provision of a water-tight cover to seal the top of the casing. Some pumps are available with close metal bases that provide the necessary closure. For pumps with an open-type base, or where the pump is not placed directly over the well, a seal is required for the annular opening between the discharge pipe and the casing. It is desirable to provide a small (sealed) opening in or below the pump base to allow for periodic water level measurements. Covers around the well should be made of concrete, elevated above the level of the adjacent land, and slope away from the well. Where possible, pitless adapters should be used in preference to buried well seals or seals located in a concrete pit.

Subsurface pollution may be introduced by nearby septic systems, adjacent industry, surface runoff, or numerous types of current and past land uses. A contaminated plume can extend a long distance in an underground stream or aquifer. Regular bacteriological and chemical testing of the water quality is required to ensure potability. Whenever a new well is completed or an old well repaired, contamination from equipment, well materials, or surface water may be introduced to the well. The addition and agitation of a chlorine compound will disinfect the well, though they may promote additional corrosion to older steel-cased wells. Thus, following the disinfection the well should be pumped to waste until all traces of chlorine are removed. As a final check on the potability of the water, two samples should be collected 24 hours apart and sent to a certified testing laboratory for bacteriological examination.

In regions where winter frost occurs, it is important to protect pumps and water lines from freezing. Pitless adapters are the most common method used to protect the well head from freezing and pollution.

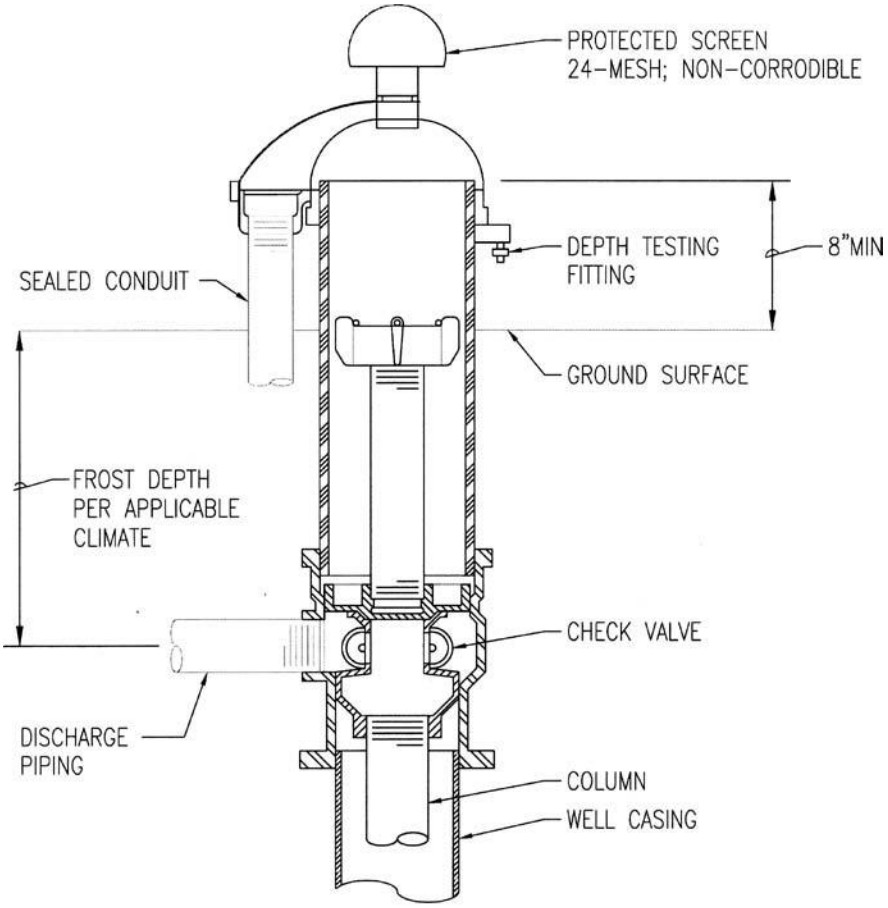


Figure 9-2 Typical Pitless Adaptor

Pitless adaptors allow for pump discharge below frost level and at the same time provide a check valve for backflow protection.

When a well is abandoned it should be properly sealed by filling it with cement grout, bentonite, or a combination thereof. Sealing prevents surface contamination from entering the well, and it also prevents accidents and the possible movement of inferior water from one aquifer to another and conserves water in flowing wells. As necessary, other sealing measures may be needed to ensure that contaminants do not migrate within the aquifer(s) by movement in the annular space between the well casing and the bore hole. To ensure the well is completely sealed, the cement and/or bentonite should be pumped under pressure through a tremie pipe or other means to discharge at the bottom of the well, forcing its way upward until it reaches the surface.

WATER DEMAND

The demand for water in a new system is determined by the design engineer. The building's system dynamic and static requirements are utilized in determining the water demand. The designer should refer to previous ASPE *Plumbing Engineering Design Handbook* or previous *Data Book* chapters that describe the methods for estimating water demand. The engineer should consult with the local administrative authority regarding local codes and regulations. Designing water systems for firefighting purposes requires knowledge of a building's construction, occupancy, and use. Nationally recognized standards, acceptable to the local administrative authority under the applicable code(s), should be followed. The flow from a 1½-in. (3-cm) nominal size nozzle at 45 psig (310.3 kPa) can be as much as 250 gpm (15.8 L/s). It is recommended to install water meters on the non-domestic demands (such as irrigation, fire protection, and heating/cooling loads) to allow the building's owner to monitor consumption.

WATER QUALITY

The Safe Drinking Water Act of 1974, subsequently amended in 1996, requires the administrator of the EPA to promulgate national standards for the purity of the drinking water and corresponding regulations to enforce them. Current EPA manuals include standards establishing maximum contamination levels. States have adopted these standards or more stringent standards. Efforts must be made to conform with these regulations in all systems.

Well water is usually satisfactory for drinking because of the natural filtration created as the water passes through the geological formations. However, when there is an excess of dissolved minerals or gases, treatment of the water is necessary. Selection of the appropriate treatment process must be made based on a thorough knowledge of the water and its chemical composition. The processes employed include filtration, softening, coagulation and flocculation, taste and odor control, prophylaxis, and disinfection. These treatment processes are described below.

Filtration

Where the water is not of an adequate purity and/or clarity, filters are required. Filters may be either gravity or pressure type and should include automatic controls for all functions. These devices may be sand or multimedia (provided that when aggressive or low pH water is processed, the sand does not contain excessive amounts of limestone or shells). The grade

of the sand and/or type of media depends on local conditions.

Coarse sand is less effective in the removal of turbidity and bacteria, while fine sand requires a shorter period between washings. Filters may use layers of various grades of sand and gravel to minimize filter gravel upset and loss of sand. These units may include anthracite coal particles or activated carbon, both of which are often effective in removing objectionable tastes, odors, and other impurities. Filters should be backwashed and disinfected before being placed back in service. Parallel filtration prevents interruption of the supply water during backwash and/or cleaning.

Softening

The two methods of reducing any dissolved calcium and magnesium that are suitable for large water supplies are the zeolite process and the lime soda method. The zeolite process replaces the calcium and magnesium chlorides, and all residues (backwash) must be disposed of in locations where the groundwater will not be contaminated. Zeolite systems may be automated or manual. When iron is removed by this process, the oxides may clog the filter beds. Cleaning the beds requires high-velocity washing.

The lime soda method removes calcium, magnesium, manganese, iron, and carbon dioxide. The pH is raised, and most units effectively destroy any harmful organisms. This method produces considerable quantities of sludge, which require proper disposal. The lime soda method involves a large installation and skilled operation. Equipment is needed to mix and feed chemicals and for flocculation and settling, recarbonating and filtering. When iron is not removed, it may be held in solution in cool water up to 72 hours by the addition of hexametaphosphate. This chemical may prevent incrustation in water with a high pH.

Scale and Corrosion Control

Elimination of any excessive scale and corrosion of the piping system is important. This may be accomplished by the proper choice of piping materials or by chemical treatment of the water. Specifying a plastic distribution system will not protect the metallic piping and equipment in buildings. The control of hardness, dissolved oxygen and carbon dioxide, and acidity may be necessary. Sodium hexametaphosphate commonly is used for corrosion control, scale prevention, and removal of hardness.

Taste and Odor Control

Potassium permanganate oxidizes iron and manganese, forming a precipitate. This compound also acts as an algaecide. Oxygenation is another way to treat the water, which may (in some cases) be more effective than treating it with potassium permanganate. Activated carbon has been found to be effective in removing phenolic compounds as well as certain other undesirable materials. Sodium thiosulfate or sodium bisulfate has been used to remove chlorine from water, and copper sulfate will destroy living organic matter.

Prophylaxis

Fluoride sometimes is added to the water with the intent of reducing dental cavities. Where amounts of fluoride are excessive, tooth enamel will become mottled. Some waters have adequate or even excessive fluoride in their natural state.

Disinfection

Disinfection should be the last step in the water treatment process. Chlorination has been shown to prevent epidemics of waterborne disease; it also destroys ammonia. It is an inexpensive method compared to ultraviolet radiation and ozone treatment. Gaseous chlorine is used in large installations, while calcium and sodium hypochlorite are satisfactory for small systems. Water from a properly constructed modern well seldom needs to be disinfected once the well and pumping equipment are initially disinfected.

Radon Contamination

In areas where radon (a radioactive gas) is present in lower quantities in the ground, the water might be contaminated. Treatment may be necessry to eliminate this from the drinking water source. Water softening is often used to accomplish this.

SYSTEM ELEMENTS

Pumps

The three most common well pump systems are vertical turbine pumps, jet pumps, and submersible pump.

The vertical turbine pump is a centrifugal pump that has the motor on the ground surface over the bore hole with a shaft and impeller suspended in the aquifer. It is well suited for large flow rates, deep wells, and high discharge heads. The jet pump is a centrifugal pump that has the motor and the impeller on the ground surface but uses a jet of water flowing down the bore hole to create a partial vacuum at the bottom that, with a special fitting, draws an additional amount of water into the discharge pipe. This pump is used for small flow rates. A submerged pump is a centrifugal pump that is entirely self-contained in a housing. It contains the electrical motor close-coupled with an impeller and an attached discharge pipe to the surface. This pump is well suited for a wide variety of flow rates and pressures.

The design of a pumping system should take into consideration maintenance and the possible failure of one pump in the system. Because this is not possible in the case of a private water well, it is sometimes necessary to have a backup (second) pump. This can

be expensive, but if the system serves fire hydrants or fire protection equipment within a building without the use of a storage tank, it may be essential. Pumps for residential or light commercial applications may be readily in stock at local supply companies in areas where many private water wells are prevalent. On the other hand, it is common to have large well drilling companies keep and maintain a large-diameter submersible well pump for large applications within their inventories for your emergency use at a cost.

A cross-section of a vertical turbine pump is illustrated in Figure 9-3. The designer should give more attention to the pump base (or foundation) than is shown in this figure. If the pump is in an unheated building, the foundation must be below the frost line to avoid any movement, and there must be sufficient mass to eliminate any vibration. Also, extreme care must be taken in setting the anchor bolts and in aligning the pump and the shaft to prevent any misalignment. Refer to ASPE *Data Book, Volume 4: Pumps* for additional information.

The vertical turbine pump shown in Figure 9-3 is very practical for large-capacity, relatively straight and plumb, shallow wells. Where deep wells or misaligned wells are encountered, it may be more practical to use a submersible pump. These units can be fitted with almost any number of stages (sections) and, depending upon the size of the well, can exceed the capacity and efficiency of the surface-mounted vertical turbine pump.

Submersible Well Pumps

Well pumps produce flow by transforming mechanical energy to hydraulic energy. Manufacturers produce a wide variety of pumps. The selection of a particular size and type of pump depends on several factors including:

1. required pumping capacity,
2. well diameter and depth,
3. depth and variability of pumping level,
4. the straightness of the well,
5. sand pumping,
6. total pumping head,
7. duration of pumping,
8. the type of power available, and
9. costs.

The total pumping head, or total dynamic head, of a pump represents the total vertical lift and pumped distance of the water from the well. The total head consists of three components:

1 the drawdown inside the well (including aquifer and well losses),

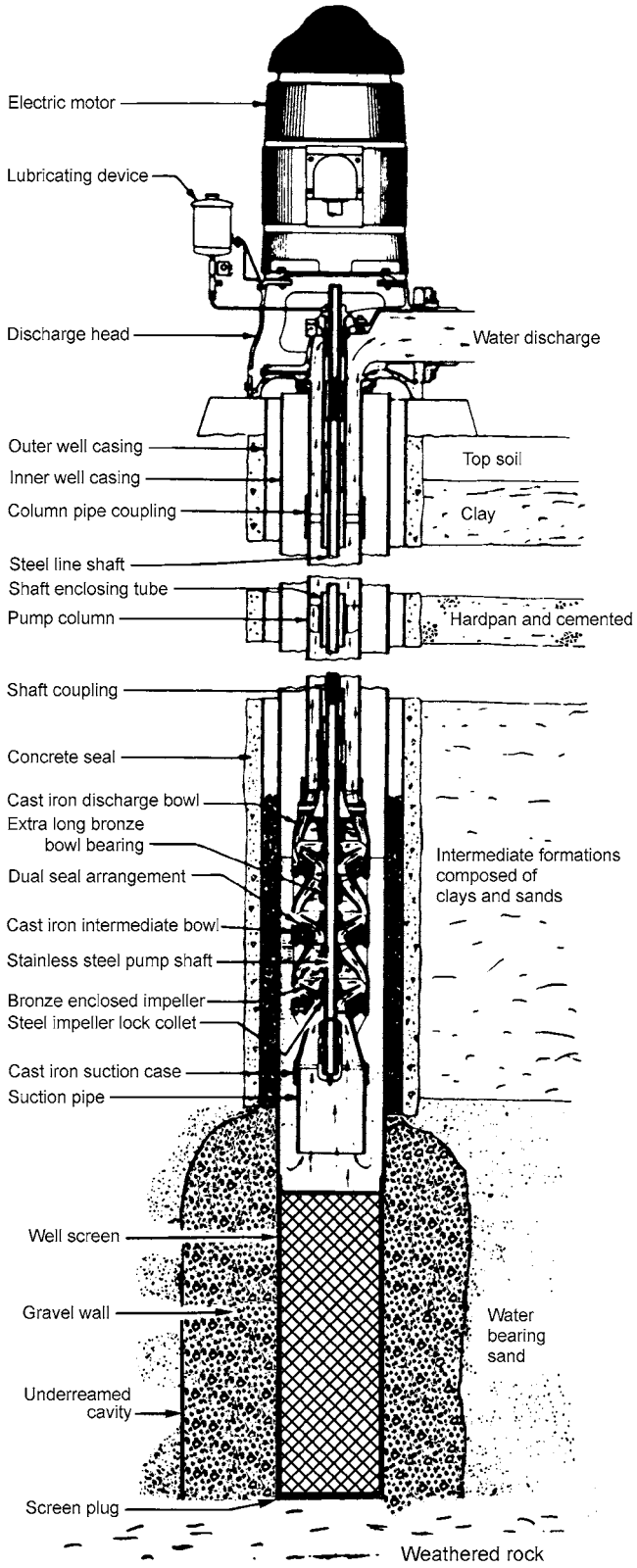


Figure 9-3 Typical Gravel Filter Well with a Vertical Turbine Pump (Note the Concrete Seal Adjacent to the Outer Well Casing.)

2 static head, or the difference between the static groundwater level and the static discharge elevation, and

3 friction losses due to flow through the intake and discharge pipes. The total pumping head increases with the discharge rate.

For shallow wells where only small discharges are needed, submersible pumps, vertical turbine pumps (Figure 9-2), or gear pumps may be installed. Discharges range up to approximately 18,000 ft^3/day (510 m^3/day). Suction lifts should not exceed approximately 23 ft (7 m) for efficient and continuous service. (Available net positive suction head, or NPSH, for lift for the selected pump is critical in this determination.)

Where a large discharge is required from a shallow well, a centrifugal pump commonly is employed. The assembly may be mounted with a horizontal or vertical shaft. The horizontal design is efficient, easy to install and maintain, and usually connected directly to an electric motor. Because of the low suction head, the pump often is placed a short distance above the water level in a large-diameter well. (The NPSH must meet the design requirements.)

Storage Tanks

Storage tanks are useful as emergency sources and to prevent overtaxing the water supply system in firefighting situations. Elevated storage tanks provide uniform pressures and reduce energy and pump costs. Storage tanks should be constructed of materials that are nontoxic and corrosion resistant. The detailed construction requirements for water storage tanks intended for firefighting purposes are outlined in National Fire Protection Association (NFPA) Standard 22: *Water Tanks for Fire Protection*. Storage tank supports usually are designed to resist seismic movement. The tanks must have provisions for cleaning. Rainwater cisterns also can be used for an emergency supply of drinking water if the water is appropriately filtered and treated prior to use.

Storage tank capacity and the size of the pump system are related. Without storage, the pumps must be large enough to supply instantaneous demand. This is impractical since instantaneous water demands are unpredictable, thus causing short-cycling of pump motors and reducing life expectancy. As the size of the storage tanks increase, the fill rate of gravity tanks can decrease with the reduction, or elimination, of peak loads to reduce costs and equipment size. This also allows continuous operation of the pumps at maximum efficiency.

Ground-mounted storage tanks located on the side of a hill must be installed on a concrete foundation with the footing below the frost line and adequate support under the entire bottom of the storage tank. Taking soil bearing tests prior to designing the foundation is extremely important. It is better to over-design than to have a portion of the foundation settle and allow the storage tank to become warped or possibly leak.

Prefabricated storage tanks are available in sections and constructed of steel with a glass lining. If a steel tank is field-erected, after its construction it must be coated on the inside with a FDA-approved epoxy-base paint, and it is suggested that the same coating be applied on the outside for weather protection. Underground tanks require coatings and cathodic protection. There are several different suppliers of this type of material, finish, and protection. It is recommended that the engineer consult an expert before specifying the coating.

In flatland areas where the terrain does not allow for a ground-mounted storage tank, it is necessary to install an elevated tank on legs or use a standpipe. The foundation in such installations is just as critical as it is with ground-mounted tanks. The installation of ground-level or aboveground storage tanks raises the question of ice forming in the storage tank itself. If the water level within the storage tank is allowed to fluctuate over a broad range, the changes in the water level will break up the ice so that it is not necessary to heat the unit. Control of the water level is discussed later in this chapter.

For a small residential system or light commercial system (for instance, that for a remotely located school), the use of a hydropneumatic storage tank is recommended because it is relatively inexpensive compared to an elevated storage tank. In sizing such a unit, the designer should assume that only one-third of the tank's capacity will be available as usable water, excluding the capacity of the well pump. Also, a compressed air supply with air-to-water balance controls to the top of the storage tank should be provided to recharge the unit since the large water surface can gradually absorb the air and reduce the volume of the air cushion. Precharged hydropneumatic tanks are available that eliminate the requirement for an air compressor for recharging. Unfortunately, the available sizes preclude their use to residential and light commercial applications. Generally, hydropneumatic tank systems do not provide sufficient storage for fire protection or for extended outages of the well pump.

The minimum size of storage, regardless of the type of tank, may be determined graphically (see Figure 9-4). The first diagram denotes the hourly water demand throughout a typical peak day. Also shown, as line A-B, is the average pumping rate, which is exceeded during the morning period from 5:00 to 10:00 a.m. and again in the afternoon from 2:00 to 3:00 p.m. During these periods, water is drawn from the storage tank. The second diagram denotes the

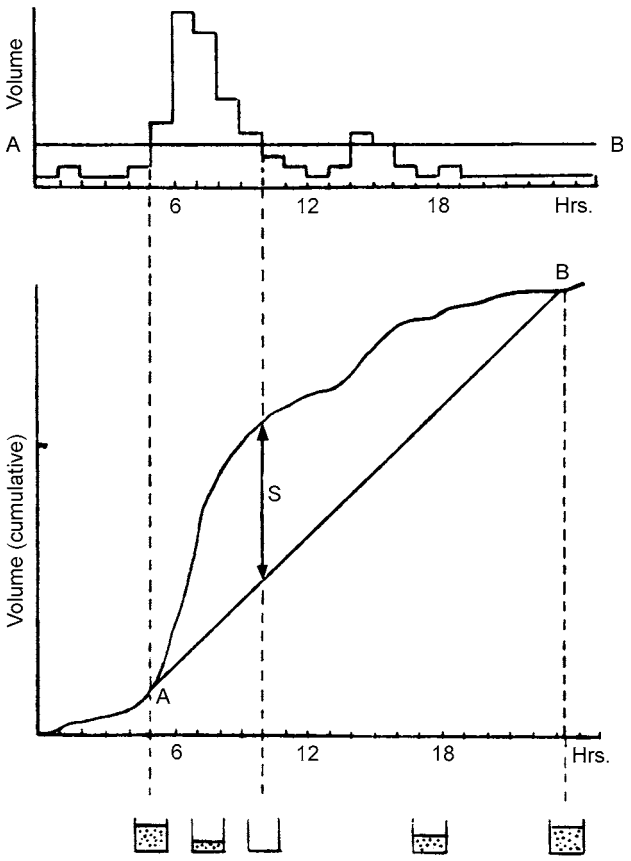


Figure 9-4 Graph Indicating Minimum Storage-Tank Size

cumulative water consumption for the day. Again the pumping volume (a constant rate) is shown as line A-B. The quantity S represents the total storage volume required with the supply rate A-B. Alternate supply rates can be drawn and the corresponding storage volume requirement determined.

Storage Tank Suction Piping

The minimum distance below the water level that a suction inlet must be to avoid drawing any air into the suction pipe is illustrated in Figure 9-5. Minimum submergence is highly desirable to develop a full pump output. In addition, the suction pipe should be a few inches (centimeters) above the bottom of the storage tank to avoid drawing any sediment into the suction pipe. Gravity storage tanks must be screened and adequately vented. Anti-vortex plates also can be utilized at suction connections to storage vessels to prevent the pump from drawing air and cavitating.

Pressure Regulators

Pressures in excess of 80 psi (551.6 kPa) in private water well systems should be avoided whenever possible; in some cases, this is required by local codes. If this is so, pressure-regulating devices must be installed in buildings. Pressure regulators, as most devices, are subject to wear and may create noisy conditions, and relief valves are required to be used in conjunction with them, in the event of regulator failure.

This condition determines the height of the elevated storage tank from the lowest point of use. The fluctuation of the water level from the top of the storage tank to the bottom is not critical. If a well pump`s starting and stopping is controlled by the storage tank level, the reduced-pressure condition of 80 psi (551.6 kPa) can be achieved by one of a number of acceptable means. The engineer should consult with the local administrative authority to determine the approved methods. Unfortunately, in northern latitudes, a float-type level control in the storage tank frequently is affected by icing and, therefore, is not a very reliable device. One of the more common ways of

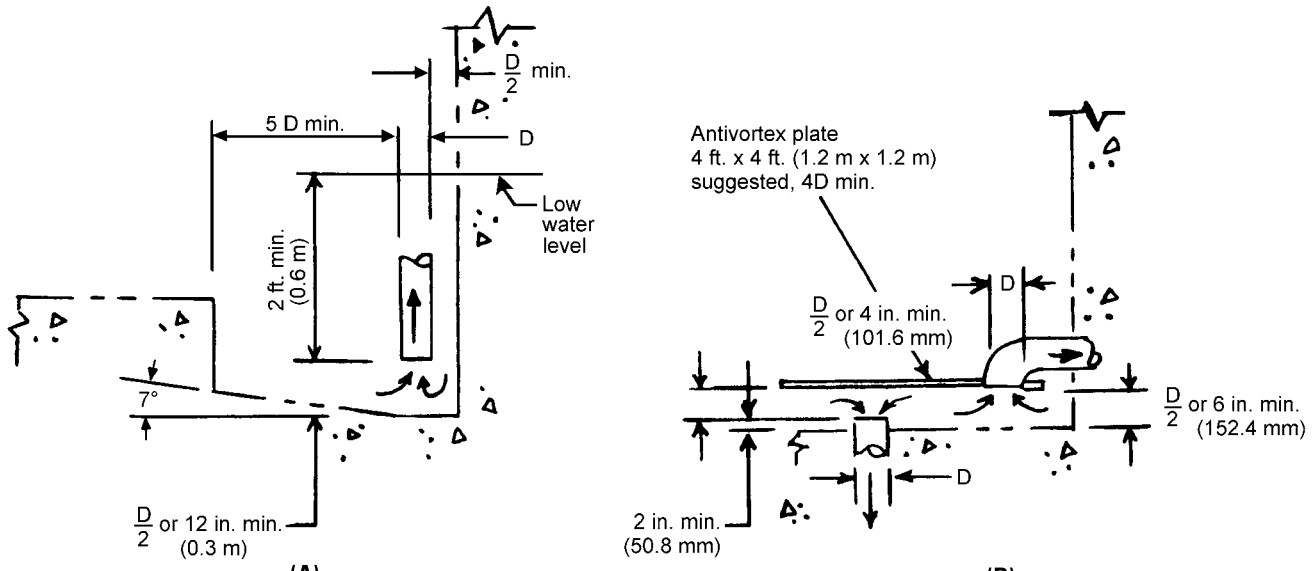


Figure 9-5 Storage-Tank Suction Piping Detail: (A) Sump Suction Alternate, (B) Anti-Vortex Alternate

eliminating the problem is the use of an altitude valve, which is installed in the supply line to an elevated storage tank, basin, or reservoir for the purpose of preventing overflow. The altitude valve closes at the predetermined high-water level and opens for refilling when the water level recedes. A single-acting altitude valve is employed for filling purposes only. The discharge from the storage tank is handled by a swing check valve in a bypass around the altitude valve. A double-acting altitude valve is designed for two-way flows and eliminates the need for a bypass. Without additional controls, the well pump(s) or system pump(s) will run continuously. Another type of system currently available controls the well pump and the storage tank level by sensing the system's pressure at the point of pump discharge.

PERFORMANCE SPECIFICATIONS

The design and specification of private water wells is not an exact science. You can consult with all the regulatory agencies and consult with previous well drilling logs within the region to find no water where X marks the spot. On the other hand, you may shift your drill hole 10 feet north and 30 feet west to find a sand and gravel vein that can be test pumped at 200 gpm (757 L/min.) for 24 hours and barely impact the elevation of the aquifer. On large-diameter wells it may be prudent to drill an inexpensive, small-diameter (2 in./5 cm) test hole to determine if water is available at the proposed location. Test pumping on a small diameter well will determine the availability of large volumes of water, as required for large-diameter wells, utilizing the equations listed within this chapter.

It is recommended to write your specifications on performance-based conditions. List estimated drilling depths through the various anticipated geographical formations and require the installing well contractor to give a plus or minus unit cost basis for penetrating through these anticipated formations. In the event they penetrate through in a lesser depth, a legitimate credit can be received; if it is a greater depth, a prenegotiated cost already is established. It also is recommended to establish a unit cost basis for well test pumping (per hour basis), installed casing pipe material (per diameter and per foot basis), installed grout/sealing material (per pound/bag), and hourly rates for well development and clearing using shots similar to nitro-glycerine blasts. Bid-form unit pricing will keep all parties on a level playing field when unexpected circumstances arise, a periodic occurrance when digging/drilling private water wells.

Corrosion Protection

Metallic piping generally is chosen because of the high presure requirements. Plastic pipes, when used, usually are not subject to corrosion. The occurrence of corrosion depends on the soil and water conditions. Proper water treatment and pipe linings can minimize interior attack; exterior attack may be reduced by coatings, cathodic protection, and careful selection of the backfill. Coatings must remain intact and protection must be inspected and maintained periodically.

Require a one-year warranty and a follow-up one-year inspection of all cathodic protection devices (anodes) and protective coatings by the installing contractor for additional quality control.

INITIAL OPERATION AND MAINTENANCE

After the well has been dug, it must be developed. Every type of drilling causes some disturbance to the aquifer by cloging the pores of the formation where it exists. After the bore hole has been completed, the casing is inserted; the intake attached; and the gravel packing installed. Development is the process that removes loose material from the natural formation around the intake and enlarging it. This is the last stage of construction and is regarded as an art rather than a science.

Following developoment of a well, the next procedure is testing for yield by measuring the flow rate of pumping and observing the lowering of the water level. This is called drawdown and shall be the quantity of water that can be withdrawn on a continuing basis without depletion of the aquifer.

All private water wells and potable water piping must be disinfected prior to being placed into service. This process may be accomplished by introducing a solution of chlorine followed by a thorough flushing of the system with clear water. Well-kept records of the piping and connections will facilitate good operation and maintenance. Periodic flushing, particularly of dead ends and low-velocity branches, will prevent sedimentation and fouling. Regularly scheduled valve exercising will ready the system for shutdown during an emergency. Leakage may be controlled by inspection. Installation of approved backflow prevention devices will protect your private water supply from nonpotable sources. Inspections during and after construction will guard against cross-connections.

ADDITIONAL INFORMATION

For additional information on groundwater protection, contact the National Ground Water Association at www.ngwa.org. For additional information on safe drinking water standards, contact the Association of State Drinking Water Administrators at www.asdwa.org.

American Society of Plumbing Engineers
NON-PROFIT ORGANIZATION
Cleveland Chapter
P.O. Box 5962
Cleveland, Ohio 44101-0962

CHAPTER OFFICERS

President
MITCH CLEMENTE, CPD
Westlake Reed Leskosky
Email: mclem@WRLdesign.com
(216) 522-1350
(216) 522-1357 (fax)

V.P. Technical
JOHN VARGA
Scheeser Buckley Mayfield, Inc.
Email: jvarga@sbmce.com
(330) 896-4664
(330) 896-9180 (fax)

V.P. Legislative
LELIA MARINESCU, PE
Department of Public Utilities
Division of Water
Email: lelia_marinescu1@clevelandwater.com
(216) 664-2444
(216) 664-2378 (fax)

V.P. Membership
GREG TROMBOLD
Trombold Equipment Company
Email: gtrombold@hotmail.com
(216) 663-8700
(216) 663-8702 (fax)

Treasurer
KEVIN NOBLE, P.E.
Scheeser Buckley Mayfield, Inc.
Email: knoble@sbmce.com
(330) 896-4664 ext. 114
(330) 896-9180 (fax)

Administrative Secretary
DAN EVANS, CPD
Hinkel Engineering, Inc.
Email: evans@hei-ohio.com
(330) 262-0042
(330) 262-0392 (fax)

Corresponding Secretary
CRAIG McDOWELL
Omar McDowell Company
Email: omarmcd@aol.com
(440) 808-2280
(440) 808-2266 (fax)

Affiliate Liaison
JOHN GRIFFIN
Libb Company
Email: jegriffin1@juno.com
(330) 297-0757
(330) 297-0157 (fax)

Newsletter Editor
MICHAEL DRAB
Thorson Baker & Associates
Email: mdrab@thorsonbaker.com
(330) 659-6688
(330) 659-6675 (fax)

The ***Cleveland Chapter*** of the American Society of Plumbing Engineers would like to thank the following members for participation in the organization:

Alag, Harjit
Austrian, Dan
Baker, David.
Banas, Mark
Bemross, William
Bentzen, Louis
Bernsdorff , Harold
Bica, Corina
Boger, John
Budd, Terrence
Burns, Edward
Cacolici, Dominic
Campbell, Thomas
Campbell, Tim
Cassell, Michael
Cebula, Joseph
Chase, Stephen
Church, Donald
Clemente, Mitchell
Conyngham, Kevin
Drab, Michael
Dunmire, Robert
Evans, Daniel
Fesz, Stephen
Frey Jr., Ralph
Friess, Gregory
Gallagher, Michael
Garramone, Guy
Gill, Gerald
Godfrey, Russell
Gray Sr., Allen
Griffin, John
Grigoriu, John
Haas, Richard
Hartsock, Robert
Hausmann, Dieter
Herbert, Deborah
Herbert, Kevin
Hicks, Guy
Hinkel Jr., Harry
Homola, Christopher
Jasinski, Jaime
Jirka, John
Johnson, Marilyn
Kerr, Kenneth
Kilbane, Terrence
Knickerbocker, Gerald
Kobuszewski, Michael.
Kovesdi, Andrew
Kuentz, Kenneth
Kummerlen, Norman
Lancaster, Paul
Laucher, Ernest
LeJarde, Emmanuel
Liggett, Edward
Lisowski, Raymond.
Lowe, Todd
Lyczko, Edward
Malkin, Dennis
Marinescu, Lelia
Massel, Tina
Mathews, Kenneth
McDowell, Craig
Melfe, Gregg
Meredith, Daniel
Miller, Craig
Morrissey, Tim
Murman, David
Neuendorf, Mark
Noble, Kevin
Oldaker, Donald
Pacek, Daniel
Porter, Thomas
Prospal, Richard
Prout, Wesley
Rechner, Michael
Roessler, Doug
Rotunda, Ann Marie
Rotunda, Thomas
Schindley, Michael
Selby, Richard
Shunk, Paul
Singh, Hardip
Staley, Josh
Stewart, Dave
Taylor, Larry
Tesar, Robert
Tomazic, Dennis
Torosian, Arek
Townley, Donald
Trombold, Greg
Uchen, Michael
Utis, Inna
Van Goor, Robert
Varga, John
Waniewski, Carl
Wanner, Thomas
Weese, Ronald
Wesner, Michael
Wickert, James
Yambert, Robert
Yeung, Todd
Zaffuto, Joseph
Zunt, Jeffrey

Roster as of August 1, 2006

American Society of Plumbing Engineers
Rochester Chapter

Special thanks to our members

Gary S. Andrzejewski
Christopher H. Baumer
Terrence P. Brown CIPE
Bruce H. Campbell
Jeffrey S. Close G.E.
Charles E. Cook
Robert L. Czerkas
Jeffrey M. Davis P.E.
Jason R. Dredger
Terry L. Gatti
Robert A. Gottermeier
Nicole Marie Guilfoyle
Dave Jereckos
Kenneth D. Kassel
Adam Paul Kramer
Kurt P. Kubli P.E., CIPE
Thomas R. R. Manz CPD
Edward M. Maybeck P.E., CIPE
Troy A. McClure P.E.
Douglas B. Meier
David M. Merchant CPD
David Walter Myers
Peiter Charles Poulton
David R. Reynolds P.E.
Timothy Robinson
James F Rubino
John T. Ruffner
Fred G. Schreiner
Alan D. Smith P.E.
Larry D. Smith P.E.
Vincent J. Stanley
Alexander C. Strasenburgh P.E.
Douglas M. Volland P.E., CIPE
Wayne A. Volpe
Jennifer J. Wengender P.E.
Robert Joseph Wind Jr., PE
Richard T. Wisotzke
Alan J. Worgo
Edward J. Yelin G.E.
Steven R. Ziblut P.E., G.E.

10 Vacuum Systems

INTRODUCTION

This chapter describes design criteria, source equipment, and piping distribution networks for vacuum systems used for general and laboratory applications and central vacuum-cleaning systems.

For the purposes of the discussion in this chapter, references to inch-pound (IP) units and international standard (SI), or metric, units shall follow the following conventions:

1. Flow-rate measurements referring to standard conditions shall be preceded by the prefix "s" for IP units and "n" for SI units.
2. Pressure designations using standard atmospheric conditions as the base shall be followed by the suffix "g" for "gauge pressure" in IP units. (No suffix is used with SI units.)
3. Pressure designations using absolute zero pressure conditions as the base shall be followed by the suffix "abs" in both IP and SI units.
4. Pipe sizes using nominal pipe-diameter dimensions in IP units shall be designated as "nominal pipe size" (NPS) and based on inches and fractions of an inch (e.g., 2 and 1½ in.); in SI units the size shall be expressed as nominal diameter (DN), based on millimeters (e.g., 50 and 40 DN).

Unless otherwise noted, measurements used in this chapter are in inch-pound (IP) units, with metric (SI) units given in parenthesis.

FUNDAMENTALS

For the purposes of this discussion, "vacuum" is any air pressure lower than atmospheric pressure. Vacuum is used by having air at atmospheric pressure enter a piping system that has a lower pressure. The way most vacuum systems function is that air becomes the transporting medium for any gas or suspended solids and the negative pressure provides the energy for transportation. These two essential factors operate in inverse proportion: as the airflow increases, the vacuum pressure decreases.

The various systems must be designed to produce specific vacuum-pressure and airflow levels that have been determined, often by experience and experimentation, to be most effective in performing their respective tasks. The exception is where vacuum pressure is intended to produce a force to lift objects or simply to evacuate and maintain a vacuum in an enclosed space. For these uses, airflow is only a function of how long it takes the system to achieve its ultimate vacuum pressure. Vacuum used for lift is outside the scope of this chapter.

The vacuum-piping network is sized using the following four criteria: total connected load/flow rate, the diversity factor, the equivalent length of piping and the allowable friction loss. The equivalent length is found by using the actual measured run and adding fifty percent of the measured run. The total is the equivalent length.

The "vacuum level" is the difference in pressure between the evacuated system and the atmosphere. Vacuum pressures fall into three general categories:

1. Rough (or course) vacuum, up to 28 in. Hg (94.8 kPa).
2. Medium (or fine) vacuum, up to 1 micron (μ).
3. Ultra-high vacuum, greater than 1 μ.

PRESSURE MEASUREMENT

While defining "vacuum" is straightforward, measuring a vacuum level (or force) is not. Several methods of measurement are used, each depending on a different reference point.

Units of Measurement and Reference Points

The two basic reference points for measuring vacuum are standard atmospheric pressure and a perfect vacuum. When the point of reference is standard atmospheric pressure, the measurement from that to a specified vacuum pressure is called "gauge pressure." If the pressure level is measured from a perfect

vacuum, the term used for the measurement is "absolute pressure." "Local barometric pressure," which is the prevailing pressure at any specific location, should not be confused with standard atmosphere, which is mean barometric pressure at sea level.

To compute work forces and changes in volume, it is necessary to convert to negative gauge pressure—expressed as pounds per square inch gauge (psig) or kilopascals (kPa)—or to absolute pressure—expressed as pounds per square inch absolute (psia) or kilopascals (kPa). The units used are inches of mercury (in. Hg) and the millibar (mbar). These units originate from the use of a barometer. The basic barometer is an evacuated vertical tube with its top end closed and the open bottom placed in a container of mercury open to the atmosphere. The pressure, or weight, exerted by the atmosphere on the open container forces the mercury up into the tube. At sea level, this pressure supports a column of mercury 29.92 in. high. In pressure units, this becomes 14.69 psi (0 kPa).

Standard reference points and conversions On the dials of most pressure gauges, atmospheric pressure is assigned the value of zero. Vacuum measurements must have a value of less than zero. "Negative gauge pressure" is the difference between the system vacuum pressure and atmospheric pressure. "Absolute pressure" is the pressure (in psia) above a perfect vacuum and is equal to atmospheric pressure less negative gauge pressure.

Other vacuum units are "atmospheres," "torr," and "microns." To calculate "atmospheres" knowing absolute pressure in psia, divide that figure by 14.7. A "torr" is 1/760 of an atmosphere, and a "micron" (μ) is 0.001 torr.

Table 10-1 compares basic vacuum-pressure measurements from the two most commonly used reference points. Figure 10-1 gives conversion from and to various IP and SI pressure measurements. Table 10-2 gives numerical conversion multipliers for converting torr into various other vacuum-pressure units. Table 10-3 gives various numerical pressure conversions.

Flow-rate measurement There are two types of flow-rate measurement. The first, used in chemical process industries, is mass flow measured by weight. The second is volumetric flow measured in cubic feet per minute, cfm (liters per minute, Lpm). Only volumetric flow is used for calculations in this chapter.

The flow-rate measurement for vacuum is exactly the opposite of that used for compressed air. Using ambient, standard free air at atmospheric pressure (referred to as "scfm") as a common reference, the ambient free air entering the vacuum pipe will expand to fill the vacuum in the piping system, creating a lower vacuum pressure. The flow in a vacuum pipe is expanded cfm and represents the flow under actual

Table 10-1 Basic Vacuum–Pressure Measurements

Negative Gage Pressure (psig)	Absolute Pressure (psia)	Inches of Mercury (in. Hg)	Kilo–Pascals Absolute (kPa)
0	14.7	0	101.4
Atmospheric pressure at sea level			
–1.0	13.7	2.04	94.8
–2.0	12.7	4.07	87.5
–4.0	10.7	8.14	74.9
–6.0	8.7	12.20	59.5
–8.0	6.7	16.30	46.2
Typical working vacuum level			
–10.0	4.7	20.40	32.5
–12.0	2.7	24.40	17.5
–14.0	0.7	28.50	10.0
–14.6	0.1	29.70	1.0
–14.7	0	29.92	0
Perfect vacuum (zero reference pressure)			

Table 10-2 Conversions from Torr to Various Vacuum-Pressure Units

0.0010 torr	=	1 micron mercury (μ Hg)
0.0075 torr	=	1 pascal (Pa)
0.7501 torr	=	1 millibar (mbar)
1.000 torr	=	1 mm mercury (mm Hg)
1.868 torr	=	1 in. water at 4°C (in. H_2O)
25.40 torr	=	1 in. mercury (in. Hg)
51.71 torr	=	1 lb/in.^{2} (psi)
735.6 torr	=	1 tech. atmosphere (at)
750.1 torr	=	1 bar
760.0 torr	=	1 standard atmosphere (atm)

Table 10-3 IP and SI Pressure Conversion

kPa abs.	in. Hg	in. Hg abs.	psia
101.4	0	29.92	14.70
97.9	1	28.92	14.2086
94.5	2	27.92	13.7173
91.5	3	26.92	13.2260
87.77	4	25.92	12.7347
84.39	5	24.92	12.2434
81.01	6	23.92	11.7521
77.63	7	22.92	11.2608
74.22	8	21.92	10.766
70.84	9	20.92	10.275
67.45	10	19.92	9.7838
64.07	11	18.92	9.2926
60.68	12	17.92	8.8015
57.29	13	16.92	8.3129
53.91	14	15.92	7.8216
50.52	15	14.92	7.328
47.13	16	13.92	6.8369
43.75	17	12.92	6.3457
40.37	18	11.92	5.8546
36.98	19	10.92	5.3634
33.59	20	9.92	4.8722
30.21	21	8.92	4.3811
26.82	22	7.92	3.8911
23.43	23	6.92	3.3988
20.05	24	5.92	2.9076
16.66	25	4.92	2.4165
13.27	26	3.92	1.9253
9.89	27	2.92	1.4342
6.502	28	1.92	0.9430
3.12	29	0.92	0.4520
2.71	29.22	0.80	0.3930
2.37	29.52	0.70	0.3439
2.03	29.72	0.60	0.2947
0	29.92	0	0

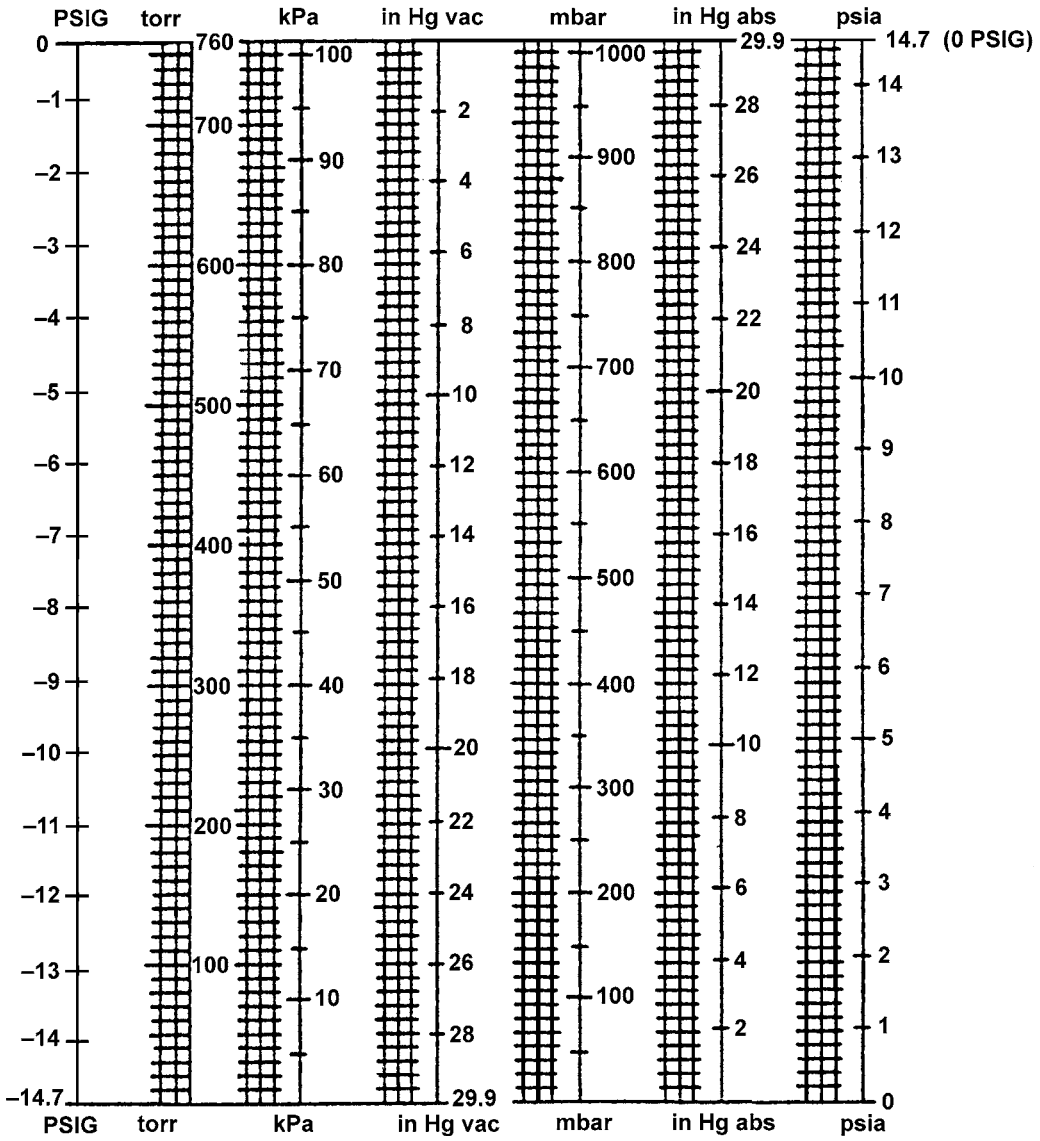


Figure 10-1 Conversion of Vacuum-Pressure Measurements

vacuum conditions. This is referred to as "actual cubic feet per minute," or "acfm." The above designations are not universally used; therefore, it is important to make certain that the correct nomenclature for vacuum-pump capacity specifications and flow rate is identified and understood prior to selection and sizing.

Standard air is dry (0.0 % relative humidity), 14.7 psia (101.4 kPa), and 60°F (15.5°C). The expanded air in the vacuum piping system is called "actual cubic feet per minute"("acfm"). Another phrase used to indicate acfm is "inlet cubic feet per minute" or "icfm." ACFM is greater than scfm.

Converting scfm to acfm The following formula is used to convert scfm to acfm:

Equation 10-1

$$\text{acfm} = \text{scfm}\,\frac{29.92}{P} \times \frac{T + 460}{520}$$

where

P = Actual pressure for the scfm being converted, in. Hg

T = Actual temperature for the scfm being converted, °F

For practical purposes, a numerical method for solving Equation 10-1 can be used if the temperature is 60°F (15.5°C). At that temperature, the second part of the equation becomes unity. Table 10-4 gives numerical values for 29.92/P. To find acfm, multiply the scfm by the value found in the table opposite the vacuum pressure, "P."

A direct ratio for converting scfm to acfm (sL/s to aL/s) for various pressures is given in Table 10-5. Multiply the scfm (sL/s) by the factor corresponding to the pressure in. Hg abs. (kPa abs.) to find acfm (aL/s).

Table 10-4 Expanded Air Ratio, 29.92/P, as a Function of Pressure, P (in. Hg)

P	29.92/P	P	29.92/P
29.92	1.00	10.92	2.7399
28.92	1.0346	9.92	3.0161
27.92	1.0716	8.92	3.3542
26.92	1.1114	7.92	3.7777
25.92	1.1543	6.92	4.3236
24.92	1.2006	5.92	5.0540
23.92	1.2508	4.92	6.0813
22.92	1.3054	3.92	7.6326
21.92	1.3650	2.92	10.2465
20.92	1.4302	1.92	15.5833
19.92	1.5020	0.92	32.5217
18.92	1.5814	0.80	37.40
17.92	1.6696	0.70	42.0742
16.92	1.7683	0.60	49.8667
15.92	1.8794	0.50	59.84
14.92	2.0054	0.40	74.80
13.92	2.1494	0.30	99.7334
12.92	2.3158	0.20	149.60
11.92	2.5101	0.10	299.20

Note: 1 in. Hg = 3.39 kPa

Table 10-5 Direct Ratio for Converting scfm to acfm (sL/s to aL/s)

In. Hg	kPa Abs.	Factor	In. Hg	kPa Abs.	Factor
1	97.9	1.05	16	47.09	2.15
2	94.5	1.1	17	43.71	2.3
3	91.15	1.1	18	40.33	2.5
4	87.77	1.15	19	36.95	2.73
5	84.39	1.2	20	33.57	3
6	81.01	1.25	21	30.20	3.33
7	77.63	1.3	22	26.82	3.75
8	74.19	1.35	23	23.37	4.28
9	70.81	1.4	24	19.99	5
10	67.43	1.5	25	16.61	6
11	64.05	1.55	26	13.23	7.5
12	60.67	1.62	27	9.85	10
13	57.29	1.75	28	6.48	15
14	53.91	1.85	29	3.10	30
15	50.54	2.0	29.92	0	60

GENERAL VACUUM CRITERIA

Adjusting Vacuum-Pump Rating for Altitude

The rating of a pump at altitude is a lower percentage of its rating at sea level. For each 1000-ft (304.8-m) increase in altitude, atmospheric pressure drops by approximately 1 in. of mercury (3.39 kPa). Refer to Table 10-6 for actual barometric pressure at various altitudes. For example, for the city of Denver (at 5000 ft [1524 m]), the local atmospheric pressure is 24.90 in. Hg (84.3 kPa). Dividing 30 in. Hg (standard atmospheric pressure at sea level) into 24.90 gives a percentage of 83.3%. If a pump is rated at 25 in. Hg (84.7 kPa) at sea level, 83.3% of 25 equals 20.8 in. Hg (70.4 kPa) at 5000 ft (1524 m). This is the required vacuum pressure that would equal 25 in. Hg (84.7 kPa) at sea level. At altitudes above sea level, there is a reduction in the scfm delivered because of the difference in local pressure compared to standard pressure. SCFM must be increased to compensate for this difference. Table 10-7 provides multiplication factors to accomplish this. To find the adjusted scfm, multiply the actual scfm by the factor found opposite the altitude where the project is located.

Table 10-6 Barometric Pressure Corresponding to Altitude

Altitude[a]		Barometric Pressure	
m	ft	in. Hg	kPa
–3040	–10,000	31.00	104.5
–152	–500	30.50	102.8
0	0	29.92	100.8
152	500	29.39	99.0
304	1,000	28.87	97.3
456	1,500	28.33	95.5
608	2,000	27.82	93.7
760	2,500	27.31	92.0
912	3,000	26.81	90.3
1064	3,500	26.32	88.7
1216	4,000	25.85	87.1
1368	4,500	25.36	85.5
1520	5,000	24.90	83.9
1672	5,500	24.43	81.9
1824	6,000	23.98	80.8
1976	6,500	23.53	79.3
2128	7,000	23.10	77.8
2280	7,500	22.65	76.3
2432	8,000	22.22	74.9
2584	8,500	21.80	73.4
2736	9,000	21.39	72.1
2888	9,500	20.98	70.7
3040	10,000	20.58	69.3

[a] Sea level = 0.

Table 10-7 Factor for Flow Rate Reduction Due to Altitude

Altitude		Factor for Adjusted scfm
m	ft	
0	0	1.0
152	500	1.02
304	1,000	1.04
456	1,500	1.06
608	2,000	1.08
760	2,500	1.10
912	3,000	1.12
1064	3,500	1.14
1216	4,000	1.16
1520	5,000	1.20
1824	6,000	1.25
2128	7,000	1.30
2432	8,000	1.35
2736	9,000	1.40
3040	10,000	1.45
3344	11,000	1.51

1 scfm = 0.472 sL/s

Time for Pump to Reach Rated Vacuum

The time a given pump will take to reach its rated vacuum pressure depends on the volume of the system in cubic feet (cubic meters) and the capacity of the pump in scfm (sL/s) at the vacuum-rated pressure. But simply dividing the system volume by the capacity of the pump will not produce an accurate answer. This is because the vacuum pump does not pump the same quantity of air at different pressures.

There is actually a logarithmic relationship that can be approximated by the following formula:

Equation 10-2

$$T = \frac{V}{Q} N$$

where

T = Time, min.
V = Volume of system, ft^3 (m^3)
Q = Flow capacity of pump, scfm (sL/s)
N = Natural log constant (see below)

For vacuum up to 10 in. Hg (33.9 kPa),
N = 1
For vacuum up to 22.5 in. Hg (76.2 kPa),
N = 2
For vacuum up to 26 in. Hg (88.0 kPa),
N = 3
For vacuum up to 28 in. Hg (94.8 kPa),
N = 4

To obtain the most accurate answer, the engineer should obtain pump curves from the manufacturer and substitute the scfm (sL/s) capacity for the pump at each 5 in. Hg (16.9 kPa) increment, then add them together to find the total time. Selection of the value for N depends on the highest level of system vacuum pressure and is constant for several calculations.

Adjusting Pressure Drop for Different Vacuum Pressures

When the sizing chart available to the design engineer uses a vacuum level different than that of the system being designed, the pressure loss for the scfm (sL/s) and pipe size for the system's vacuum pressure can be found by dividing the pressure drop in the chart by the ratio found from the following formula:

Equation 10-3

$$30 - \frac{\text{new vacuum pressure}}{\text{pressure used to create chart}}$$

Simplified Method of Calculating Velocity

Use the following formula to find the velocity of a gas stream under a vacuum:

Equation 10-4

$$V = C \times Q$$

where

V = Velocity, fpm (m/s)
C = Constant for velocity based on pipe size (Refer to Table 10-8.)
Q = Flow rate based on an absolute vacuum pressure, acfm (aL/s)

Example:

Calculate the velocity of 100 scfm (47.2 sL/s) through a 2-in. (50 DN) pipe with a pressure of 20 in. Hg (67.7 kPa).

Table 10-8 Constant, C, for Finding Mean Air Velocity

DN	40 Sched. Pipe Size, in.	C	DN	40 Sched. Pipe Size, in.	C
12	⅜	740.9	65	2½	30.12
15	½	481.9	75	3	19.53
20	¾	270.0	90	3½	14.7
25	1	168.0	100	4	11.32
32	1¼	96.15	125	5	7.27
40	1½	71.43	150	6	5.0
50	2	42.92	200	8	2.95

1 in. = 25.4 mm

1. First, find the equivalent absolute pressure of 20 in. Hg (67.7 kPa). Using Table 10-3, read 9.92 in. Hg abs (33.57 kPa abs).
2. Convert 100 scfm (47.2 sL/s) to acfm (aL/s) at a pressure of 9.92 in. Hg abs (33.57 kPa abs) by using Table 10-5. Opposite 10 in. Hg (33.9 kPa) read 1.5.

   100 scfm × 1.5 = 150 acfm (70.8 aL/s)
3. Refer to Table 10-8 to obtain C. This table has been developed from flow characteristics of air in schedule 40 pipe. Opposite 2-in. (50-mm) pipe read 42.92.
4. V = 150 acfm × 42.92

   V = 6438 fps (1962 m/s)

Vacuum Work Forces

The total force of the vacuum system acting on a load is based on the vacuum pressure and the surface area on which the vacuum is acting. This is expressed in the following formula:

Equation 10-5

$$F = P \times A$$

where

F = Force, lbs (N)
P = Vacuum pressure, psig (Pa or N/m^2)
A = Area, $in.^2$ (m^2)

Note: 1 Pa = 1 N/m^2

Since the above formula is theoretical, it is common practice to use a safety factor in the range of 3 to 5 times the calculated force to compensate for the quality of the air seal and other factors such as configuration of the load and outside forces such as acceleration.

VACUUM SOURCE AND SOURCE COMPONENTS

General

Vacuum is produced by a single or multiple vacuum-pump source drawing air from remote vacuum inlets or equipment. Except for some rare industrial applications, vacuum pumps withdraw air from a receiver to produce the vacuum in the system.

Air exhausted from the system must be discharged to the atmosphere by means of an exhaust piping system. The pipe size shall be large enough so as not to restrict operation of the vacuum pump. (See separate discussions under the "Laboratory and Vacuum Systems" and "Vacuum-Cleaning Systems" sections, which follow.)

Alarms are required for maintenance purposes or to annunciate trouble, generally inadequate vacuum pressure, in the system.

Vacuum Pumps

The majority of vacuum pumps are divided into two general groups: gas transfer and capture. Capture-type pumps are outside the scope of this chapter.

Gas-transfer pumps These are essentially air compressors that use the vacuum system as their inlet and discharge "compressed" air to the atmosphere. The majority of pumps used for most applications are gas-transfer pumps. They operate by removing gas from the lower pressure of the system and conveying it to the higher pressure of the free-air environment through one or more stages of compression provided by a vacuum pump. These pumps are also known as mechanical rotary-type pumps and are the type used most often for industrial and laboratory purposes. These pumps can be divided into two categories: Liquid sealed and dry pumps. Liquid sealed pumps use liquid, typically water or oil, to create a seal between the rotor and casing to produce a vacuum. Examples of liquid sealed gas-transfer pumps include:

1. Rotary vane, once-through-oil (OTO) type.
2. Rotary vane, recirculating oil sealed type.
3. Oil sealed reciprocating (rotary) piston pumps.
4. Liquid ring.

Dry vacuum pumps use tight tolerances to seal the pump chamber to produce vacuum. This can be done using closely machined tolerances or replaceable wearing sealing elements. These types of pumps generally run hotter than liquid sealed pumps. Examples of dry pumps are:

1. Rotary sliding vane, oil-less type.
2. Reciprocating (rotary) dry piston pumps.
3. Rotary lobe (roots), ordinary lobe or claw type.
4. Screw.
5. Diaphragm.
6. Centrifugal (turbo).

The diaphragm and centrifugal turbo type pumps are used more for small benchtop applications and not for central systems.

Equipment Configuration

It is best to buy a vacuum pump as a complete package with all accessories included. To have a single point of responsibility buy packages assembled by the pump manufacturer. There are packagers who buy pumps and accessories and assemble their own package. Sometimes there may be issues of who is responsible if problems result. The pump or pumps, receiver, inlet filter, oil mist filter, oil separator, heat exchangers, cooling fans, water reservoir tanks, sensors, gauges, piping, valves, starters, disconnects and controls can all be packaged together and factory tested prior to delivery on site. Once on site, all that remains is field connection to the utilities and system piping. The individual components can be purchased separately, field located and interconnected, but it requires additional time. If problems arise, determining the cause is problematic. Equipment can be tank mounted or skid mounted. Skid-mounted equipment can be made in stackable-modular sections to conserve space or allow expansion in the future.

Receivers

The piping-distribution system is connected to the pump(s) through a tank called a receiver. The receiver will even out the extremes of vacuum pressure produced by operation of the pump and maintain the desired range of vacuum as the demand rises or falls depending on the number of inlets that open or close. When the system vacuum pressure drops to a predetermined level beyond the capacity of a single pump, additional pumps in a multiplex assembly are started. When the desired high level of vacuum is reached, the pumps could be shut off. Larger units may be constantly operated, loading, unloading, or bypassing on demand. Often, there is a timer on the system allowing the pumps to run for a longer time than required by system pressure to prevent rapid cycling. If vacuum level cannot be achieved or maintained, an audible or visual alarm indicates the shortage.

Factors that effect receiver sizing are pump capacity, operating range and volume of the piping system. On small piping systems the receiver size is more important to avoid short cycling the pump(s). On larger piping systems the size of the receiver has little effect on actual system operation, it is selected by the manufacturer based on experience.

For laboratory systems with a liquid ring pump or known to handle liquids, the receiver and hence the pumps, should be placed at the lowest level of the building or piping system with the piping pitched back to the receiver. The receiver should have a sight glass and drain valve to drain all liquid from the receiver. Other laboratory and process systems can have the receiver and pumps installed anywhere in

the building. If they are installed above the spaces like in a mechanical penthouse, make sure provisions for draining the piping system at the low points are considered.

Seal Liquids

For liquid-ring pumps, a circulating liquid in the pump casing is an integral part of the pump operation. This liquid, generally water or oil, is commonly known as "seal liquid" and is not intended to refer to shaft or any other kinds of sealing.

Water, commonly used for sealing purposes, must be continuously replaced. With no conservation, approximately 0.5 gpm/hp (1.9 L/hp) is used. Manufacturers have developed proprietary water-conservation methods that typically reduce the usage to approximately 0.1 gpm/hp (0.4 L/hp). Specific information about any water usage and additional space required must be obtained from the manufacturer.

Oil used for sealing purposes is recirculated, and may have to be cooled. The pump does not require any water to operate. The oil eventually becomes contaminated and must be replaced on a regular basis. Typically, a running time of 1500 to 2000 hours is the useful life of seal oil. It may be desirable to install a running time meter on these pumps to aid in maintenance. Some pumps using oil, like the once-thru-oil rotary vane, often require more installation space than other types of pump. Specific information about additional space required shall be obtained from the manufacturer. Other recirculating oil sealed units will fit within the space required for other types of vacuum systems.

For the once-thru-oil sealed pumps an oil supply and collections system can be engineered to supply oil and collect the waste oil from the pumps. The disposal of the waste oil should be considered in evaluating the cost of ownership in the pump selection.

Additional types of liquids can be used for seal liquid in the vacuum pump. A liquid from the process can be used and the pump materials selected to suit the application. Consult a vendor to select the materials and design a system like this.

Vacuum-Pressure Gauges

There are two commonly used gauges, the Bourdon type and the diaphragm type.

Bourdon gauge This is a mechanical gauge used to measure the difference in relative pressure between the system and local barometric pressure. The most widely used type of gauge, it is simple, inexpensive, and rugged. The heart of the gauge is the Bourdon tube that is closed at one end and open to the vacuum at the other. As the vacuum pressure varies, the tube changes shape. A pointer attached to the tube moves, indicating the pressure on a dial.

Diaphragm gauge The diaphragm gauge measures the pressure difference by sensing the deflection of a thin metal diaphragm or capsular element. Similarly to the Bourden gauge, its operation relies on the deformation of an elastic metal under pressure.

Ancillary Equipment

Control panels should be mounted by the manufacturer on the skid to avoid field wiring. It can also be remotely mounted on a wall near the equipment, preferably within line of site. All equipment on the skid, including the control panel shall be UL listed.

A coalescing, or oil-mist, filter should be used on the exhaust of any pump that uses oil to prevent the discharge of oil into the atmosphere. It can also be used to recover solvents from the discharge airstream.

A knockout pot is a device that prevents entrained liquid or slugs of liquid from entering the inlet of mechanical pumps used in industrial applications. It can also be combined with an inlet filter in one housing.

Inlet filters are used to remove solids or liquids that may be present in the inlet airstream prior to the air entering the pump. Various filter elements are available to remove particulates approximately 0.3 μ in size.

Cooling of the vacuum pumps needs to be considered in the layout of the system. Most units can be air cooled with radiators and cooling fans mounted on the skid. The heat rejection into the space needs to be considered by the HVAC engineer or else the space may become quite hot, a temperature increase of 5 to 20 degrees F is not uncommon. Other units can be furnished with heat exchangers and cooled with domestic water or chilled water. Means of obtaining year round chilled water sources need to be considered. Cooling with domestic water on a once-through basis which is then sent to the drainage system is discouraged. Systems have been developed to use an aluminum reservoir tank to cool the water through convection and radiation using relatively little makeup water.

In some cases where the system as a whole has a high vacuum pressure, it may be desired to lower the vacuum pressure to a branch. For liquid ring pumps this is generally done with an air-bleed valve on the branch where the lower vacuum pressure is desired. The valve is opened and air is allowed to enter the system. For precise control, a needle valve is used. Bleeding air into the system must be accounted for in the selection of the pump capacity. For other mechanical pumps this can be done by using a throttling valve at the inlet. This creates a higher vacuum drop at the throttling valve allowing lower vacuum level on the user side of the valve while maintaining the high vacuum level on the system side. This way no additional load (bleed air) needs to be accounted for on the system.

Some laboratory and most process pump skids using oil sealed pumps may use an air or nitrogen gas purge. A purge usually occurs at the end of a pump run cycle to evacuate the pump of any chemical vapors that may condense as the pump cools. It can also occur at startup to warm up the pump and remove any condensed liquids. The purge cycle may be between 5 to 15 minutes.

LABORATORY VACUUM SYSTEMS

The laboratory vacuum system serves general chemical, biological, and physics laboratory purposes. Principal among such purposes are drying, filtering, fluid transfer, and evacuating air from apparatus. The usual working pressure of standard vacuum systems is in the range of 12 to 20 in. Hg (40.6 to 67.7 kPa).

In some cases, usually in chemistry laboratories, there is a need for "high" vacuum in the range of 24 to 29 in. Hg (81.3 to 98.2 kPa), which is usually produced with a separate point-of-use vacuum pump adjacent to the area of application. Central systems can be designed to accommodate high vacuum uses down to 29.64 in. Hg (7 torr). With the use of a booster (blower) a vacuum level of 29.88 in. Hg (1 torr) is possible, but not recommended for large systems. These high vacuum systems should only be used for closed-ended systems. In other words closed vessels at the use points. If used for general drying and filtering the system, it will not maintain vacuum levels. The system should be designed using an extensive program or spreadsheet to size the piping. Pipe sizes tend to be large due to the expansion of the air and vapor from atmospheric pressure to deep vacuum.

Other types of systems serve light industrial and manufacturing purposes, such as those of the pharmaceutical and chemical industries.

Codes and Standards

There are no codes and standards applicable to the design of laboratory vacuum and manufacturing systems. The most important requirements are those of the end user and good engineering practice. For laboratory work within health-care facilities, conformance to NFPA 99, *Standard for Health Care Facilities*, is required. The standard addresses different levels of systems based upon the use of the facility. Some laboratories may fall under one of the categories listed so the code should be investigated for applicability to your system.

Laboratories conducting biological work where airborne pathogens could be released are required to follow the appropriate biological level criteria established by the National Institutes of Health (NIH). For most biological installations, it is recommended check valves be installed in each branch line to every room or area to prevent any cross discharge. It is common to have separate pumps for different biological areas. In addition, the vacuum pump exhaust shall be provided with duplex 0.02-μ filters on the exhaust to eliminate all pathogenic particulates. Considerations for decontamination of the piping and equipment should be evaluated for maintenance purposes. Additional isolation, sampling and vent valves may be required to successfully allow for decontamination of the piping and equipment.

Vacuum Source

The vacuum source usually consists of two or more pumps that are designed to operate as system demand requires, a receiver used to provide a vacuum reservoir and to separate liquids from the vacuum airstream, the interconnecting piping around the pumps and receiver, and alarms. A duplex pump, with each

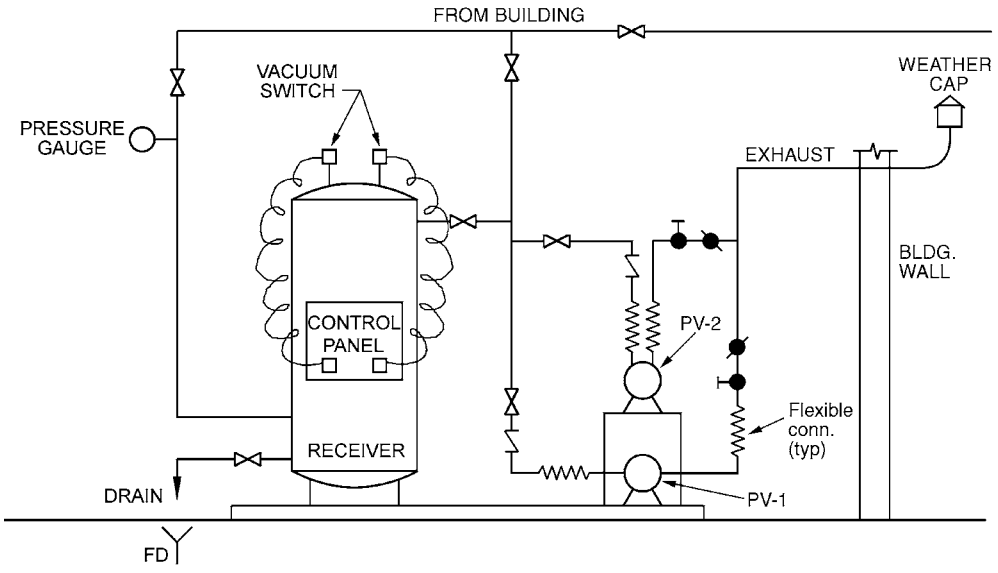


Figure 10-2 Schematic Detail of a Typical Laboratory Vacuum-Pump Assembly

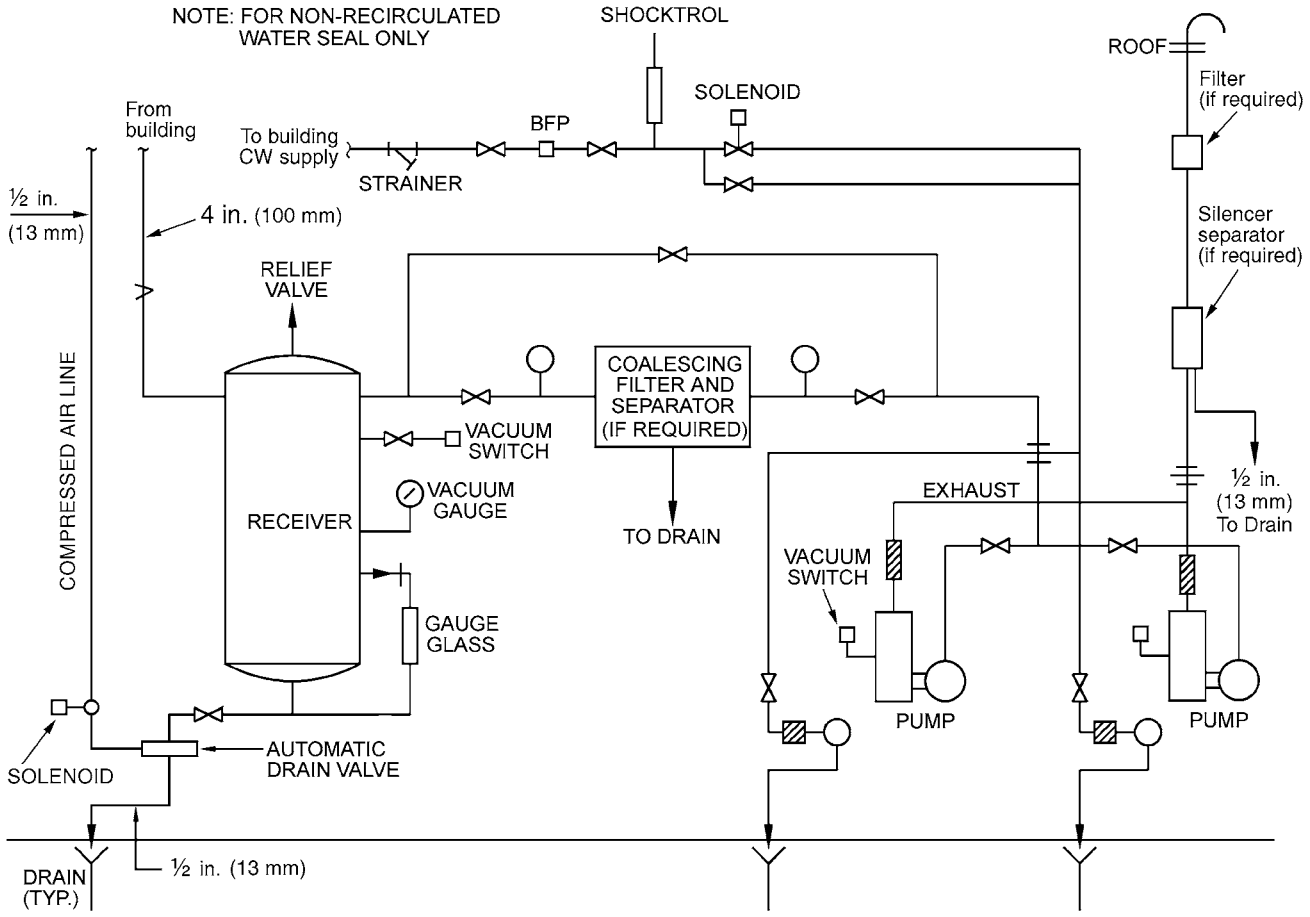


Figure 10-3 Typical Process Vacuum-Pump Duplex Arrangement

pump capable of assuming the entire load is usually selected if the system is critical to the operation of the laboratory. In some smaller installations where the vacuum system is not critical, it may be acceptable to have a single vacuum pump.

The pumps selected should be based upon the anticipated design conditions consisting of vacuum level, process gases or liquids, first cost, maintenance cost, utility cost, and reliability. No single pump type will suit all applications, they each have strong and weak points.

The two most often used pump types are liquid ring and sliding vane. A common configuration for more than one pump is a rack mounting one above the other and both pumps installed over the receiver for a compact footprint. A schematic detail of a typical laboratory vacuum pump assembly is illustrated in Figure 10-2. A schematic detail of a typical process vacuum pump duplex assembly is illustrated in Figure 10-3.

Dry pump technology has gained prominence over the past years due to water conservation concerns and waste oil disposal. These pumps have moved from strictly chemical duty into the laboratory and medical industry. Since they do run hot they need to be evaluated for use on a laboratory or medical system so auto-ignition of the vapors does not happen.

Distribution Network

Pipe material and joints Piping for the distribution system shall be a corrosion-resistant material such as copper tube type K or L, stainless steel, galvanized steel pipe (usually schedule 40 ASTM A-53) or even plastics such as polypropylene or high density polyethylene. Copper tube shall be hard tempered except when installed underground, when soft tempered should be used. Although cost has a major influence on the selection of the piping material, the most commonly used is copper tube type L, ASTM B-88 up to 4 in. (100 mm) in size, with soldered joints. Pipe 5 in. (125 mm) and larger is usually schedule 40 galvanized steel pipe with malleable iron fittings and threaded joints. Fittings shall have a long-turn drainage pattern so as not to impede the flow of fluids in the pipe. For high vacuum systems steel pipe with welded joints should be considered to eliminate possible leaks.

General System Layout

It is best the vacuum equipment be at the lowest level of the system, this way gravity will work with the system to carry solids and liquids. The vacuum

equipment may be at the top of the system such as in a penthouse, but remember heavy liquids and materials will collect at the low points. Proper clearances should be provided for maintenance and accessibility, including pump removal. Piping should be run with a slight slope back toward the receiver. Risers should have isolation valves. Provisions for cleanouts should be considered to allow cleaning of vacuum piping. This is important since vacuum piping acts as a receiver and over the years will collect material along the walls. Vacuum pump exhaust should vent outside clear of any air intakes and windows. The routing should be as direct as possible and insulated for personnel protection near the pump since it may get hot depending on the pumps selected. Provide a low point drain valve since rainwater and condensed liquids in the exhaust stream may collect in the pipe.

Sizing criteria

Number of inlets Using plans of the project, locate and count the number of inlets and decide the required flow rate for each. There are no codes or other mandated requirements specifying locations of vacuum inlets. The number of inlets is given by the architect and determined by the user, based on a program of requirements for all rooms, areas, and equipment used in the facility. Inlets for laboratory stations, fume hoods, etc. shall be appropriate for the intended use, based on the requirements of the end user.

Determine the location of the supply source Select the location in conjunction with the architect, electrical department and any others that are involved.

Determine the system pressure Obtain the system operating pressure, usually from the end user but most often the engineer makes the decision.

Calculate the flow rate The basic flow rate from each laboratory inlet shall be 1.0 scfm (0.47 sL/m). This flow rate is used in conjunction with the direct reading figure for the diversity factor. Other manufacturers use a different inlet flow rate. This is an arbitrary number based on experience, the flow rate is in direct proportion to the diversity factor. For manufacturing facilities, the flow rate shall be obtained from the manufacturer of the equipment or operation being supported.

Allowable system pressure loss A generally accepted criterion used to size a piping system is to allow a high-to-low pressure range of 3 to 5 in. Hg (10.2 to 16.9 kPa) for the entire system (after the source assembly) and a maximum velocity of between 4000 and 5000 fpm (1219 to1524 m/min). If noise may be a problem, use 4000 fpm (1219 m/min). For smaller systems, use a figure of 1 in. Hg (3.4 kPa) allowable pressure loss for each 100 ft (31 m) of pipe. If dealing with high vacuum applications the allowable high-to-low pressure loss is much less, in the range of 0.12 to 0.2 in. Hg (3 to 5 torr). A generally accepted criterion is to use 10 percent of the highest pressure at the source.

Calculate the equivalent run of pipe The equivalent run means the longest length of pipe plus an additional number of feet to allow for valves and fittings. This is based on the longest actual run from the source to the furthest point of the piping system. It is accepted engineering practice to add an additional 50% of the measured length of piping to calculate the equivalent length.

Allowable piping pressure loss This is calculated using the allowable pressure loss for the system divided by the equivalent run of pipe in 100's of feet. For example if the measured run is 350 ft., add 150 ft additional for fittings equals 500 ft of equivalent run. The allowable system pressure loss is calculated at 5 in.hg., so divide the allowable system pressure loss by the equivalent run. The result is a piping pressure loss of 1 in.hg per 100 feet. This calculation however, must be made in terms compatible with the chart or table for flow rate and pressure loss per length of pipe that you have selected for sizing.

Diversity factor The diversity factor established for general laboratories is based on experience. It has been found to be slightly more than that used for compressed air because the vacuum is often left on for longer periods of time. Refer to Figure 10-4 for a direct reading chart to determine the adjusted general laboratory vacuum flow rate based on the number of connected inlets regardless of type or location. Find the connected number of inlets on the bottom and where the number crosses the reference line, determine the scfm (sL/s) on the side of the chart.

For the design of classrooms, the diversity factor for one and two classrooms on one branch is 100%. For more than two classrooms, use a diversity factor double that found in Table 10-9, but never less than the largest scfm (sL/s) calculated for the first two rooms. Since the above flow rates and diversity factors are arbitrary, they must be used with judgment and modified if necessary for special conditions and client requirements. Always consult the user for definitive information regarding the maximum probable simultaneous usage of connected inlets. Table 10-9 has been prepared for a numerical calculation of the diversity factor, if desired.

Table 10-9 Diversity Factor for Laboratory Vacuum Air Systems

Number %	Use of Inlets Factor
1–2	100
3–5	80
6–10	66
11–20	35
21–100	25

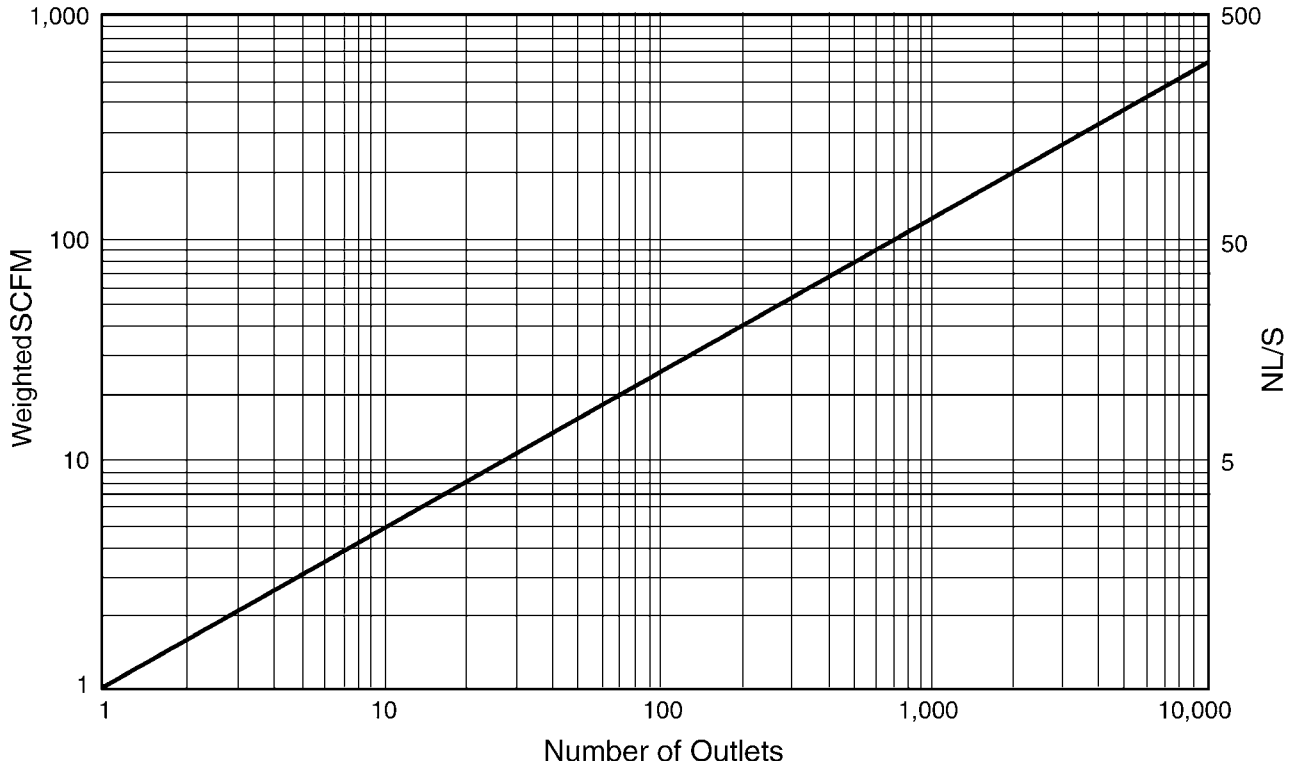


Figure 10-4 Direct Reading Chart Showing Diversity for Laboratory Vacuum

Table 10-10 Pressure Loss Data for Sizing Vacuum Pipe
Low Pressure Vacuum System

Standard Air Flow, cfm (L/min)	Pressure Drop per 100 ft (30 m) of Pipe, in. Hg (kPa) Nominal Pipe Size, in. (DN)							
	¾ (20)	1 (25)	1¼ (32)	1½ (40)	2 (50)	2½ (65)	3 (80)	4 (100)
1 (28.3)	0.15 (0.5)							
2 (56.6)	0.39 (1.3)	0.10 (0.3)						
3 (85.0)	0.77 (2.6)	0.19 (0.6)						
4 (113.3)	1.24 (4.2)	0.31 (1.1)	0.10 (0.3)					
5 (141.6)	1.78 (6.0)	0.44 (1.5)	0.14 (0.5)					
6 (169.9)	2.40 (8.1)	0.60 (2.0)	0.19 (0.6)					
7 (198.2)		0.77 (2.6)	0.24 (0.8)	0.12 (0.4)				
8 (226.6)		0.95 (3.2)	0.31 (1.1)	0.15 (0.5)				
9 (254.9)		1.17 (4.0)	0.38 (1.3)	0.18 (0.6)				
10 (283.2)		1.38 (4.7)	0.45 (1.5)	0.22 (0.7)				
15 (424.8)		2.80 (9.5)	0.88 (3.0)	0.44 (1.5)	0.12 (0.4)			
20 (566.4)			1.46 (4.9)	0.72 (2.4)	0.19 (0.6)			
25 (708.0)			2.20 (7.4)	1.09 (3.7)	0.29 (1.0)			
30 (849.6)				1.52 (5.1)	0.41 (1.4)	0.14 (0.5)		
35 (991.2)				2.00 (6.8)	0.54 (1.8)	0.18 (0.6)		
40 (1132.8)				2.50 (8.4)	0.67 (2.3)	0.22 (0.7)	0.10 (0.3)	
45 (1274.4)					0.81 (2.7)	0.27 (0.9)	0.12 (0.4)	
50 (1416.0)					0.99 (3.3)	0.33 (1.1)	0.14 (0.5)	
60 (1699.2)					1.34 (4.5)	0.45 (1.5)	0.19 (0.6)	
70 (1982.4)					1.79 (6.1)	0.60 (2.0)	0.26 (0.9)	0.07 (0.2)
80 (2265.6)					2.30 (7.8)	0.77 (2.6)	0.32 (1.1)	0.09 (0.3)
90 (2548.8)						0.96 (3.2)	0.41 (1.4)	0.11 (0.4)
100 (2832.0)						1.17 (4.0)	0.50 (1.7)	0.14 (0.5)
125 (3540.0)						1.71 (5.8)	0.74 (2.5)	0.20 (0.7)
150 (4248.0)						2.30 (7.8)	0.99 (3.3)	0.27 (0.9)
175 (4956.0)							1.28 (4.3)	0.35 (1.2)
200 (5664.0)							1.61 (5.4)	0.44 (1.5)

Source: Courtesy of Ohmeda.
Note: Based on copper pipe type L, ASTM B88.

Table 10-10(A) High Vacuum Pressure System

Laboratory Vacuum Branch Piping – 26" Hg					
Total Outlets	Outlets Used	SCFM	Pipe Size	Velocity (FPM)	Pressure Drop (in Hg)
1	1.0	0.5	½	2,556	0.04
2	2.0	1.0	¾	2,454	0.02
3	3.0	1.5	¾	3,705	0.06
4	4.0	2.0	¾	4,998	0.12
5	5.0	2.5	1	3,617	0.05
6	5.7	2.9	1	4,209	0.07
7	6.4	3.2	1	4,657	0.08
8	7.1	3.6	1¼	3,412	0.04
9	7.9	3.9	1¼	3,701	0.05
10	8.6	4.3	1¼	4,088	0.05
11	9.3	4.6	1¼	4,380	0.06
12	10.0	5.0	1¼	4,771	0.07
13	10.5	5.2	1¼	4,967	0.08
14	11.0	5.5	1½	3,683	0.04
15	11.4	5.7	1½	3,819	0.04
16	11.9	6.0	1½	4,023	0.05
17	12.4	6.2	1½	4,160	0.05
18	12.9	6.4	1½	4,296	0.05
19	13.3	6.7	1½	4,502	0.06
20	13.8	6.9	1½	4,639	0.06
21	14.3	7.1	1½	4,777	0.06
22	14.8	7.4	1½	4,984	0.07
23	15.2	7.6	2	2,915	0.02
24	15.7	7.9	2	3,031	0.02

Velocity of 4000FPM,Type L Copper, Pressure Drop in in. Hg/100ft

Piping network sizing The following method should be used to size the pipe at each design point. Use the previously calculated allowable piping pressure loss and adjusted scfm (sL/s) at each design point. For sizing the low vacuum distribution system use the vacuum sizing chart Table 10-10 which is based on scfm (sL/s) flow rate and friction loss in psi per 100 foot length of piping. Proceed from the furthest point to the source. Enter Table 10-10 with the scfm (nL/m) and find the value equal to or less than the previously calculated allowable pressure loss for the system. Read the size at the top of the column where the selected value is found. For a high vacuum pressure, use Table 10-10A.

For industrial facilities, the information shall be obtained from the end user.

Source vacuum-pump sizing The source pump for laboratories is selected using the flow rate of gas calculated using all inlets, the diversity factor for the whole facility, and a range of vacuum pressure. The source pumps for industrial facilities are sized using the total connected load reduced by a diversity factor determined from the duty cycle of the equipment and a diversity factor based on end-user requirements.

The pressure range usually extends from 5 in. Hg (16.9 kPa) higher than the highest required vacuum pressure (the pump stopping point) to a low figure equal to the lowest acceptable system pressure (the pump starting point). For duplex and triplex pump arrangements, the intermediate vacuum settings for multiple pumps shall be adjusted accordingly.

Vacuum-pump exhaust-pipe sizing For sizing the exhaust piping from the vacuum-pump source assembly, refer to Table 10-11, using the equivalent length of exhaust piping as the length of piping. (See "Piping-Network Sizing" section below for a definition of "equivalent length.")

System leakage There is a difference between desirable and acceptable leakage in a vacuum system. Ideally, there should be no leakage. It is common practice to test laboratory vacuum-piping systems, section by section, at rated maximum working pressure for 24 hours with no loss of pressure permitted. For large systems, it is almost impossible to install an entire system that does not have small leaks. If such is the case, what is an acceptable amount?

There is no generally accepted value for allowable leakage in a vacuum system. That figure should be related to the volume of the piping network in order to be meaningful. The Heat Exchange Institute has developed a standard based on system volume. This formula, transposed to solve for leakage, is:

Equation 10-6

$$L = \frac{\frac{0.15 \times V}{T}}{4.5}$$

where

L = Leakage, scfm (sL/s)
(Note: To convert to metric, multiply L by 0.4719.)
V = Total piping system volume, ft^3 (m^3)
T = Time for vacuum pressure to drop 1 in. Hg (kPa), min

After calculating the system volume and the leakage from the system, use Figure 10-5 to determine if the intersection of the two values falls within the acceptable portion of the chart.

Table 10-11 Vacuum – Pump Exhaust Pipe Sizing

Total Vacuum Plant Capacity, All Pumps		Equivalent Pipe Length, ft (m)						
		50 (15.2)	100 (30.4)	150 (45.6)	200 (60.8)	300 (91.2)	400 (121.6)	500 (152)
scfm	nL/s	Pipe Size, in. (DN)						
10	4.72	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)	2 (50)
50	23.6	2 (50)	2½ (65)	3 (75)	3 (75)	3 (75)	3 (75)	3 (75)
100	47.2	3 (75)	3 (75)	3 (75)	4 (100)	4 (100)	5 (125)	5 (125)
150	71	3 (75)	4 (100)	4 (100)	4 (100)	5 (125)	5 (125)	5 (125)
200	55	4 (100)	4 (100)	4 (100)	5 (125)	5 (125)	5 (125)	5 (125)
300	142	4 (100)	5 (125)	5 (125)	5 (125)	6 (150)	6 (150)	6 (150)
400	189	5 (125)	5 (125)	6 (150)	6 (150)	6 (150)	8 (200)	8 (200)
500	236	5 (125)	6 (150)	6 (150)	6 (150)	8 (200)	8 (200)	8 (200)

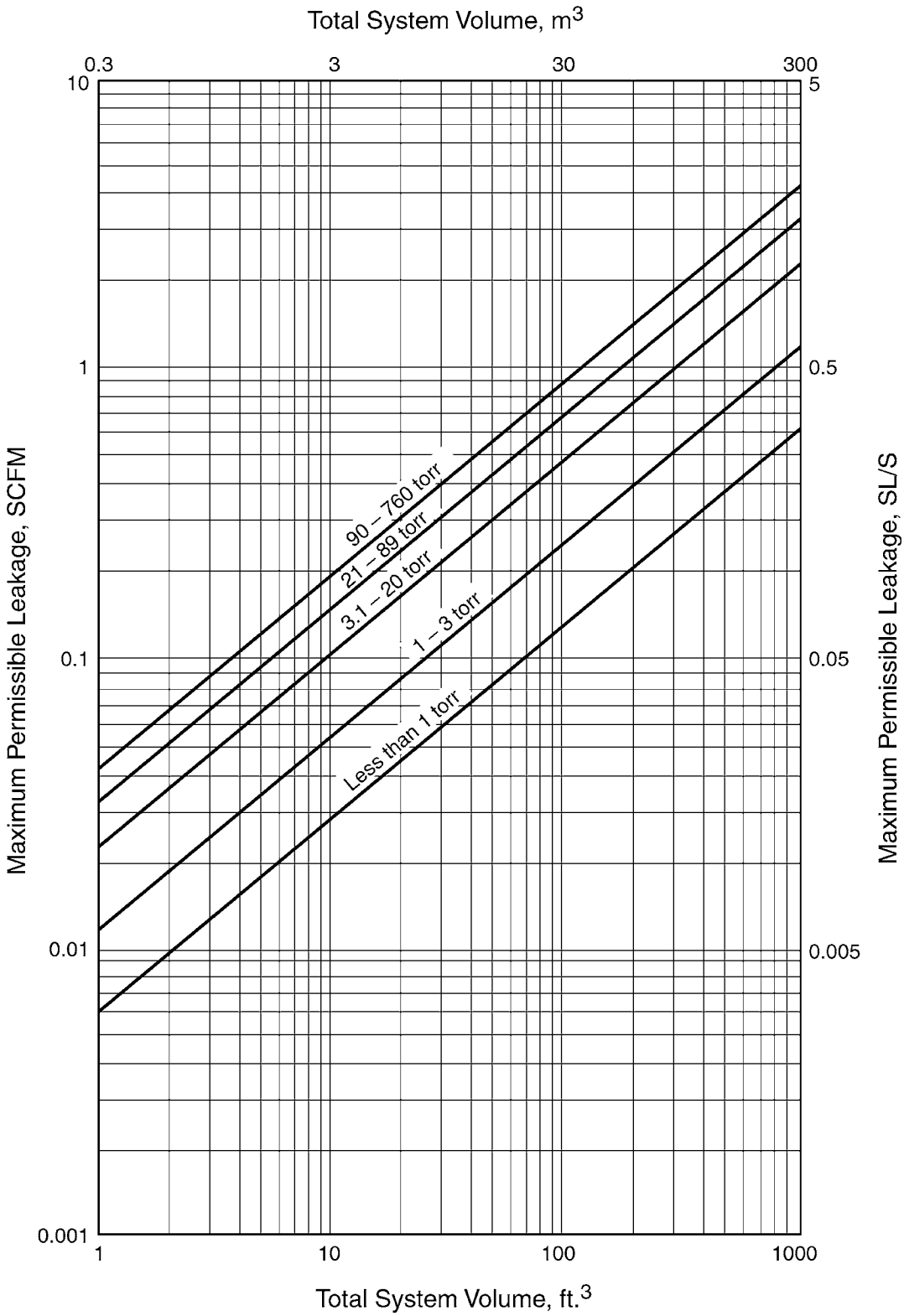


Figure 10-5 Acceptable Leakage in Vacuum Systems

Source: Courtesy of Becker Pumps.

VACUUM-CLEANING SYSTEMS

This section discusses vacuum systems used for removing unwanted solid dirt, dust, and liquids from floors, walls, and ceilings. This involves the use of either a permanent, centrally located system or portable, self-contained, electric-powered units. A central system transports the unwanted debris to a central location where it can be easily disposed of or recovered. Portable units can be easily moved throughout all areas of a facility. The design of portable units is outside the scope of this chapter.

Types of System and Equipment

There are three types of permanent systems: dry, wet and combination. The dry system is intended exclusively for free-flowing, dry material. It is the most commonly used type of system, with cleaning capabilities ranging from cleaning carpets to removing potentially toxic and explosive product spills from the floors of an industrial facility. Equipment consists of a vacuum producer, one or more separators that remove collected material from the airstream, tubing to convey the air and material to the separator, and inlets located throughout the facility. A wide variety of separators are available to allow disposal and recovery of the collected material.

The wet system is intended exclusively for liquid handling and pickup. It is commonly found in health-care, industrial, and laboratory facilities where sanitation is important and frequent washings are required. Equipment consists of a vacuum producer, a wet separator constructed to resist the chemical action of the liquids involved, piping or tubing of a material resistant to the chemical action of the liquid, and inlets located throughout the facility.

A combination system is capable of both wet and dry pickup. Equipment consists of a vacuum producer, a wet separator constructed to resist the chemical action of the liquid mixtures involved, pipe or tubing of a material resistant to the chemical action of the combined solid/liquid, and inlets located throughout the facility.

Codes and Standards

There are no codes and standards directly governing the design and installation of vacuum-cleaning systems. If dealing with explosive powders, NFPA 68, *Guide for Venting of Deflagrations* and NFPA 69, *Standard on Explosion Prevention Systems* may apply.

System Components

Vacuum producer (exhauster) Vacuum producers for typical vacuum-cleaning systems consist of a single or multistage, centrifugal-type units powered by an electric motor. The housing can be constructed of various materials to handle special chemicals and nonsparking aluminum for potentially explosive dust. The discharge of the unit can be positioned at various points to accommodate the requirements of the exhaust-piping system. Silencers, sound attenuating enclosures or rooms can be provided to attenuate the noise.

Separators Separators are used to remove the solid particulates in the airstream generated by the vacuum producers. For dry-type systems, tubular-bag and centrifugal-type separators can be used. If only dust and other fine materials are expected, a tubular-bag type is adequate. The bag(s) are permanently installed and cannot be removed. They function as an air filter for fine particles and collect a majority of the dirt. This dirt eventually falls into a hopper or dirt can at the bottom of the unit. To empty the entire unit, the system must be shut down. The bag(s) must be shaken to remove as much of the collected material as possible and emptied into the dirt can. The dirt can is removed (or the hopper is emptied into a separate container) to clean out the unit. The dirt can should be sized to hold at least one full day's storage. Units are available with multiple bags to increase filter-bag area. Shaking can be done either manually or by motor. The motor-operated shaker has adjustable time periods to start operation after a variable length of time from shut down of the system and to shake the bags for a variable length of time. If continuous operation is required, compressed air can be used to blow through the bags and remove the dirt without requiring a shutdown.

The centrifugal-type separator is designed to remove coarser, dry particles from the airstream. It is also recommended when more than six simultaneous operators are anticipated to remove the bulk of the dirt. The air enters the separator tangential to the unit, and the air containing particulates is forced into a circular motion within the unit. Centrifugal force accomplishes separation.

The wet separator system collects the liquid, separates the water from the airstream, and discharges the waste to drain. This type of separator can be equipped with an automatic overflow shutoff that stops the system if the water level reaches a predetermined high-water level and with automatic emptying features.

Immersion-type separators are used to collect explosive or flammable material in a water compartment. If there is a potential for explosion, such as exists in a grain or flour-handling facility, the separator shall be provided with an integral explosion relief/rupture device that is vented to the outside of the building.

Filters Vacuum producers are normally exhausted to the outside air and do not require any filtration. However, when substances removed from the facility are considered harmful to the environment, a HEPA

filter must be installed in the discharge line to eliminate the possibility of contamination of the outside air. The recommended location is between the separator and vacuum producer, but an alternate location immediately prior to penetration of the building wall or roof is also acceptable.

Silencers When the exhaust from the vacuum producer is considered too noisy, a silencer shall be installed in the exhaust to reduce the noise to an acceptable level. Pulsating airflow requires special design considerations. The connection to silencers shall be made with flexible connections. Additional support for silencers is recommended. Filters and silencers can be economically combined into a single, integral unit.

Inlets Inlets are female inlet valves and are equipped with self-closing covers. They provide a quick connection for any male hose or equipment. The covers can be locked as an option. Many different inlet types are available, in sizes ranging from 1½ to 4 in. (40 to 100 mm) and of various materials.

Control and check valves Valves for vacuum-cleaning systems are different than standard valves. They are used to control the flow or stop the reverse flow of air in the vacuum-cleaning system. When used only fully open or closed, they are generally referred to as "blast gates." When used as regulating valves, they are called "wafer butterfly valves." A less costly substitute for a blast gate is an "air gate valve," which operates using a sliding plate in a channel. The plate has a hole that matches the size of the opening in the channel, with room to close off the opening completely. Air gates can only be used in low-pressure systems and are generally available in sizes from 2 to 6 in. (50 to 150 mm).

Check valves are typically spring-loaded, swing-type valves hinged in the center.

Air-bleed control If the exhauster is constantly operated with low or no inlet air, there is a possibility that the exhauster motor will become hot enough to require shutdown due to overheating.

To avoid this, an air-bleed device can be installed on the inlet to the exhauster that will automatically allow air to enter the piping system. If the facility indicates that this may be a possibility, the manufacturer of the unit should be consulted to determine the need for this device for the system selected.

Pipe and fittings The material most often used is thin-wall tubing, generally in a range of 12 to 16 gauge. This tubing is available in plain carbon steel, zinc-coated steel, aluminum, and stainless steel. Fittings are specially designed for the vacuum-cleaning system. Tubing is normally joined using shrink sleeves over the joints. Compression fittings and flexible rubber sleeves and clamps are also used.

Tubing shall be supported every 8 to 10 ft (2.4 to 3.1 m), depending on size, under normal conditions.

Standard steel pipe is often used in areas where the additional strength is required. In special areas where leakage prevention and strength are mandatory, the tubing joints can be welded if required.

Detailed System Design

Inlet location and spacing The first step in system design is to locate the inlets throughout the facility.

The spacing of inlets depends on the length of hose selected for use. After this is decided, the inlet locations shall be planned in such a manner that all areas can be reached by the selected hose length. This planning must take into account furniture, doorways, columns and all obstructions. Some small overlap must be provided to allow for hoses not being able to be stretched to the absolute end of their length. Consideration should be given to providing a 25 ft 0 in. (7.5 m) spacing for areas where spills are frequent, heavy floor deposits may occur or frequent spot cleaning is necessary.

Generally, there are several alternate locations possible for any given valve. Inlets should be placed near room entrances. Wherever possible, try to locate inlets in a constant pattern on every floor. This allows for the location of common vertical risers since the distance between floors is less than the distance between inlets. In any system, minimizing piping system losses by a careful layout will be reflected in reduced power requirements of the exhauster.

The inlets should be located between 24 and 36 in. (600 and 900 mm) above the floor.

Determining the number of simultaneous operators This is another major design consideration because an underdesigned system will not produce the desired level of vacuum and an oversized system will be costly.

The maximum number of simultaneous operators is decided by the facility's housekeeping or maintenance department and depends on a number of factors:

1. Is the preferred method to have gang cleaning? Is it possible to alter this practice in order to result in a less costly system?
2. What is the maximum number of operators expected to use the system at the same time?
3. Is the work done daily?

For commercial facilities where there may be no available information, the following guidelines are based on experience and can be used to estimate simultaneous use based on productivity. These figures consider the greater efficiency of using a central system compared to portable units, often in the order

Table 10-12 Recommended Sizes of Hand Tools and Hose

Nominal Size		Average Floor Cleaning and Moderate Spills	Close Hand Work	Removing Heavy Spills or Large Quantities of Materials	Overhead Vacuum Cleaning	Standard Hose Length	
DN	in.					ft	m
25	1	Not used	Yes	Inadequate	Not used	8	2.4
40	1½	Excellent	Yes	Fair	Preferred	25 and 50	7.5 and 15
50	2	Good	No	Good	Poor	25 and 50	7.5 and 15
65	2½	Not used	No	Excellent	Not used	25 and 50	7.5 and 15

Source: Courtesy of Hoffman.

of 25%. They must be verified and based on actual methods anticipated.

1. For carpets, one operator will be expected to cover 20,000 ft^2 (1860 m^2) of area for regular carpeting in an 8-hour shift. For long or shag carpets, the figure is about 10,000 ft^2 (930 m^2). Another generally accepted figure for short time periods is 3000 ft^2/hr (280 m^2/hr) for standard floors, and 2500 ft^2/hr (233 m^2/hr) for shag and long carpets.
2. For hotels, an average figure of 100 rooms, including adjacent corridors, per 8-hour shift would be expected. For long or shag carpets, the figure is about 75 rooms.
3. For theaters, use the number of seats divided by 1000 to establish the number of simultaneous operators.
4. For schools, 12 classrooms per day is an average figure for a custodian to clean in addition to other duties normally accomplished.

Inlet-valve, tool, and hose sizing The recommended inlet size for hand tools and hose is given in Table 10-12.

Experience has shown that 1½-in. (DN 40) size hose and tools for cleaning floors, walls, and ceilings is the most practical size to use. Smaller, 1-in. (DN 25), size tools are used for cleaning production tools, equipment, and benches. Larger hose and tools are used for picking up expected large spills and cleaning large tanks, boxcars, and the holds of ships. Refer to Table 10-12 for general recommendations for tool and hose sizes.

Standard hoses are available in 25, 37.5, and 50-ft (7.5, 12, and 15-m) lengths. For general cleaning, the location of inlet valves should allow for convenient cleaning with a maximum of 50 ft 0 in. (15 m) of hose. This represents a labor saving by halving the number of times an operator has to change outlets. This length should not be exceeded, except for occasional cleaning, because of excessive pressure drop.

Locating the vacuum-producer assembly The vacuum-producer assembly consists of the vacuum producer, commonly called an "exhauster," and the separators. The following shall be considered when locating the vacuum equipment:

1. Provide enough headroom for the piping above the equipment and for the various pieces to be brought easily into the room or area where they are to be installed.
2. An ideal location is on the floor below the lowest inlet of the building or facility and centrally located to minimize the differences at remote inlet locations.
3. A convenient means to dispose of the collected debris should be available close by. If a separator is used, an adequately sized floor drain is required.
4. Enough room around the separators shall be provided to allow for easy inspection, and, where dirt bins must be emptied, room must be provided for the carts needed to move them. Dry separators can be located outside the building for direct truck disposal of the dirt, if sufficiently protected.

Sizing the piping network

General After the inlets and vacuum equipment have been located, the layout of the piping system accomplished, and the number of simultaneous operators determined, system sizing can begin.

Cleaning systems using hose and tools shall have sufficient capacity so that one pass over an area is all that is necessary for cleaning. With adequate vacuum, light to medium dirt deposits shall be removed as fast as the operator moves the floor tool across the surface. The actual cleaning agent is the velocity of the air sweeping across the floor.

Vacuum-pressure requirements and hose capacity To achieve the necessary air velocity, the minimum recommended vacuum pressure for ordinary use is 2 in. Hg (7 kPa). For hard-to-clean and industrial-type materials, 3 in. Hg (10 kPa) vacuum pressure is required. The flow rate must be enough to bring the dirt into the tool nozzle. Refer to Table 10-13 to determine the minimum and maximum recommended flow rate of air and the friction losses of each hose size for the flow rate selected. For ordinary carpeting and floor-cleaning purposes, a generally accepted flow rate of 70 scfm (35 sL/s) is recommended.

Recommended velocity The recommended velocity in the vacuum-cleaning piping system depends on the pipe's orientation (horizontal or vertical) and size. Since the velocity of the air in the pipe conveys the suspended particles, it should be kept within a recommended range. Refer to Table 10-14 for recom-

Table 10-13 Flow Rate and Friction Loss for Vacuum-Cleaning Tools and Hoses

Use	Nominal Size of Tools and Hose	Minimum Volume and Pressure Drop[a]		Maximum Volume and Pressure Drop[a]	
		Volume, scfm	Pressure Drop, in. Hg	Volume, scfm	Pressure, in. Hg
Bench use	1-in. diam., 8-ft 1-in. flexible hose	40	1.20	50	1.90
White rooms or areas with very low dust content	1½-in. diam., 50-ft 1½-in. flexible hose	60	2.25	90	4.10
Usual industrial	1½-in. diam., 50-ft 1½-in. flexible hose	70	2.80	100[b]	4.80
Fissionable materials or other heavy metallic dusts and minute particles of copper, iron, etc.	1½-in. diam., 50-ft 1½-in. flexible hose	100	2.50	120	4.20
Heavy spills, Cleaning railroad cars and ship holds	2-in. diam., 50-ft 2-in. flexible hose	120	2.60	150	3.8

Source: Courtesy of Hoffman.
Note: 1 scfm = 0.5 nL/s; 1 in. Hg = 3.4 kPa
[a] The pressure drop in flexible hose is 2½ times the pressure drop for the same length and size of Schedule 40 pipe.
[b] Can be exceeded by 10% if necessary.

mended velocity based on pipe size and orientation of the pipe.

The air velocity moves the dirt in the system. Oversizing the pipe will lead to low velocity and poor system performance.

Selecting the number of outlets used simultaneously Facilities may have many inlet valves but only a few will be used at once. Under normal operating conditions, these inlets are chosen at random by the operators. To aid in the determination of simultaneous usage the following conditions, which should be expected, are given:

1. Adjacent inlet valves will not be used simultaneously.
2. For the purposes of calculating simultaneous use, the most remote inlet on the main and the inlet closest to the separator will be assumed to be in use, along with other inlet valves between the two.
3. Where mains and outlets are located on several floors, the use of inlets will be evenly distributed along a main on one floor or on different floors.
4. For long horizontal runs on one floor, allow for two operators on that branch.

Sizing the piping Refer to Table 10-15 for selecting the initial pipe size based on the number of simultaneous operators. This table has been calculated to achieve the minimum velocity of air required for adequate cleaning. In this table, "line" refers to permanently installed pipe from inlet to separator and "hose" is the hose connecting the tool to the inlet. Hose size 1½ in.(DN 40) is recommended except where the material to be cleaned will not pass through hose this size or a large volume of material is expected.

After the initial selection of the pipe sizes, the actual velocity and friction loss based on anticipated flow rates in each section of the piping system should be checked by using Figure 10-6. This chart provides a more accurate method of determining the pipe size, friction loss, and velocity of the system. To use it,

Table 10-14 Recommended Velocities for Vacuum-Cleaning Systems

Nominal Tubing Size		Horizontal Runs of Branches and Mains and Vertical Down-Flow Risers		Vertical Up-Flow Risers	
in.	DN	Minimum Velocity (ft/min)	Recommended Max. Velocity (ft/min)	Minimum Velocity (ft/min)	Recommended Max. Velocity (ft/min)
1½	40	1800	3000	2600	3800
2	50	2000	3500	3000	4200
2½	65	2200	3900	3200	4700
3	75	2400	4200	3800	5100
4	100	2800	4900	4200	6000
5	125	3000	5400	4800	6500
6	150	3400	6000	5000	7200

Source: Courtesy of Hoffman.
Note: 1 ft/min = 0.3 m/min

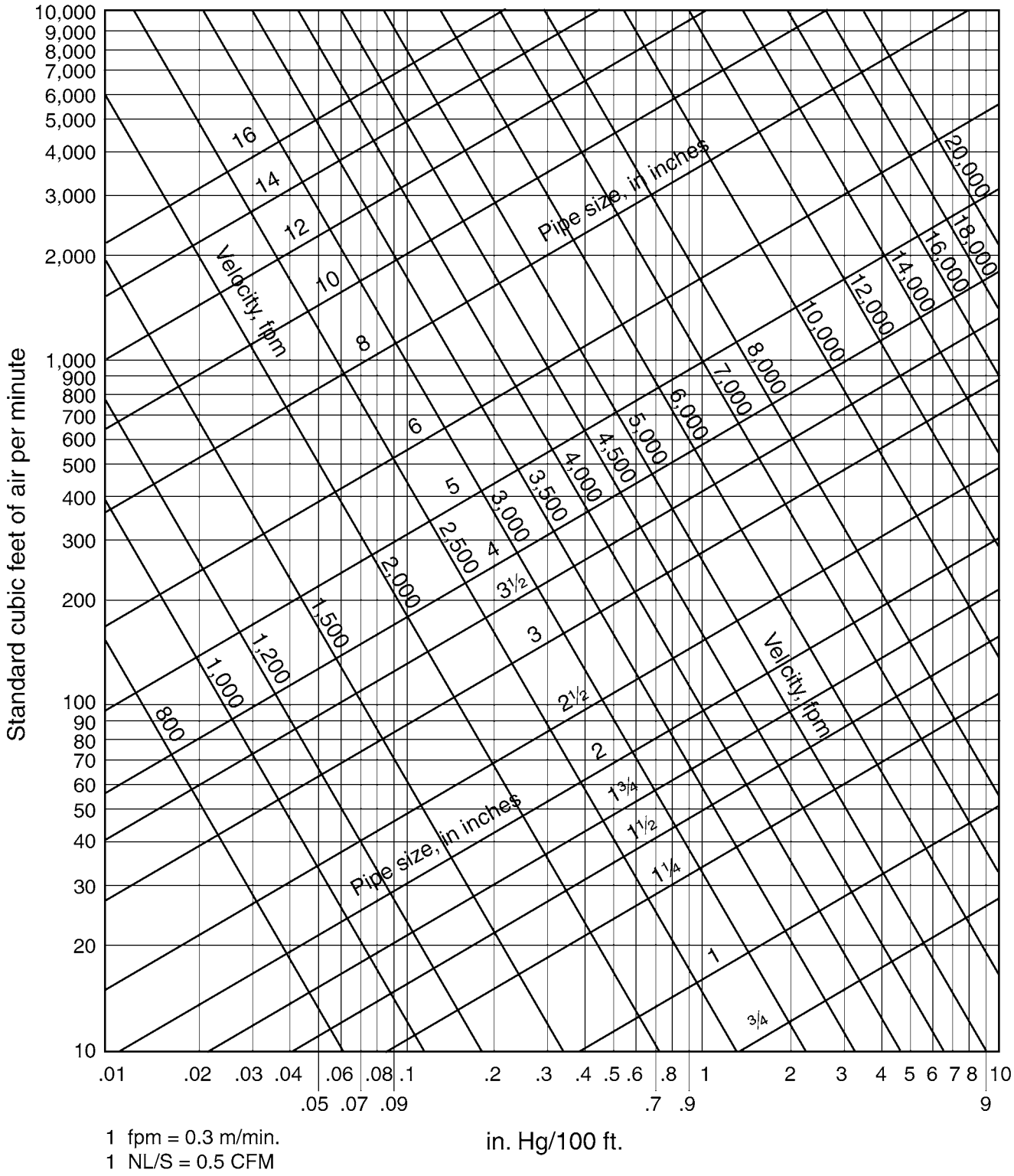


Figure 10-6 Vacuum-Cleaning Piping Friction Loss Chart

Table 10-15 Pipe Size Based on Simultaneous Usage

Line Diam.,		Number of Operators	
in.	DN	70 scfm, 1.5-in. hose	140 scfm, 2-in. hose
2	50	1	—
2½	65	2	1
3	75	3	2
4	100	5	3
5	125	8	4
6	150	12	6
8	200	20	10

Source: Courtesy of Spencer Turbine.
Note: 1 scfm = 0.5 sL/s.

enter the chart with the adjusted scfm and allowable pressure loss. Read the pipe size at the point where these two values intersect. If this point is between lines, use the larger pipe size. If any parameter is found to be outside any of the calculated ranges, the pipe size should be revised.

Pipe sizing is an iterative procedure, and the sizes may have to be adjusted to reduce or increase friction loss and velocity as design progresses.

Piping-system friction losses With the piping network sized, the next step is to calculate precisely the "worst-case" total system friction losses, in. Hg (kPa), so that the exhauster can be sized. These are calculated by adding together all of the following values, starting with the inlet most remote from the exhauster and continuing to the source:

1. *Initial level of vacuum required*. For average conditions, the generally accepted figure is 2 in. Hg (6.8 kPa). For hard-to-clean material, industrial applications, and long shag-type carpet, the initial vacuum should be increased to 3 in. Hg (10.2 kPa).
2. *Pressure drop through the hose and tool*. Refer to Table 10-13 for the friction loss through individual tools and hose based on the intended size and length of hose and the flow rate selected for the project.
3. *Loss of vacuum pressure due to friction of the air in the pipe*. Losses in the straight runs of the piping system are based on the flow rate of air in the pipe at the point of design. Refer to Figure 10-6. Fittings are figured separately, using an equivalent length of pipe to be added to the straight run. Refer to Table 10-16 to determine the equivalent length of run for each type and size of fitting. Starting from the farthest inlet, use the cfm, the pipe size, fitting allowance, and the pipe length along the entire run of pipe to find the total friction loss.
4. *Loss through the separator*. A generally accepted figure is 1 in. Hg (3.4 kPa) loss through all types of separators. The exact figure must be obtained from the manufacturer.
5. *Exhaust line loss*. This can usually be ignored except for long runs. Allow 0.1 in. Hg (0.34 kPa) as an average figure for a run of 100 ft (30 m).

Table 10-16 Equivalent Length (ft.) of Vacuum Cleaning Pipe Fittings

Nominal Pipe Size,		Equivalent Length of Pipe Fittings (ft)[a]	
in.	DN	90° Change in Direction	45° Change in Direction
1¼	32	3	1½
1½	40	4	2
2	50	5	2½
2½	65	6	3
3	75	7	4
4	100	10	5
5	125	12	6
6	150	15	7½
8	200	20	10

Notes: 1) For smooth-flow fittings, use 90% of these values.
2) 1 ft = 0.3 m
[a] Lengths based on use of cast-iron drainage fittings.

Vacuum-producer (exhauster) sizing

Exhauster-inlet rating determination It is now possible to size the exhauster. There are two exhauster ratings that must be known in order to select the size and horsepower. They are 1) the "worst-case" piping-system vacuum-pressure losses and 2) the flow rate, in scfm (sL/s), of air required by the system.

The vacuum pressure required from the exhauster is the total pressure necessary to overcome all piping system losses. This consists of the total pressure drop from all components in the piping network from the inlet farthest from the exhauster. Included are the initial inlet vacuum level required; the pressure lost through the tool and hose selected; the friction loss of air flowing through the piping system; the pressure lost through separators, filters, and silencers; and finally the exhaust pressure to be overcome, if required. These values are added together to establish the vacuum rating of the exhauster.

The flow rate of air, in scfm (sL/s), entering the system is calculated by multiplying the number of simultaneous operators by the scfm (sL/s) selected as appropriate for the intended cleanup requirements. For smaller, less complex systems, using only the actual selected inlet cfm (L/s) is sufficient.

Exhauster discharge The discharge from the exhauster is usually steel pipe routed outside the building. It is also possible to route the exhauster discharge into an HVAC exhaust duct that is routed directly outside the building.

Table 10-17 Classification of Material for Separator Selection

Size of material	Very Fine		Fine		Granular		Lumpy		Irregular
	Recommended Sep. (S)	Ratio Vol. Bag Area	Recommended Sep. (S)	Ratio Vol. Bag Area	Recommended Sep. (S)	Ratio Vol. Bag Area	Recommended Sep. (S)	Ratio Vol. Bag Area	Separator Selection & Bag Area
Small	Cent.	Not appl.	Cent.	Not appl.	Cent.	Not appl.	Cent.	Not appl.	dependent on material
Medium	TB	6:1	Cent. and TB	6:1	Cent.	Not appl.	Cent.	Not appl.	
Large	Cent. and TB	3:1	Cent. and TB	6:1	Cent. and TB	6:1	Cent.	Not appl.	

Source: Courtesy of Spencer Turbine Co.

Notes: 1. Centrifugal separators do not utilize bags.

2. Definition of terms:
   Small: Light accumulations, such as those found in clean rooms, white rooms, laboratories, and so on.
   Medium: Average accumulations, such as those found in classrooms, motels, assembly areas, and so on.
   Large: Heavy accumulations, such as those found in foundries, spillage from conveyor belts, waste from processing machines, and so on.
   Fine: 100 mesh to 8 in. (3.2 mm).
   Very fine: Less than 100 mesh.
   Granular: 8 to ½ in. (3.2 to 12.7 mm).
   Lumpy: Lumps ½ in. (12.7 mm) and over.
   Irregular: Fibrous, stringy, and so on.

3. Abbreviations: Cent. = centrifugal; TB = tubular bag.

For a piped exhaust, if the end is elbowed down, it shall be a minimum of 8 ft 0 in. (2.4 m) above grade. If the end is vertical, an end cap shall be installed to prevent rain from entering the pipe. A screen will prevent insects from entering. The size shall be equal to or one size larger than the size of the pipe into the exhauster. Use HVAC ductwork sizing methods to find the size of the exhaust piping while keeping the air pressure loss to a minimum.

The pressure loss through the exhaust pipe shall be added to the exhauster inlet pressure drop, the total of which will be calculated into the pressure that the exhauster must overcome. For short runs of about 20 ft 0 in. (6 m), this can be ignored.

To account for the various fittings comprising the exhaust system, an additional 30% should be added to the measured run to calculate the equivalent piping run.

Exhauster rating adjustments

Adjustment of cfm (L/s) for long runs For systems with very long runs or complex systems with both long and short runs of piping, some adjustment in the selected inlet cfm (L/s) shall be made. This is necessary because the actual cfm (L/s) at the inlets closest to the exhauster will be greater than the cfm (L/s) at the end of the longest run due to the smaller friction loss. The adjustment will establish an average inlet cfm (L/s) flow rate for all inlets that will be used for sizing instead of the selected inlet cfm (L/s).

To establish the adjusted cfm (L/s), it is necessary to calculate separately the total system friction loss for each branch line containing inlets nearest and farthest from the exhauster. Following the procedures previously explained will result in minimum and maximum system friction loss figures. The following formula can be used to calculate the adjusted cfm (L/s):

Equation 10-7

$$\text{adjusted cfm} = \frac{\text{farthest inlet friction loss (in. Hg)}}{\text{closest inlet friction loss (in. Hg)}} \times \text{selected cfm}$$

The adjusted cfm (L/s) figure is used instead of the selected cfm (L/s) and multiplied by the number of simultaneous operators to size the exhauster.

Adjustment due to elevation All of the above calculations are based on scfm (sL/s) at sea level. If the location of the project is at an elevation higher than sea level, the scfm (sL/s) should be adjusted to allow for the difference in barometric pressure. Refer to Table 10-7 for the factor. This factor shall be multiplied by the scfm (sL/s) figure to calculate the adjusted cfm (L/s) to be used in sizing the exhauster.

Adjustment for different cfm (L/s) standards Another adjustment to the scfm (sL/s) figure used to size the exhauster is required if the equipment manufacturer uses inlet icfm (iL/s) instead of scfm (sL/s). Icfm (iL/s) is the actual volume of air at the inlet of the exhauster using local temperature and barometric conditions. Previously discussed temperature and barometric conversions shall be used.

Separator selection and sizing The separator is sized based on the cfm (L/s) of the vacuum producer and the type of material expected to be collected. Refer to Table 10-17 for a classification of such material.

For dry separators, a starting point for sizing would provide a 6:1 ratio of filter bag area to bag volume for smaller volumes of course material and a 3:1 ratio for fine dust and larger quantities of all material. Wet and centrifugal-separator sizing is proprietary to each manufacturer and is dependent on the quantity and type of material expected to be removed.

Some automatic-separator cleaning systems use compressed air to aid in the dislodging of dust. The

air pressure recommended is generally in the range of 100 to 125 psig (689 to 1034 kPa).

General design considerations "Abrasion" is the wearing away of the interior of the pipe wall by large, hard particles at the point where these particles strike the pipe. The effects are greatest at changes of direction of the pipe, such as at elbows and tees and under the bag plates of separators. When abrasive particles are expected, it is recommended that either cast-iron drainage fittings or schedule 40 steel pipe fittings using sanitary pattern sweeps and tees be substituted for normally used tubing materials.

It is good practice to provide a safety factor of extra cfm (L/s) to ensure that additional capacity is available from the exhauster without affecting the available vacuum. This should not exceed 5% of the total cfm (L/s) and is used only when selecting the exhauster, not for sizing the piping system. The exhauster size should be selected and then the safety factor added. The unit selected should have that extra flow available.

The piping shall be pitched toward the separator. Plugged cleanouts should be installed at the base of all risers and at 90° changes in direction to allow any blockages to be easily cleared.

Piping geometry in the design of wet-system piping could become critical. Every effort shall be made to keep the piping below the inlet valves to prevent any liquid from running out of the inlet after completion of the cleaning routines and to ease the flow of the liquid into the pipe. The wet-system pipe should pitch back to the separator at about 8 in./ft (1 cm/m). All drops should be no larger than 2 in. (50 mm) in size and only 1 inlet shall be placed on a single drop. Each drop should terminate in a plugged tee facing down. This will allow any liquid still clinging to the sides of the pipe to collect at the bottom of the riser and be carried away the next time the system is used. A typical wet vacuum-cleaning system is shown in Figure 10-7.

In facilities using controlled substances, there is always a possibility that a spill will occur. For clean-

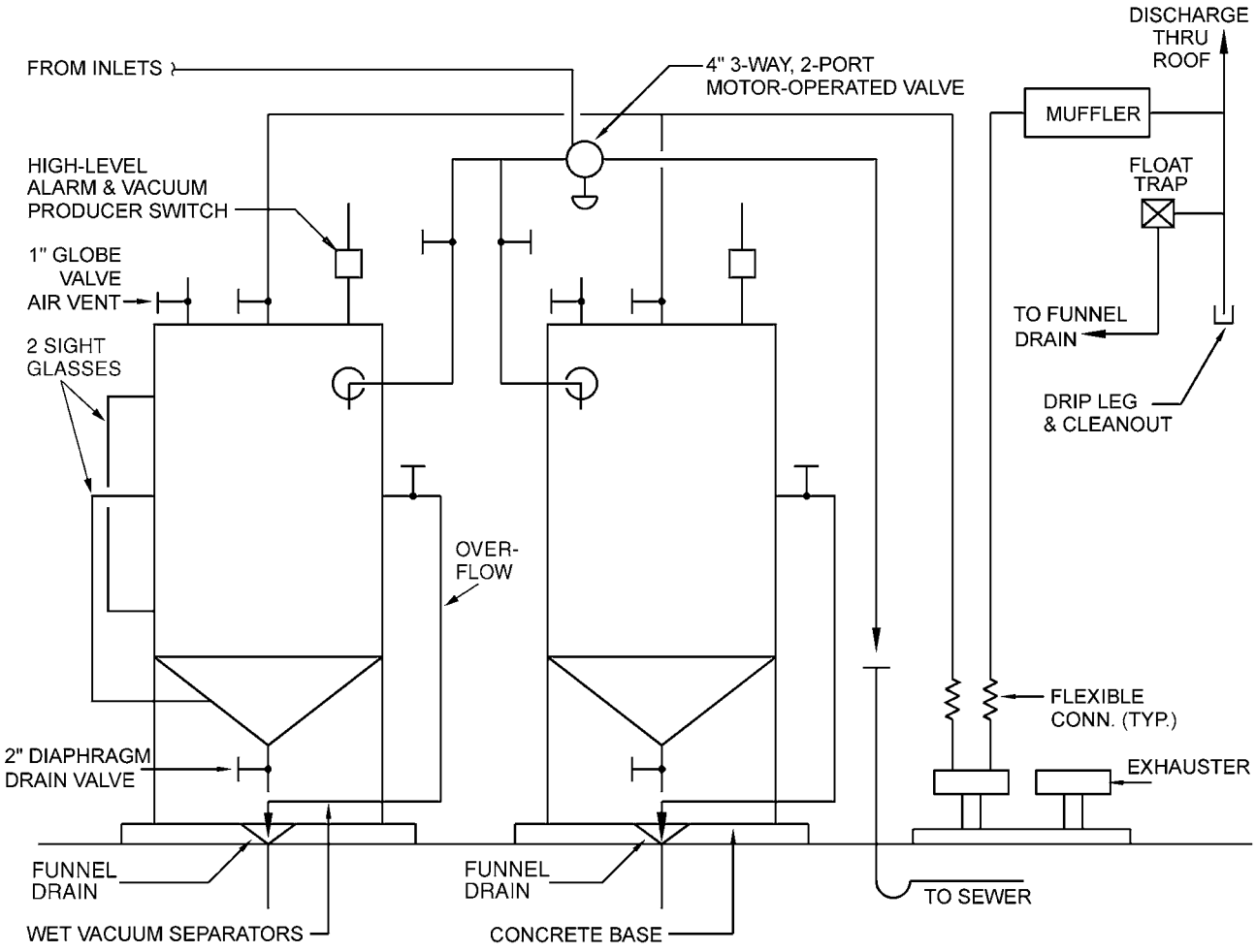


Figure 10-7 Schematic of a Typical Wet-Vacuum Cleaning Pump Assembly

ing this type of spill, a portable vacuum-cleaning unit should be selected so that the filter can easily be weighed both before and after cleanup to account for the controlled substances picked up in the cleaning unit.

REFERENCES

1. Albern, W. F. 1972. Vacuum piping systems. *Building Systems Design*.
2. Frankel, M. 1996. *Facility piping systems handbook*. New York: McGraw-Hill.
3. Harris, Nigel S. 1990. *Modern vacuum practice*. New York: McGraw-Hill.
4. Hesser, Henry H. 1993. Vacuum sources. *Pumps and Systems Magazine* August.
5. Hoffman Industries. *Design of Hoffman industrial vacuum cleaning systems*.
6. McSweeney, D.P., and R. Glidden. 1993. Vacuum cleaning systems, unpublished Manuscript.
7. Moffat, R. 1987. Putting industrial vacuum to work. *Hydraulics and Pneumatics Magazine*.
8. The Spencer Turbine Co. How to design Spencer central vacuum systems.

11 Water Treatment, Conditioning, and Purification

INTRODUCTION

This chapter describes the logic behind the selection of various water-treatment methods to partially remove and replace various chemical and suspended agents from a feed-water stream. It also discusses water-conditioning chemicals used to control the impact of ionic compounds, adjust pH, and inhibit corrosion; and pure-water systems that remove impurities from the feed water to a level at or below the limits desired by the end user.

Information on basic water chemistry, impurities found in water, water analysis, and impurity measurement is presented. General selection criteria for the removal or reduction of specific impurities from water are also discussed. Explanations on water-conditioning systems for boiler feed water, water-conditioning systems for cooling water, and the generation of purified water are also found in this chapter.

For the purposes of discussion in this chapter, the term "water treatment" is intended to mean the chemical or mechanical removal and/or replacement of ionic or non-ionic substances in feed water to produce water for a predefined use. "Water conditioning" is intended to mean the addition of chemicals to water for the purposes of inhibiting corrosion, chelating hardness, chelating trace metals, suspending colloids, and adjusting pH. "Pure-water systems" are intended to mean systems designed to produce water pure enough for use in pharmaceutical plants, laboratories, high-density semiconductor manufacturing, and very high-pressure boilers. The explanations and definitions given are simplified but suffice for the purposes of this chapter.

CODES AND STANDARDS

Many codes and standards apply to various systems; among them are the following:

1. Potable water treatment shall comply with the 1986 Safe Drinking Water Act and amendments.
2. The Environmental Protection Agency (EPA) has identified treatment technologies with given contaminant removal efficiencies for potable water.
3. Pure-water treatment shall comply with one or more of the following, depending on the purity of the water desired.
   A. College of American Pathologists (CAP) and American Society for Testing and Materials (ASTM) reagent grade water.
   B. US Pharmacopeia (USP) standards for water purity.
   C. Association for the Advancement of Medical Instrumentation (AAMI) standards.
   D. National Committee for Clinical Laboratory Standards, Inc. (NCCLS) standards.
   E. Semiconductor Equipment and Materials International (SEMI) and ASTM electronics grade water.
4. Water treatment for boiler feed water, cooling water and process water.
5. Food and Drug Administration (FDA).

BASIC WATER CHEMISTRY

Water to be treated is known variously as "raw water," "feed water," or "source water." Water that has been treated is known as "treated water," "product water," and "solute." Chemicals or substances that dissolve in water can be "electrolytes" or "non-electrolytes." "Electrolytes" are chemicals that dissolve in water to form ions, for example:

$$\text{Sodium chloride} \rightarrow Na^{+}Cl^{-}$$

$$\text{Magnesium sulfate} \rightarrow Mg^{2+}SO_4^{2-}$$

"Non-electrolytes" are chemicals that dissolve in water but do not break down, for example, ethanol (C_2H_5OH), sugars, and many organics. The positively charged atoms are called "cations" because they migrate to the cathode electrode and the negatively charged atoms are called "anions" because they

migrate to the anode electrode. The ions in solution act almost independently. For example, magnesium sulfate dissociates to form positive magnesium ions and negative sulfate ions. Ions are often generally referred to as "salts" in reference to reverse osmosis water production.

When an electrolyte compound dissolves in water, the molecules of the compound separate, disperse among the molecules of water, and are held in suspension. "Suspension" usually refers to colloids, particles, etc. that are suspended in solution and do not settle under the influence of just gravity. When the limit of solubility is reached, those same compounds become suspended solids. There is no chemical reaction. Dissolved materials cannot be removed by filtration, except by reverse osmosis.

Some types of liquid cannot be dissolved. They break down into extremely small-sized particles and then disperse into the water, even though they are not soluble. These liquids are called "immiscible liquids." The resulting small-sized particles are known as "colloids." Colloidal material is at the upper end of the size range for ions and molecules, in the general range of 0.001 to 1.0 micron (μ). In most cases, other liquids, such as oil and grease, cannot separate into smaller-sized particles and become dispersed but simply remain in suspension. If they are lighter than water, they float on top. If heavier, they sink below the surface.

All acid compounds referred to in water chemistry consist of hydrogen combined with an acid radical. Since the acid radical moves around as a unit, it is convenient to view the acid radicals as an integral anion unit. When a metal radical and acid radical combine, they form a class of chemicals called "salts." If a metal cation and a hydroxide anion combine, a "base" results.

An "acid" is any compound capable of giving up a hydrogen ion (H^+) or proton. The acid's conjugate base, or anion, is the compound remaining after the loss of the H^+:

$$HCl \rightarrow \text{conjugate base} = Cl^-$$

A "base" is any compound capable of accepting a hydrogen ion or giving up a hydroxide (OH^-) ion:

$$NaOH \rightarrow \text{conjugate acid} = Na^+$$

The "valence" of any element is a measure of its chemical combining power compared to that of a hydrogen atom, which has the assigned value of 1. The valence is the number of electrons in an atom that are free to share, give, or take from other atoms. An element with a value of +2 can replace two hydrogen atoms in a compound, or an element with a valence of -2 can react with two hydrogen atoms. When atoms combine to form compounds, a cation atom must combine with an anion atom and, in addition, the valence of the two basic elements must equal one another in order to form the compound.

Most of the basic chemical reactions in water treatment consist of rearranging cation and anion atoms using their valence. As can be seen in Table 11-1, hydrogen has a valence of 1, and sulfate has a valence of 2. When combined to form sulfuric acid, two hydrogen atoms are required to form the combination, resulting in the formula H_2SO_4. The chief exception is the case where carbonates and bicarbonates are destroyed by heating or aeration, giving off carbon dioxide.

The term "equivalent weight" is the weight, in grams (g), of any element that could combine with or displace 1.008 g of hydrogen or 8 g of oxygen. Since the valence of an element is proportional to its combining power, the equivalent weight is based on its valence. This is illustrated in Table 11-1.

Water Impurities

Natural, or source, water is never chemically pure H_2O. Water dissolves ionic compounds as it comes in contact with the ground surface or mineral formations when percolated through the earth. It also contains dissolved gases and dust picked up when falling through the air as rain, snow, or hail or when surface water is in contact with the air above the water level. Water is classified as "surface water" when obtained from sources such as lakes and rivers and "ground water" when obtained from streams, wells, or other aquifers originating underground.

Suspended matter (particulates), turbidity "Turbidity," also called "suspended solids," is a general term used to describe any form of insoluble matter suspended in water. Color is another chemical phenomenon often associated with turbidity. Color may be an indication of water containing decaying vegetation. However, the term "turbidity" is most often used when referring to mineral particulates such as silt because they are usually the most plentiful. Other commonly occurring impurities are liquids, such as oil, and the residue caused by decaying vegetation. Coarse particles that settle rapidly when water is standing are referred to as "sediment," and fine particles that mostly remain in suspension are called "silt."

Microorganisms "Microorganisms" are bacteria and viruses. They are living forms of particulate matter. Their unusual physiology allows them to grow and multiply in water containing only trace levels of nutrients. The presence of these nutrients in untreated water is an indicator of the presence of microorganisms, if the temperature is favorable for their growth. Although microorganisms are a suspended solid, the treatment required for their removal or neutralization puts them in a separate category.

"Pyrogens" cause fever, and "pathogenic" organisms (such as Legionella) cause diseases of all kinds.

Table 11-1 Important Elements, Acid Radicals, and Acids in Water Chemistry

Element	Symbol	Atomic Weight	Valence	Equivalent Weight
Aluminum	Al	27.0	3	9.0
Barium	Ba	137.4	2	68.70
Calcium	Ca	40.1	2	20.05
Carbon	C	12.0	Variable	—
Chlorine	Cl	35.46	Variable	35.46
Fluorine	F	19.0	1	19.0
Iron (ferrous)	Fe^{2+}	55.8	2	27.9
Iron (ferric)	Fe^{3+}	55.8	3	18.6
Hydrogen	H	1.0	1	1.0
Magnesium	Mg	24.3	2	12.15
Nitrogen	N	14.0	Variable	—
Potassium	K	39.1	1	39.1
Oxygen	O	16.0	2	8.00
Phosphorus	P	31.02	Variable	—
Sodium	Na	23.0	1	23.0
Sulfur	S	32.0	Variable	—
Silicon	Si	28.06	4	7.01

Acid Radicals	Formula	Molecular Weight	Valence	Equivalent Weight
Bicarbonate	HCO_3	61.0	1	61.0
Carbonate	CO_3	60.0	2	30.0
Chloride	Cl	35.46	1	35.46
Nitrate	NO_3	62.0	1	62.0
Hydroxide	OH	17.0	1	17.0
Phosphate	PO_4	95.0	3	31.66
Sulfite	SO_3	80.0	2	40.0
Sulfate	SO_4	96.06	2	48.03

Acid	Formula	Molecular Weight	Equivalent Weight
Carbonic acid	H_2CO_3	62.0	31.0
Hydrochloric acid	HCl	36.46	36.46
Phosphoric acid	H_3PO_4	98.0	32.67
Sulfuric acid	H_2SO_4	98.1	49.05
Sulfurous acid	H_2SO_3	82.1	41.05

Miscellaneous Compounds	Formula	Molecular Weight	Equivalent Weight
Aluminum hydroxide	$Al(OH)_3$	78.0	26.0
Calcium bicarbonate	$Ca(HCo_3)_2$	162	81.0
Calcium carbonate	$CaCO_3$	100	50.0
Calcium sulfate	$CaSO_4$	136	68.0
Carbon dioxide	CO_2	44.0	22.0
Ferric hydroxide	$Fe(OH)_3$	107	35.6
Magnesium carbonate	$MgCO_3$	84.3	42.1
Magnesium hydroxide	$Mg(OH)_2$	58.3	29.1
Magnesium sulfate	$MgSO_4$	120	60.1
Sodium sulfate	Na_2SO_4	142	71.0

"Endotoxins," which are fragments derived from the cell walls of gram-negative bacteria, are considered the most important and widely occurring group of pyrogens. Other organic growths include "algae" (a primitive form of plant life), "fungi" (plants lacking the chlorophyll required for photosynthesis) and bacteria exhibit both plant and animal characteristics. Bacteria are further subdivided into "slime bacteria," which secrete slime; "iron bacteria," which thrive on iron; "sulfate-reducing bacteria," which live by consuming sulfate and converting it to hydrogen sulfide gas; and "nitrifying bacteria," which use ammonia and whose byproduct results in the formation of nitric acid.

Several methods of measurement are used, including viable-count essays, direct-count epifluorescent microscopy, scanning electron microscopy, and biochemical techniques. The most common means of measuring bacterial contamination is the viable-count method. This is done by passing the water being measured through a sterile nutrient medium, and counting the number of colonies appearing on the medium after a period of time is allowed for growth. These are called "colony forming units," or cfus. Endotoxins are measured in endotoxin units per milliliter (eu/mL). An often-used form of measurement for endotoxins is the limulus amoebocyte lysate (LAL) test, wherein a blood extract of the horseshoe crab becomes turbid in the presence of bacterial endotoxins. This detection technique uses optical density (turbidity level) measured over a period of time.

Other organisms This term for biological life is applied to larger living things, such as clams, mussels, their larvae, and other forms of life. They tend to clog water inlets from bodies of salt and fresh water and also may find their way into the piping system of a facility.

Dissolved minerals and organics Dissolved organic substances typically found in water include both man-made and natural substances. Man-made chemical compounds, some of which are harmful to the environment, include herbicides, pesticides, trihalomethanes, surfactants, and detergents. Naturally occurring chemical compounds, which are typically not harmful in trace amounts, include lignins, tannins, humic and fulvic acid, and other bio-decomposition products.

Alkalinity "Alkalinity" is a measurement of the quantity of dissolved earth minerals in water and the water's ability to neutralize acids. All natural water contains some measure of alkalinity. It is mainly the sum of carbonate, bicarbonate, and hydroxide ions in water, with borate, phosphate, and silicate ions partially contributing to the total. It is reported as parts per million (ppm) equivalent of calcium carbonate. Alkalinity is regarded as an important characteristic of water in determining its scale-forming tendency.

Alkalinity is measured using two end-point pH indicators in a titration with acid. The phenolphthalein alkalinity, or P alkalinity, measures the strong alkali in the solution. The methyl orange alkalinity, or M alkalinity, measures all of the alkalinity present in the solution. The M alkalinity is often called the "total alkalinity" because it also includes the P alkalinity. Alkalinity is not a measure of pH but is a contributor to the pH of the solution.

Hardness "Hardness" is a measure of the total calcium, magnesium, iron, and other metallic elements

that contribute to the "hard" feel of water. Carbonate, sulfate, and chloride salts of these elements are responsible for most of the scaling deposited on pipe and boiler walls. Generally accepted practice limits the term "hardness" to include only calcium and magnesium. Hardness is usually expressed in terms of mg/L as $CaCO_3$.

Often, water is characterized in general terms by the amount of hardness, as follows:

Soft	0–75 mg/L as $CaCO_3$
Moderate	76–150 mg/L as $CaCO_3$
Hard	151–300 mg/L as $CaCO_3$
Very hard	Over 300 mg/L as $CaCO_3$

Iron The most common form of iron is ferrous bicarbonate. Because this form of iron is soluble it may be treated the way one treats for hardness.

Iron creates problems in ion-exchange processes where polymeric resins are predominant. Iron also creates problems on the surface of separation membranes. Soluble iron is called "ferrous" (Fe^{2+}), while insoluble iron is called "ferric" (Fe^{3+}). Iron in the ferrous form is subject to receiving an electron; it is said to be subject to oxidation. The presence of oxidation agents in water with ferrous iron is the root of the trouble. Common oxidants are oxygen O_2 and Chlorine Cl_2.

If it were possible to maintain the iron as ferrous throughout the process, including regeneration of softening resin and the shutdown of membrane systems, the (Fe^{2+}) would not present a problem. However, for all practical purposes, it is impossible to prevent some of the ferrous substance from oxidizing to the ferric substance. During the oxidation process, other ionic substances are involved. Typically there is a long hydrocarbon chain when resin or separation membranes are made. In these long chains there are sites where the ferric iron connects to the polymer. The ferric connection point acts as a catalyst for further crystallization or chemical reactions with the iron or related substances, thereby creating a snowball effect for further chemical reactions.

Calcium Calcium is a silver-white, bivalent, metallic element of the alkaline-earth group occurring only in combination. Common combinations are calcium carbonate, calcium chloride, calcium hydroxide, calcium phosphate, and calcium silicates.

Magnesium The most common forms of magnesium are magnesium carbonate, magnesium bicarbonate, and magnesium chloride. These impurities tend to deposit scale on surfaces with which they come in contact.

Silica The three common kinds of silica are soluble, colloidal, and particulate. Soluble silica is often referred to as "reactive silica," and colloidal silica is sometimes called "non-reactive" or "polymeric." The most common form in solution is silicon oxide, and in suspension it is found as a fine colloid. These impurities tend to deposit a scale on surfaces they come in contact with and form a gelatinous mass on reverse-osmosis (RO) membranes.

Sodium and potassium Sodium and potassium form similar salts, with the most common being sodium or potassium chloride, sodium or potassium carbonate, and sodium or potassium bicarbonate.

Chlorides and sulfates The most common forms of chlorides and sulfates are dissolved salts of sodium, potassium, calcium, and magnesium. These impurities tend to deposit a scale on surfaces with which they come in contact.

Nitrates The federal EPA has set drinking-water limits for nitrates at 10 mg/L. Though water with high nitrate levels are treatable, the systems designer must be aware of the supply water concentration. If neutralized ion-exchange regeneration waste or membrane-separation concentrate is discharged directly into the environment or into a municipal treatment system, limits are placed on the discharge nitrate concentration. Knowing the concentration of the supply and the local discharge limits is critical to the selection of equipment and system design.

Trace elements Trace elements are present in very small quantities and are only considered problems if the amount is above an accepted level for the intended use of the water. Examples are lead, cadmium, copper, barium, silver, lithium, zinc, chromium, mercury, arsenic, and selenium. When a supply-water treatment system is selected, the waste products must be considered. Many municipalities sell the sludge created by their process to local farms as fertilizer or cattle feed. Therefore, they place considerable restrictions on treatment discharges. The systems designer/specifier needs to be aware of all local codes and practices to be effective. Though elements may be identified as trace by analysis of the supply water, in the concentrate they may exceed local, state, and federal discharge limits.

Dissolved gases The most common dissolved gases in natural raw water are oxygen, carbon dioxide, nitrogen, and hydrogen sulfide. Water obtained from a potable water supply usually also has chlorine and fluorides present, added for public-health purposes. Of increasing concern is the presence of radon gas in many water supplies obtained from wells.

Oxygen is the basic factor in the corrosion process; it must be present for the corrosion of metals. Its removal or reduction reduces the corrosiveness of the water. Carbon dioxide, nitrogen oxides, sulfur oxides, and hydrogen sulfide contribute to corrosion by making water acidic.

For chlorine, no pretreatment is usually necessary for a feed water with less than 1 ppm. When more than 1 ppm of chlorine is present, an activated carbon filter is recommended.

Volatile organic compounds (VOC) "Volatile organic compounds" are those compounds that evaporate readily at ambient temperatures and pressures. For the most part VOCs are man made. Swamp gas is an example of a naturally occurring VOC. However, most of the compounds that are a concern regarding the production of chemically pure water are man made. The federal EPA as well as most state EPAs have lists of 21 regulated VOC compounds and 34 more unregulated VOC compounds.

It may interest the plumbing engineer, however, that most of the VOCs creating concern for the end user of chemically pure water come from the process itself. VOCs may come from the following typical treatment elements and associated transport systems:

1. Polyvinyl chloride (PVC) and chlorinated polyvinyl chloride (CPVC) pipe.
2. Polypropylene and polyethylene pipe.
3. Cation ion-exchange resin, the solvent used to make the polymer.
4. Anion ion-exchange resin, the solvent and the organic amines ($NH_3 - NH_4^+$)
5. Reverse osmosis membrane, the solvent used to create the barrier polymer.
6. UF and nanofilter membranes, the solvent used to create the polymer.
7. Fiberglass-reinforced plastic (FRP), polypropylene, and polyethylene-treated water-storage tanks.
8. Filter and ion-exchange vessel linings.
9. Pipe solvent, glue, and "dope."
10. Cross-flow filter media.
11. Other "plastic" wetted materials used in the construction of the system.

Many of the items listed above have substitute materials or can be treated to remove the serious VOCs. To determine the best approach for avoiding serious contamination, contact the supplier of the treatment products considered. Remember, however, these organic compounds are volatile—meaning , with use, the VOCs will dissipate dramatically. Also, there are commercially available flushing solutions used to rinse down high-purity installations before they are placed in service. These solutions kill bacteria and rinse VOCs without severe damage to the system. To determine the best approach for the materials selected for the process, always consult with the vendor before proceeding. Furthermore, consult the user to determine the impact of the VOCs given off by the treatment on the process. Consultation can save considerable effort, time, and money.

WATER ANALYSIS AND IMPURITY MEASUREMENT

The analysis of a water sample is the process of finding the quantities of various impurities present. The quantities must be presented in a logical and understandable manner to allow for easy and practical interpretation. It is of utmost importance the initial analysis of incoming water be accurate and contain a worst-case scenario and the desired output quality be established prior to the selection of any treatment system.

The most accurate analyses of water samples are done by laboratories specializing in this type of work. Sterile containers must be used and several samples must be taken over a period of time to ensure peak readings and average values are obtained. There are also many field tests of water samples, which, while not as accurate as laboratory tests, may provide an accuracy acceptable to the user.

The results of the analysis are expressed in many ways. A common method used to report the concentration of ions in solution is the weight of an element or compound per liter of water, expressed as milligrams per liter (mg/L) of water. Another method is parts per million (ppm). PPM can be expressed either by the weight of an impurity compared to the weight of water (abbreviated "w/w," weight to weight) or by the volume of the impurity to the volume of water (abbreviated "v/v"). Other units are also used, such as grains per gallon (gpg) and equivalents per million (epm). Mg/L differs from ppm in expressing a proportion in weight per volume. This finds specific use in the analysis of saline waters. For common supplies where the specific gravity of the liquid is around 1, mg/L and ppm are equal. Grains per gallon (gpg) is a term often used in discussion of ion-exchange equipment capabilities, where 1 gpg = 17.1 ppm.

As previously explained, compounds break down into ions when dissolved. Although chemists can measure the amount of each ion present in a sample, it is not practical to find the total amount of each compound that actually went into solution. In practice, the actual method of analysis measures only ions. Using the ionic measurement when reporting impurities makes it easier and more convenient to interpret the results.

To further simplify reporting, it is desirable to reduce all ions present in solution to a common denominator. The common denominator is calcium carbonate. This is accomplished by comparing the equivalent weight of all ions present and expressing them as the ppm anion and cation equivalent of calcium carbonate. The main reason is the molecular

weight of calcium carbonate is 100 and its equivalent weight is 50. This method of expression is a widely accepted standard for reporting a water analysis, but it is not universal. Table 11-2 presents the conversion factors used for major impurities. Figure 11-1 illustrates a typical water analysis report indicating impurities in ppm, equivalents useful in calculating reacting chemicals, and a comparison of positive and negative ions.

pH

"pH" is a measurement of the hydrogen ion concentration in water and, therefore, a measure of the water's acidity. pH is calculated from the logarithmic reciprocal of the hydrogen ion concentration in water.

Table 11-2 Converting ppm of Impurities to ppm of Calcium Carbonate

Cations	Ionic ppm Multiplier	Anions	Ionic ppm Multiplier
Hydrogen	50.00	Hydroxide	2.94
Ammonium	2.78	Chloride	1.41
Sodium	2.18	Bicarbonate	0.82
Potassium	1.28	Nitrate	0.81
Magnesium	4.10	Bisulfate	0.52
Calcium	2.50	Carbonate	1.67
Ferrous iron	1.79	Sulfate	1.04
Ferric iron	2.69		
Cupric	1.57		
Zinc	1.53	**Other**	
Aluminum	5.55	Carbon dioxide	2.27
Chromic	2.89	Silica	1.67

WATER ANALYSIS REPORT

Collected _____

Sample No. 605

Analyzed _____

For ABC Co.

Reported _____

	Ion		epm	ppm as $CaCO_3$
Cations	Calcium as Ca	62 ppm	3.10	155
	Magnesium as Mg	31 ppm	2.54	127
	Sodium and potassium as Na	38 ppm	1.64	83
	Total cations		7.28	365
Anions	Bicarbonate as HCO_3	250 ppm	4.10	205
	Carbonate as CO_3	0 ppm	0	0
	Hydroxide as OH	0 ppm	0	0
	Chloride as Cl	11 ppm	0.31	15
	Sulfate as SO_4	138 ppm	2.87	145
	Nitrate as NO_3	_____ ppm		
	Total anions		7.28	365

Silica as SiO_2	5 ppm	Total hardness	282 ppm $CaCO_3$
Iron as Fe_2O_3	1.2 ppm	Methyl orange alkalinity	205 ppm $CaCO_3$
Total dissolved solids	536 ppm	Phenolphthalein alkalinity	0 ppm $CaCO_3$
Suspended solids (weight)	5 ppm		
Chloroform-extractable matter	_____ ppm		
Turbidity (after shaking)	5 ppm	pH 7.7	Color _____
Carbon dioxide as CO_2	10 ppm	Sp conductance _____	μmhos

Figure 11-1 Typical Water Analysis Report

The pH scale ranges from 0 to 14, with values lower than 7 being acid, values higher than 7 being alkaline, and 7 being neutral. When an acid is added to water, the concentration of hydrogen ions increases, resulting in a lower pH. When an alkaline is added to water, the hydrogen ions decrease, resulting in a higher pH. The change of a pH unit represents a tenfold increase (or decrease) in strength. The pH is not a measure of alkalinity.

Specific Resistance

"Specific resistance" (megaohm-cm) is a measure of the amount of electrolytes in water. It measures the ability of 1 cm^3 of the sample solution at a given temperature to resist the flow of an electrical current. It is based on the activity of the compounds dissolved in water and is the most practical method of measuring ionic impurities from a given sample. Resistance is given in ohms (Ω). The resistance is based on the amount of ionized salts only and varies with the temperature of the water.

Pure water has an electrical resistance of approximately 18.3 megaohm-cm (MΩ-cm), at 77°F (25°C). This maximum resistance value is based on calculation of the electrical resistance from the very small concentrations of hydrogen and hydroxide ions from the slight dissociation of water. This dissociation yields concentrations of 1×10^{-7} moles/L for each hydrogen and hydroxide. Temperature is a significant factor in the measurement of the electrical resistance of water, with warmer temperatures producing higher values. For example, the electrical resistance of water at 50°F (10°C) is 8.8 MΩ-cm, and at 104°F (40°C), 43.3 MΩ-cm.

Instruments, referred to as "water resistivity meters," are now available to accurately measure the electrical resistance of water. Because of the large impact of temperature, these meters typically report electrical resistance normalized to 77°F (25°C). Resistivity meters are typically used as a measure of the total amount of electrolytes in purified water when the concentrations are very low. Resistivity conversions are given in Table 11-3.

Specific Conductance

"Specific conductance" (micromho/cm) measures the ability of 1 cm^3 of the sample solution at a given temperature to conduct an electrical current. It is the reciprocal of the resistance, in ohms. Since it is the opposite of resistance, it is given the name "mho," which is "ohm" spelled backwards. The actual conductance is so small it is measured in micromhos (μmho), which is one millionth of a mho. As an example, at 70°F (19°C) demineralized water with ½ ppm dissolved salt has a conductance of 1 μmho. Pure water has a specific conductance of 0.055 μmho/cm at 77°F (25°C). Conductivity conversions are given in Table 11-3. Specific conductance in actual practice is normally measured by probes suspended in the stream of water.

Table 11-3 Resistivity and Conductivity Conversion

Grains/gal[a] as $CaCO_3$	ppm as $CaCO_3$	ppm NaCl	Conductivity, μmho/cm	Resistivity, MΩ/cm
99.3	1700	2000	3860	0.00026
74.5	1275	1500	2930	0.00034
49.6	850	1000	1990	0.00050
24.8	425	500	1020	0.00099
9.93	170	200	415	0.0024
7.45	127.5	150	315	0.0032
4.96	85.0	100	210	0.0048
2.48	42.5	50	105	0.0095
0.992	17.0	20	42.7	0.023
0.742	12.7	15	32.1	0.031
0.496	8.5	10	21.4	0.047
0.248	4.25	5.0	10.8	0.093
0.099	1.70	2.0	4.35	0.23
0.074	1.27	1.5	3.28	0.30
0.048	0.85	1.00	2.21	0.45
0.025	0.42	0.50	1.13	0.88
0.0099	0.17	0.20	0.49	2.05
0.0076	0.13	0.15	0.38	2.65
0.0050	0.085	0.10	0.27	3.70
0.0025	0.042	0.05	0.16	6.15
0.00099	0.017	0.02	0.098	10.2
0.00070	0.012	0.015	0.087	11.5
0.00047	0.008	0.010	0.076	13.1
0.00023	0.004	0.005	0.066	15.2
0.00012	0.002	0.002	0.059	16.9
0.00006	0.001	0.001	0.057	17.6
none	none	none	0.055	18.3[b]

[a] Grains per gal = 17.1 ppm ($CaCO_3$).
[b] Theoretical maximum.

Total Suspended Solids

"Total suspended solids" is the sum of all the suspended material found in the water sample and is commonly measured in either parts per million (ppm, w/w) or milligrams per liter (mg/L), which measures the weight of the material per volume of the sample. For all practical purposes, these two forms of measurement are equal to each other (1 ppm = 1 mg/L).

Turbidity in water is classified by the size of the particulates in microns (μ) (1/1000 in. [0.03 mm] diameter) and tested by a light interference method known as a nephelometric. This test compares the water sample by color to a standard color scale. This measurement is obtained by comparing the sample being tested with a known color reference; the total suspended solids are indicated based on this comparison. The most common reporting method is the nephelometric turbidity unit (ntu)—the higher the number, the more turbid the water.

The nephelometric turbidity unit measures the color of a beam of light passed through the water sample being tested. An often-used standard for potable water is the standard method for the examination of water and waste water developed by the American Public Health Service, which uses formazin as the standard for producing a known volume of turbidity. The standard color scale to which it is compared is

derived from the platinum cobalt unit (PCU). Other methods less frequently used are the comparator tube determination using formazin, called the formazin turbidity unit (FTU); and the original test, the Jackson turbidity unit (JTU), named for the man who developed a standard candle used to compare the color of candle light through a sample to a color standard. The most accurate method of measuring solids is gravimeterically, wherein a known quantity of water is evaporated and the resulting solids weighed.

The most effective method of removing turbidity is by the use of filters and strainers. The equipment chosen to accomplish this task depends for the most part on the sizes and types of the solids to be retained. Other factors include the materials of construction of the device, the nature of the raw water, flow-rate requirements, the particle removal target, initial and operating costs, and maintenance requirements.

Total Dissolved Solids (TDS)

Often referred to as "dissolved inorganics" and "mineral salts," the "total dissolved solids" (TDS) is generally the sum of all the dissolved minerals, including chlorides, sulfates, and carbonates. Dissolved solids contribute to scale deposit and corrosion of piping and equipment. When dissolved in water, mineral salts form positively charged ions, mostly sodium and calcium, and negatively charged ions, mostly chlorides and sulfates.

TDS is considered two diverse ways in the field of water treatment. Engineers designing ion-exchange systems consider TDS differently than those designing membrane-separation systems. Neither approach is incorrect, but if the approach is not defined it can cause design errors in the final process. Quantitatively, TDS is the difference in the weight between the tare weight of a crucible and the residue remaining after filtered water is evaporated. The quantitative chemical definition is used by membrane-separation systems designers. The analytic, ionic, definition is used by ion-exchange systems designers. Since ion-exchange by definition is an ionic chemical process, the systems designer must consider a balanced ionic solution when figuring capacity and equipment size. When designing a treatment system consisting of both membrane separation and ion exchange, care must be taken when moving from the separation unit's product water analysis to that of the ion-exchange system.

Separation systems analysis reports, as well as most laboratory water analysis reports, are shown as ppm as $CaCO_3$. For example, sodium would be reported as Na^+, as would calcium be reported as Ca^{2+}. However, to simplify the task, when designing an ion-exchange system the "as ion" is converted to $CaCO_3$. The conversion is done by considering the equivalent weight of the ion, the atomic weight divided by the ion's existing exchange valance. The equivalent weight is then converted to $CaCO_3$ by dividing the ion's equivalent by itself, then multiplying the product by the equivalent weight of $CaCO_3$ or 50.

Total Organic Carbon (TOC)

"Total organic carbon" (TOC) is a measurement of the organic carbon compounds found dissolved in water. These compounds contribute to corrosion, cause problems in manufacturing, and usually indicate the presence of endotoxins in water for pharmaceutical use. The test is widely requested to determine the contamination of water by trace organic compounds that could produce a residue or interfere in further laboratory apparatus tests or provide trace contamination in a pharmaceutical product.

The measurement is generally complicated and dependent on the expected level. For higher levels, the organic compound is first converted to carbon dioxide, which is measured by infrared absorption. Gas stripping is required to remove other forms of carbon ions from dissolved mineral compounds. For parts per billion (ppb) levels, photolytic oxidation is used and the resulting carbon dioxide is then measured.

Silt Density Index (SDI)

The "silt density index" (SDI) is a measure of the fouling potential of a feed-water source. Since colloids and other solids can be any size in the submicron range, there is no direct method to measure their concentration in feed water. The SDI is found by passing the feed water through a 0.45-μm rated Millipore® filter at 30 psi (207 kPa). The SDI is found from the following formula:

Equation 11-1

$$SDI = \frac{1 - \frac{t_1}{t_2} \times 100}{T}$$

where

t_1 = Initial time needed to collect a 500-mL sample of water through a fresh 0.45-μm filter, 47 mm in diameter (s)

t_2 = Time to filter and collect a second 500-mL sample after exposing the same filter as above for 15 min to the flow of feed water (s)

T = Total test time (min) (Typically 15 min. For high SDI, T may be less.)

To obtain an accurate test, at the end of the elapsed time the filter should not become more than approximately 74% plugged. If this figure is exceeded, the test should be repeated using a shorter overall elapsed time. A Millipore™ filter is the only membrane currently approved by the American Society of Testing Materials (ASTM) for determining the SDI. The higher the number is, the greater the potential for fouling.

Many manufacturers of reverse osmosis (RO) cartridges recommend allowable SDI figures for feed

water. Typically, for hollow-fiber modules there is a maximum SDI of 3 and for spiral wound modules the allowable SDI figure is 4. For continuous deionization, an SDI of 4 or less is recommended. In practice, when water has an SDI greater than 4, a pre-filter with a 4-μm depth is recommended. In addition to the 4-μm filter, an additional 1-μm filter is recommended downstream. The use of a 4-μm filter on the feedwater stream is always recommended as a precaution against fouling regardless of the potential SDI.

DEPOSITS AND CORROSION

The contaminants previously discussed will cause piping system fouling by depositing material on the walls of the pipe, thereby reducing the efficiency of the system; and reduce the thickness of the pipe wall by corrosion, which will cause failure of the piping system. Following is a brief discussion of these categories of problems and treatment methods as they generally apply to most systems.

Deposits

Scale and sludge "Scale" is a solid deposit on the walls of a pipe resulting from the precipitation of dissolved mineral solids in the fluid stream. This scale reduces heat transfer and interferes with the flow of water by increasing the friction of the fluid with the walls of the pipe. Boiler scale consists of calcium, magnesium, iron, and silica minerals. It is prevented by pretreating water prior to its entering the boiler to remove much of the scale-forming ingredients and adding effective chemicals to the feed water to adjust pH, prevent corrosion, and prevent deposits from occurring.

"Sludge" is a sticky, adherent deposit in the feed water resulting from the settling out of suspended matter from several sources. One source is an excess of iron in the liquid, generally iron oxide (rust) and iron carbonate (a corrosion product). Another is mud, dirt, and clay that tend to collect and adhere in areas of low circulation. Sludge is prevented by filtering the incoming feed water and adding chemical dispersants to keep the solids in suspension. They are removed by blowdown. Mud, dirt, and clay are rarely encountered except when the feed water is from surface sources.

Condenser scale deposits consist of calcium carbonate, calcium sulfate, or silica minerals. They form when the minerals' concentration in water reaches a level where their solubility or the pH of saturation is exceeded and the minerals come out of solution. This can be prevented by controlling the pH, diluting the circulating water to prevent concentration, and adding chemicals to inhibit and prevent scale formation.

Biological fouling Microbiological fouling is caused by the growth of bacteria, algae, fungi, and other organisms. Their growth is aided by a favorable water temperature, favorable pH, the presence of oxygen, and food. "Slime" is the buildup of microbes and their waste products, which also include dust and other suspended matter.

Microbial control is achieved by sterilization, disinfection, and sanitation. "Sterilization" is defined as the lethal disruption of all bacteria, mold and yeast, and eliminates biofilm and spores. Numerically, it is a 12 log reduction in bacteria. Disinfection is a 6 log reduction of microbials. "Sanitation" is generally considered as a killing of the vegetative organisms and minimizes the presence of bacteria and endotoxins. Numerically, it is a 3 log reduction in bacteria.

There are different methods of controlling biofouling. Chemicals, ultraviolet radiation, heat, filtering, and ozone are the ones most commonly used. The method selected depends on the intended use of the treated water and the proposed materials of the system components.

Corrosion

"Corrosion" is the loss and eventual failure of metals and alloys from the electrochemical reaction between water and the pipe material. It is separated into two basic types: general and localized. General corrosion describes the potential dissolution of pipe over its entire exposed surface. Localized corrosion affects only a small area of the pipe surface.

General corrosion. This is a breakdown of the pipe material at a uniform rate over its entire surface by direct chemical attack. It is caused by the loss of the protective passive film that forms on the surface of the pipe coupled with a chemical reaction occurring between the pipe material and the chemicals in the fluid. Particular types of corrosion include the following:

1. "Galvanic corrosion" is a type of corrosion that occurs in a liquid medium (called an electrolyte) when a more active metal (anode) and a less active metal (cathode) come in contact with one another and form an electrode potential. When this occurs, the more active (noble) metal will tend to dissolve in the electrolyte and go into solution.

2. "Intergranular corrosion" is a type of corrosion that occurs in the pipe wall when material in the grain boundary of some alloys is less resistant to the corroding agent than the grains themselves, and the bonds between the grains are destroyed.

3. "Erosion corrosion" is caused by a wearing away of the pipe wall, usually as a result of excessive fluid velocity or constant wearing away by solids in the water striking the walls of the pipe.

- *Localized corrosion*. This takes place on small areas of the surface, usually at high rates, and takes various forms:

1. "Stress-corrosion cracking" is a physical deterioration and cracking of the pipe wall caused by a combination of high operating temperature, tensile stress on the pipe, and chemicals in the fluid stream.
2. "Pitting" is characterized by deep penetration of the metal at small areas of the surface, concentrating in small cells without affecting the entire surface.
3. "Crevice attack corrosion" occurs at junctions between surfaces (often called crud traps) where a crack exists that allows an accumulation of a corroding agent.

Conventional corrosion treatment of feed water for boilers and cooling water systems consists of pH control and the use of chemical corrosion inhibitors. Dissolved gases are removed by deaeration. The acronium "CRUD" is reportidly taken from the Navy meaning "Corrosion Resulting from Unknown Deposits".

PREDICTING SCALE FORMATION AND CORROSION TENDENCIES

A common and costly water-caused problem is the formation and deposit of mineral scale. Although scale deposits may contain a complex mixture of mineral salts, the primary constituent is calcium carbonate.

Most salts are more soluble in hot water than in cold water. Calcium and magnesium salts, on the other hand, will dissolve more readily in cold water than in hot. As a result, they will tend to deposit on surfaces when there is a rise in temperature. The following are the primary factors that affect this tendency:

1. Alkalinity.
2. Hardness (calcium).
3. pH.
4. Total dissolved solids.
5. Temperature.

pH

The pH value reflects the concentration of hydrogen protons (H^+) or hydroxyl ions (OH^-) in aqueous solutions. The level of this concentration, as indicated by pH, defines the ratio of bicarbonate to carbonate alkalinity. The measure of pH is made on a logarithmic scale. One end of the scale is the hydrogen proton, the other end is the hydroxyl ion. When the pH is 7, it is an indication that there is an exact balance of hydrogen protons to hydroxyl ions in water. A pH below 7 indicates an acid or a predominance of hydrogen protons. A pH above 7 indicates a basic solution or a predominance of hydroxyl ions. In either direction the molar concentration of either is increasing by a factor of ten. A pH below 5.0 indicates 100% carbonic and other mineral acids. A pH in the range between 5.3 and 8.2 indicates a bicarbonate/carbonate relationship of the water. A pH above 8.2 indicates carbonate and hydroxyl alkalinity. As the pH proceeds upward from acidic to basic, the increase in carbonates increases the tendency for calcium and magnesium carbonates to precipitate out of solution.

Temperature

The higher the temperature, the greater the tendency of dissolved solids to precipitate out of solution because of their property of inverse solubility. This is particularly true of calcium carbonate.

Langelier Saturation Index (LSI)

In the 1930s, W. F. Langelier studied the primary factors that affect the tendency of water to form deposits of mineral scale on heat transfer equipment. As a result of this work, the Langelier index, best known as the Langelier Saturation Index (LSI), was created. This index is based on numerical values given to the factors that affect deposits.

The index is actually a calcium carbonate saturation index. It is based on the assumption water with a scaling tendency will tend to deposit a corrosion-inhibiting film of calcium carbonate and thus be less corrosive. Water with a non-scaling tendency will tend to dissolve protective films and thus be more corrosive. The interpretation of the LSI is based on the numerical values given in Table 11-4.

Table 11-4 Prediction of Water Tendencies by the Langelier Index

Langelier Saturation Index	Tendency of Water
2.0	Scale-forming and for practical purposes noncorrosive.
0.5	Slightly corrosive and scale - forming.
0.0	Balanced, but pitting corrosion possible.
–0.5	Slightly corrosive and nonscale-forming.
–2.0	Serious corrosion.

The LSI is calculated as follows:

Equation 11-2

$$LSI = pH - pH_s$$

where

LSI = Langelier saturation index number.
pH = pH value obtained from testing the water in question.
pH_s = Calculated pH of saturation for the calcium carbonate present in the water in question.

The most accurate method is to use the following formula:

Equation 11-3

$$pH_s = (9.3 + A + B) - (C + D)$$

The numerical values of A, B, C, and D for substitution into Equation 11-3 are found in Table 11-5. A more empirical method to find pH_s is to use Figure 11-2.

Ryzner Stability Index (RI)

The Ryzner stability index (RI), often referred to as the "stability index," is an empirical method used to predict the scale-forming tendencies of water. The RI is calculated from the following formula applying the same definitions used for the LSI:

Equation 11-4

$$RI = 2\ pH_s - pH$$

The RI is always positive. When it falls below 6.0, scale formation is possible; the lower the number of the index, the more

Table 11-5 Numerical Values for Substitution in Equation 11-3 to Find the pH_s of Saturation for Water

Total Solids (ppm)	A	Ca as $CaCO_3$ (ppm)	C	M. Alkalinity (ppm)	D
50–330	0.1	10–11	0.6	10–11	1.0
400–1000	0.2	12–13	0.7	12–13	1.1
		14–17	0.8	14–17	1.2
Temp., °F (°C)	**B**	18–22	0.9	18–22	1.3
32–34 (0–1.1)	2.6	23–27	1.0	23–27	1.4
36–42 (2.2–5.6)	2.5	28–34	1.1	28–35	1.5
44–48 (6.7–8.9)	2.4	35–43	1.2	36–44	1.6
50–56 (10–13.3)	2.3	44–55	1.3	45–55	1.7
58–62 (14.4–16.7)	2.2	56–69	1.4	56–69	1.8
64–70 (17.8–21.1)	2.1	70–87	1.5	70–88	1.9
72–80 (22.2–26.7)	2.0	88–110	1.6	89–110	2.0
82–88 (27.8–31.1)	1.9	111–138	1.7	111–139	2.1
90–98 (32.2–36.7)	1.8	139–174	1.8	140–176	2.2
100–110 (37.8–43.3)	1.7	175–220	1.9	177–220	2.3
112–122 (44.4–50)	1.6	230–270	2.0	230–270	2.4
124–132 (51.1–55.6)	1.5	280–340	2.1	280–340	2.5
134–146 (56.7–63.3)	1.4	350–430	2.2	350–440	2.6
148–160 (64.4–71.1)	1.3	440–550	2.3	450–550	2.7
162–178 (72.2–81.1)	1.2	560–690	2.4	560–690	2.8
178–194 (81.1–90)	1.1	700–870	2.5	700–880	2.9
194–210 (90–98.9)	1.0	880–1000	2.6	890–1000	3.0

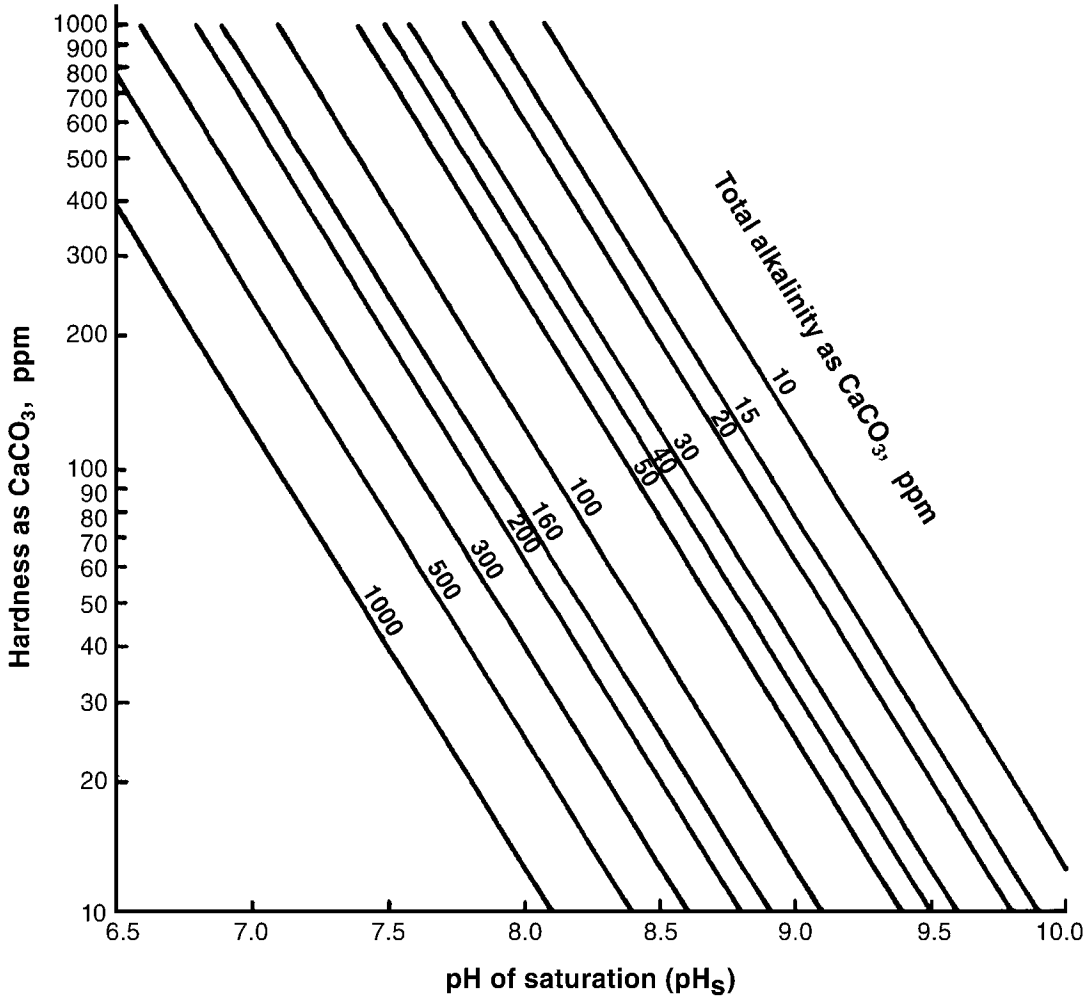


Figure 11-2 pH of Saturation for Water

Table 11-6 Prediction of Water Tendencies by the Ryzner Index

Ryzner Index	Tendency of Water
4.0–5.0	Heavy scale
5.0–6.0	Light scale
6.0–7.0	Little scale or corrosion
7.0–7.5	Significant corrosion
7.5–9.0	Heavy corrosion
9.0 and higher	Intolerable corrosion

probable scale formation becomes. For an interpretation of the RI, refer to Table 11-6.

Aggressiveness Index (AI)

Developed by the EPA, the aggressiveness index is used as a guideline parameter to find the corrosive tendency of potable water. This index is calculated as follows:

Equation 11-5

$$AI = pH + Log\ 10\ (Alkalinity \times Hardness)$$

Values lower than 10 indicate an aggressive water, values between 10 and 12 indicate a moderately aggressive water, and a value higher than 12 indicates a nonaggressive water.

TREATMENT METHODOLOGIES

Aeration

"Aeration" is a gas-transfer process in which water is brought into contact with air for the purpose of transferring volatile substances to or from the raw water. It is used most often to remove undesirable gases such as carbon dioxide, hydrogen sulfide, and methane. Aeration, by introducing oxygen, is also used to remove iron and manganese and to lower the amount of VOCs in ground water. The following are criteria for its use:

1. Reduction of carbon dioxide by 90% is obtained by near saturation with oxygen. Carbon dioxide dissolved in ground water will consume lime in the lime-soda softening process without any accompanying softening. Generally accepted practice indicates aeration is not economical for carbon-dioxide concentrations in water of less than 10 mg/L. The amount of lime saved should be compared to the cost of purchasing and operating the aerator before deciding on its use.
2. Aeration will partially remove VOCs from raw water by oxidation, making them insoluble. They are then coagulated and removed from the water.
3. Aeration alone could be used for the removal of hydrogen sulfide in concentrations of 2 mg/L or less. Above this level, it could be used in conjunction with chlorination, which oxidizes hydrogen sulfide.
4. Iron and manganese can be removed by aeration if this will not be done by other methods. These metals are oxidized to form insoluble hydroxides, which precipitate out at the proper pH levels. They can then be removed by settlement or filtered out of the water stream. Each ppm of dissolved oxygen will oxidize about 7 ppm of iron or manganese.

Several types of aerator are commonly used: waterfall, diffusion (or bubble), and mechanical. The type of system used most commonly in utility water treatment is the waterfall.

Waterfall aerators are made in several types: cascade, spray nozzle, and multiple tray. They operate by having the raw water enter the unit from the top and fall by gravity to the bottom, using various methods to evenly distribute the water and disperse it evenly throughout the unit. The type of waterfall aerator most commonly used is the naturally ventilated, multiple-tray type. This unit consists of a series of trays, one above the other, with perforated, slot, or mesh bottoms. The trays are filled with 2 to 6 in.(40 to 140 mm) of a medium, such as coke, stone, or ceramic balls, to improve water distribution and gas transfer as well as provide catalytic oxidation in the medium. The vertical opening between trays ranges between 12 and 30 in. (305 and 762 mm), depending on the number of trays required. Water loading on the trays is usually in the range of 10 to 20 gpm/ft^2 (379 to 757 L/m/m^2). Efficiency can be improved by the use of enclosures and forced air blowers to provide counter-flow ventilation.

The simplest type of aerator is the diffusion type, which bubbles compressed air up through the water tank. The large volume of air required limits this to smaller flows of water. Air requirements vary from 0.1 to 0.2 standard ft^3/min (scfm)/gal (0.003 to 0.006 m^3/min/L) of water aerated. A detention time, which ranges from 10 to 30 min, is necessary. Advantages of this type of aerator are the freedom from cold-weather operating problems, very low head loss, and the possibility of using this process for chemical mixing.

Mechanical aerators consist of an open impeller operating on the water surface of a tank. They are not as efficient as either of the two systems previously described, so longer retention times are necessary.

Clarification

"Clarification" is a process to reduce or remove turbidity, silt, and sediment present in the raw-water supply. The water could be treated with chemicals or filtered, depending on the amount of impurities present and the volume of water to be treated. If treated with chemicals, time is required for the solids to settle

out of suspension. The chemical treatment process is usually reserved for large volumes of water.

Suspended and colloidal particles are normally in the range of 0.1 to 10 μ in size. They stay apart because negatively charged ionized matter are absorbed on their surfaces and repel each other. A measure of the charge surrounding the colloid is known as the "zeta potential." These negative charges are reduced by the use of positively charged chemicals called "coagulants." Coagulants, through a chemical reaction, reduce the zeta potential and allow the colloids to cluster to form a larger, jelly-like mass called "floc." In a process called "flocculation," colloidal particles, bacteria, and organic matter are mechanically brought together into larger and heavier particles. Too heavy to remain suspended, these particles now settle out of the water to the bottom. This process is called "sedimentation."

Clarification of large volumes of water is done in a basin. First, the coagulant(s) must be introduced with a strong action in order to completely disperse and mix the chemicals with the incoming water. Often, some of the sludge produced by flocculation is mixed with the coagulant. After coagulation is accomplished, the mixture is then gently mixed to allow the now larger particles to settle rapidly to the bottom of the tank. The particles and chemicals that settle out are called "sludge," which must be removed from the tank and disposed of. Most clarifier designs have these processes done in the same operating unit.

The most frequently used chemical coagulant is aluminum sulfate, called "alum" or "filter alum." Other frequently used coagulants are sodium aluminate and potash alum. Iron coagulants include ferric sulfate, ferris sulfate, and ferric chloride. Organic polyelectrolytes, which are high molecular weight polymers, are also employed in low dosages to increase the effectiveness of treatment.

It is usually a matter of trial and error to find the correct amount of alum. This is because the amount depends on the size and quantity of the suspended solids in the raw water, the retention time prior to flocculation, the water temperature, and the amount of mixing. All of these conditions change from day to day.

As with almost every process, there is more than one method for achieving a desired goal where the demand for water is not very large. One alternative flocculation method is to produce a finer floc, which can be removed by an appropriate filter system. By eliminating a large settling basin, a high-quality water can be produced more quickly with smaller equipment.

Deaeration

Dissolved gases in the water supply, such as oxygen, carbon dioxide, hydrogen sulfide, and ammonia, can produce corrosion and pitting. They must be removed prior to using the water for most purposes.

Although carbon dioxide and hydrogen sulfide can be removed by aeration, in many cases it is easier and less expensive to remove them by "deaeration." This process operates on the principle of raising the water temperature to the saturation point for the existing pressure. There are two types of deaerator: steam and vacuum. When heated water is needed, such as for boilers, the steam type is preferred. When cold water is required, the vacuum type is used.

Steam deaerators break up water into a spray or thin film, then sweep the steam across and through it to force out the dissolved gases. With this method, oxygen can be reduced to near the limit of detection. Design use is spread evenly among spray, tray, and combination units. Typical deaerators have a heating and deaeration section and a storage section for hot, deareated water. Often, a separate tank is provided to hold an additional 10-min supply of deaerated water. The direction of steam may be cross flow, down flow, or counter current. The majority of the steam condenses in the first section of the unit. The remaining mixture of noncondensable gases is discharged to atmosphere through a vent condenser.

Vacuum deaerators use a steam jet or mechanical vacuum pump to develop the required vacuum used to draw off the unwanted gases. The vessel has a packing material inside, and the inlet water is introduced to the top of the unit and passed down through this packing. Deaerated water is stored at the bottom of this vessel. The steam or vapor vacuum located at the top of the unit discharges the unwanted gases. The vacuum unit is far less efficient than the steam one, and is most often used in demineralizer systems to reduce the chemical operating cost and the demineralizer size, and to protect anion-exchange resins from possible oxidation damage.

Dealkalizing

"Dealkalizing" is a process that reduces the alkalinity of feed water. This can be done either with or without the use of acid regenerant. Without the use of acid, the regenerant used is salt, and the process is often called "salt splitting." The salt-splitting process exchanges all bicarbonate, sulfate, and nitrate anions for chloride anions. For best results, it is recommended deionized water to be used as feed water. Where hard, alkaline, and low-sodium water is available, the use of a weak acid resin should be considered.

The entire regeneration cycle is similar to water softening (which is described later in this chapter). It is not uncommon to use the same salt and regenerant piping to accommodate both the softener and the dealkalizer. Some caustic soda may be added (1 part caustic soda to 9 parts salt) to reduce the leakage of alkalinity and carbon dioxide. Since this can cause

hardness leakage from the dealkalizer, a filter downstream of the processed water is necessary.

A weak acid resin can also be used. The process transfers the alkaline salts of calcium and magnesium to the weak acid resin. This process should include degasification if required by the product water. The weak acid process operates at a very high utilization factor, near the theoretically required amount. Hydrochloric acid, rather than sulfuric acid, is preferred for regeneration. This process is very sensitive to the flow rate, temperature, and contaminant level of the feed water. These changing conditions must be considered by the manufacturer in the design of the process. The entire regeneration cycle is similar to that of a cation ion-exchange column.

Decarbonation

Decarbonation is rarely used but should be considered if the bicarbonate level in the feed water is in the range of 14 to 20 mg/L or higher. Decarbonation is usually accomplished in smaller systems by the use of filtered air counter flowing through the water stream and stripping out the carbon dioxide.

Distillation

In its basic form, "distillation" is the process of boiling feed water, condensing the steam produced from the feed water, and collecting the condensate, which yields a product water theoretically free from nonvolatile impurities. There are three methods currently used to produce distilled water: single-stage distillation, vapor compression, and multi-effect distillation.

Single-stage distillation The still used for single-stage distillation is the simplest type of still. Feed water enters the still and is evaporated and condensed in a single stage. Cooling water is required to condense the steam produced. This type of still produces water of approximately 1 megohm-cm, with higher purity possible with optional equipment that removes dissolved gaseous impurities. This still has a small footprint, is less labor intensive, and tolerates feed water with a high level of impurity.

Vapor-compression distillation "Vapor compression," sometimes called "thermocompression distillation," is a method of evaporation in which a liquid is boiled inside a bank of tubes. The vapor generated then passes through a mist eliminator that removes any water droplets. The pure vapor is withdrawn by a compressor where the energy imparted results in a compressed steam with increased pressure and temperature. The higher-energy compressed steam is discharged into an evaporator. At this point, the steam gives up most of its energy (latent heat) to the water inside the tubes. More vapor is generated and the process is repeated. The condensate (distilled water) is withdrawn by the distillate pump and is discharged through a two-stream heat exchanger.

The excess feed water that did not evaporate is also pumped through an exchanger. Both the distillate and the blowdown are cooled, and the feed water is preheated prior to its entering the evaporator. These exchangers minimize the energy consumption of the system and eliminate the need for additional cooling water. The system operates continuously once it is started. Additional makeup heat, usually supplied by steam, is required for continuous operation. Vapor compression is generally considered more economical for large quantities of water and does not require a high-quality feed water for proper operation. The vapor compression still is moderate in both first and operating costs.

Refer to Figure 11-3 for a typical flow diagram of a vapor-compression distillation unit.

Multi-effect distillation Multi-effect distillation units use the process of staged evaporation and condensation to generate distilled water. Each stage is called an "effect." Distilled water is produced in each effect by condensing the steam generated by the evaporation of high-purity feed water in the previous stage. The initial driving force for the evaporation is "power steam" applied to the shell side of the first effect vessel. The multi-effect still has the highest initial cost and the lowest operating cost and requires the highest-quality feed water of all the stills.

The feed water enters the vessel, and its pressure is boosted by the feed pump. The feed water flows through a coil in the condenser, which allows it to pick up heat from the condensing steam. This preheated feed water flows through the feed-control valve and into the tube side of the first effect. The first effect level controller senses the feed-water level and signals the feed-control valve to maintain the desired level. Power steam is introduced into the unit and flows through the steam-control valve and into the shell side of the first effect.

Temperature sensors sense the temperature on the tube side of the first effect and signal the steam-control valve to maintain the required temperature. This steam condenses on the outside of the tubes of the first effect, giving up its latent heat of vaporization to the feed water inside the tubes, causing it to boil and generate vapor.

The pure steam generated in the first effect is introduced into the shell side of the second effect. The pure steam condenses, producing distilled water while giving up its latent heat to the high-purity feed water inside the second effect tubes, causing the feed water to boil and generate vapor. Each effect operates at a lower pressure than the previous effect to provide the temperature difference that allows the transfer of heat. The pure steam generated in the tube side of

the first effect by the condensing power steam passes through the mist eliminator to remove any entrained water droplets. Feed water from the first effect passes through an orifice and into the tube side of the second effect. The first effect pure steam enters the shell side of the second effect and is condensed on the outside of the tubes.

The condensate (distilled water) passes through an orifice and enters the shell side of the third effect. Feed water in the second effect passes through an orifice and into the tube side of the third effect.

After passing through the mist eliminator, the last effect, pure steam enters the condenser and condenses on the outside of the condenser coils. This distilled water from the last effect and the distilled water from the previous effects is cooled by the cooling water of the condenser. The distilled water exits the condenser and enters the distillate pump. The distillate is pumped through the distillate control valve and through the storage/dump valve. The condenser level controller senses the distillate level and signals the control valve to maintain the desired level.

Noncondensable gases in the condenser are vented to the atmosphere. The condenser temperature is maintained at a predetermined level by the cooling water flow. The unit is protected by pressure-relief valves along with high and low-level alarms.

Refer to Figure 11-4 for a typical flow diagram of a multi-effect distillation unit.

Filtration

Deep-bed sand filtration Deep-bed filters are designed to remove coarse suspended particulates larger than 10 μ in size. It is a pressure type filter using either multi-graded sand or multimedia as the filter medium. Particulate removal in the order of 98% should be expected.

Sand-only filters for laboratory water systems should generally operate at a face velocity of about 4 gpm/ft^2 (192 L/min/m^2) of cross-sectional bed area. Multimedia filters operate at about 6 gpm/ft^2 (228 L/min/m^2) of cross-sectional bed area. Since the above values are general in nature, it is important to operate these units at the velocities recommended by the individual manufacturer.

The multimedia filter achieves a more uniform distribution of filter media throughout the bed than the sand-only filter and is considered a more effective type of filter. A typical multimedia filter for laboratory use consists of a top layer of anthracite having a 1.1-mm grain size and a 1.5 specific gravity, a middle layer of sand having a 0.5-mm diameter grain size and a specific gravity of 26, and a bottom layer of garnet having a 0.2-mm grain size and a 4.2 specific gravity. The normal operational flow rate ranges from 6 to 15 gal/min (gpm)/ft^2 (228 to 570 L/min/m^2) of bed area.

Backwashing is required to clean the filter, with the effluent discharged to the sanitary drainage system. A backwash flow rate of 10 to 15 gpm/ft^2 (380 to 570 L/min/m^2) is generally required for effective cleaning.

Cross-flow and tangential-flow filtration In the past 10 years a number of membrane filters have appeared on the market. The membrane systems have greatly expanded the field of mechanical filtration. The following are several typical media and membrane-filtration systems:

1. Bag filter gross filtration, including limited membrane applications.
2. Standard cartridge depth filtration.
3. Hurricane™ (a trademark of the Harmsco Corporation). The Hurricane™ filter is a cross between a standard tangential cartridge application and a cross-flow filter.
4. Horizontal and vertical pressure media filters, with or without a precoat.
5. Sub-micron cartridge filtration, including point-of-use (POU) ultrafiltration cartridges.
6. Cross-flow membrane system designed for particulate removal in the concentrate.
7. Ultra-filtration to less than 10,000 molecular weight compounds.
8. Nano-filtration with a very low molecular weight filtration, to ionic levels of calcium sulfate.
9. Reverse-osmosis waste-treatment applications.

The above filtration systems are typically used in conjunction with ion-exchange and reverse-osmosis, high-purity systems to remove bacteria, pyrogens, and nonvolatile TOC compounds. These filtration systems are used in waste-treatment applications, including the concentrated waste of reverse-osmosis systems and ion-exchange waste.

Activated carbon filtration Activated carbon is used to remove residual chlorine, chlorimine disinfectants, dissolved organics such as trihalomethanes, and a major portion of naturally occurring dissolved organic material from municipal water supplies. The nonionic organics tend to coat ion-exchange resins and all types of membranes.

There is a reluctance on the part of system designers to use the activated carbon filter in the generation of pure water (PW) because of the possible development of significant levels of bacteria in the unit itself. This can be controlled by periodically sanitizing it with pure steam or hot water with a temperature greater than 176°F (80°C). The need for sanitizing can only be determined by testing the water. Because of this need for sterilization, the interior of the filter housing should be lined or coated. When using PW

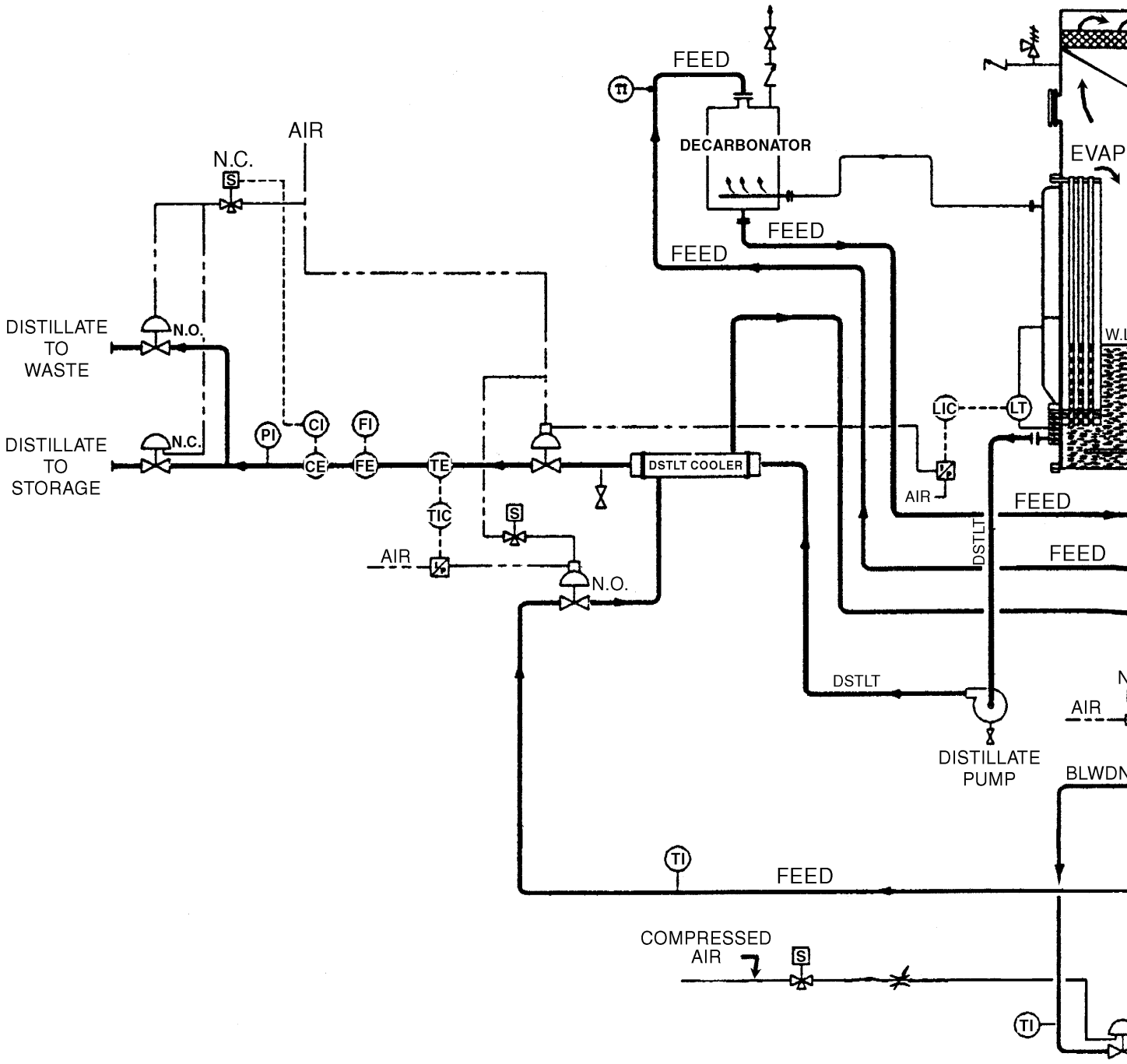
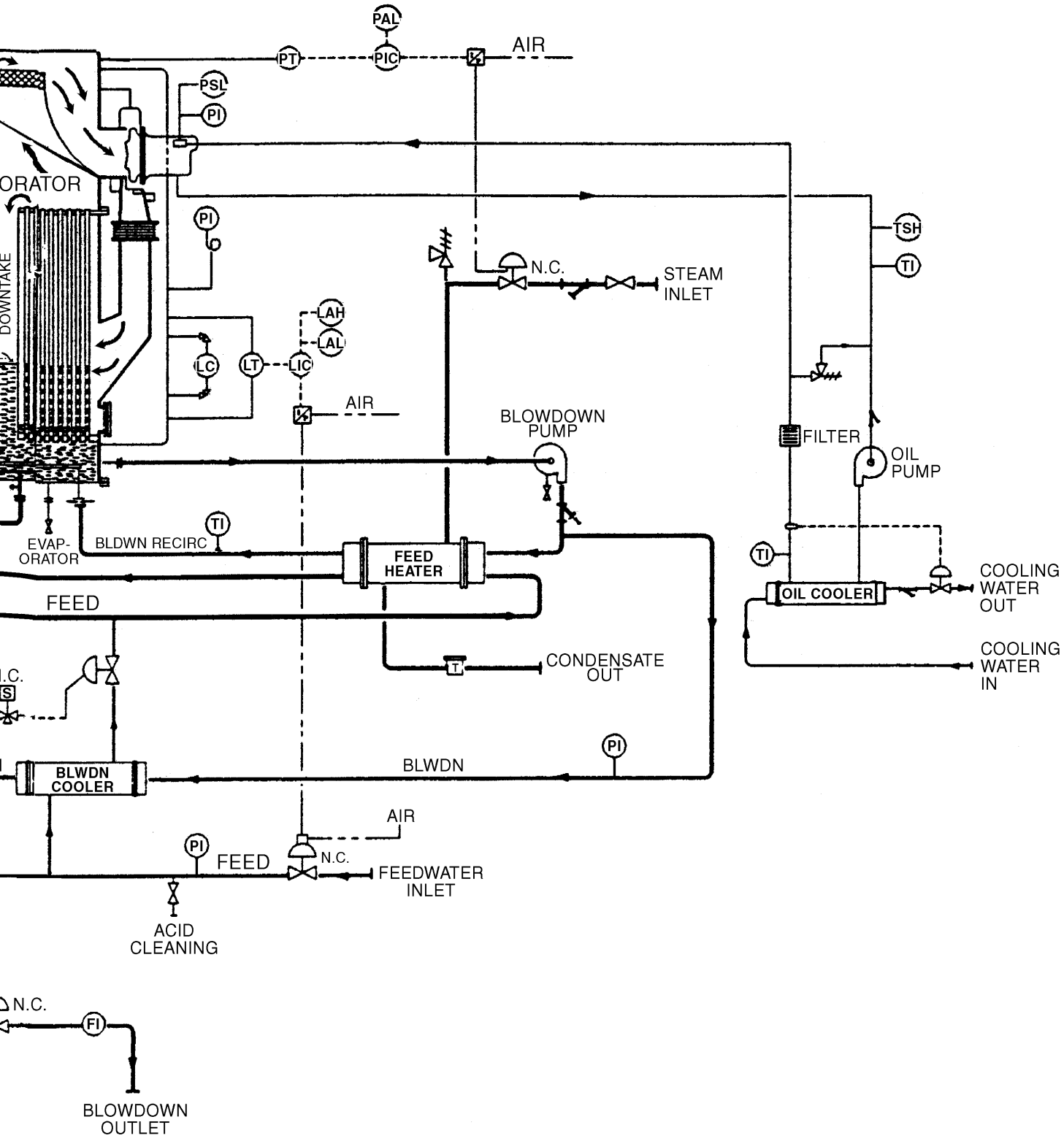


Figure 11-3 Detail of Vapor Compression Still


PAL
PT
PIC
AIR
PSL
PI
ORATOR
DOWNTAKE
PI
N.C.
STEAM
INLET
TSH
TI
LAH
LAL
LC
LT
LIC
AIR
BLOWDOWN
PUMP
FILTER
OIL
PUMP
EVAP-
ORATOR
BLDWN RECIRC
TI
FEED
HEATER
TI
OIL COOLER
COOLING
WATER
OUT
FEED
T
CONDENSATE
OUT
COOLING
WATER
IN
PI
BLWDN
BLWDN
COOLER
AIR
PI
FEED
N.C.
FEEDWATER
INLET
ACID
CLEANING
N.C.
FI
BLOWDOWN
OUTLET

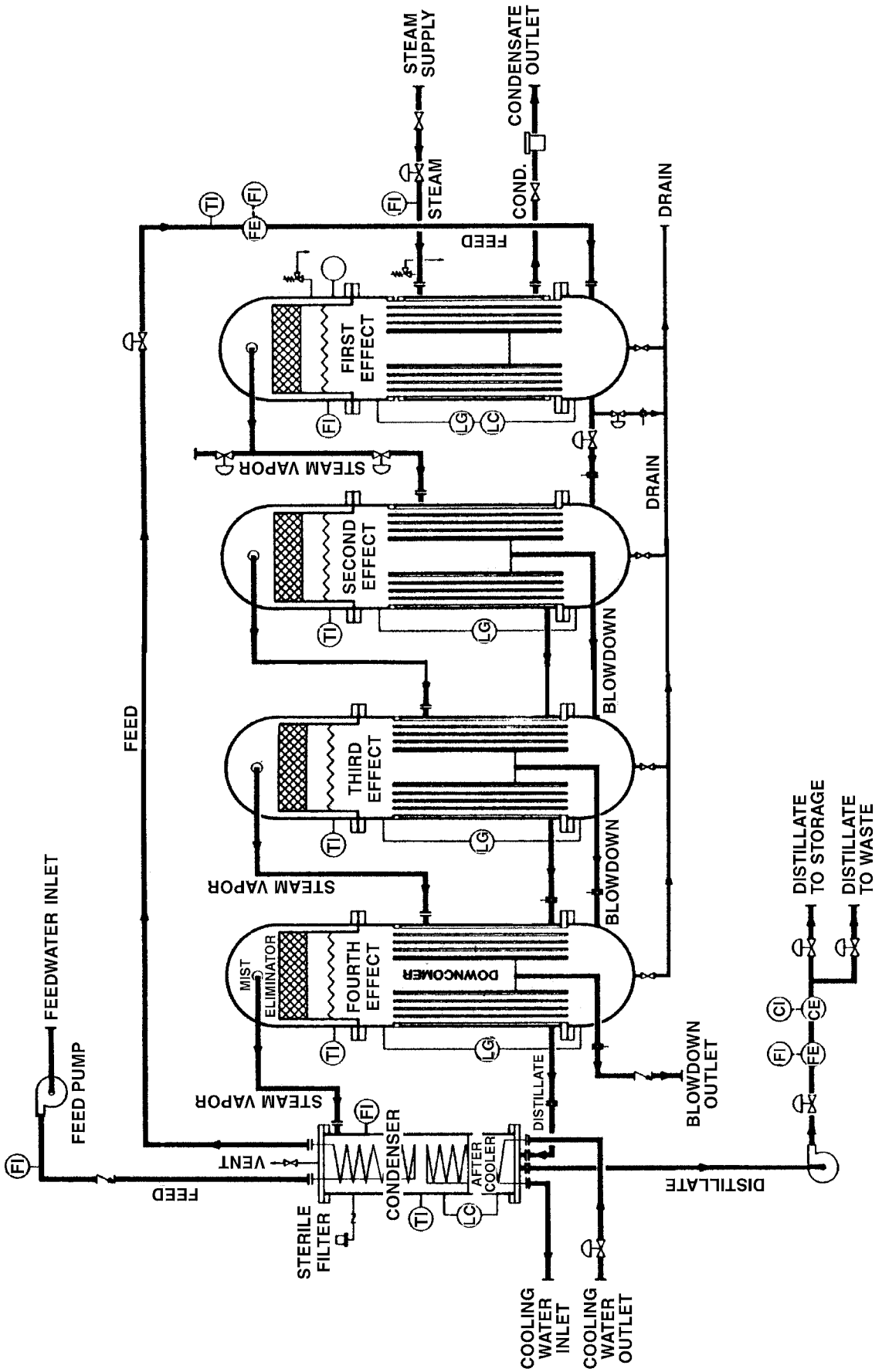


Figure 11-4 Detail of Multi-Effect Still

as feed water, stainless-steel housings should be avoided because of possible chloride stress corrosion and chloride pitting resulting from the chlorine in the feed water. A typical detail of a packed-bed, activated-carbon unit is illustrated in Figure 11-5.

Ion Exchange and Removal

"Ion exchange" is the basic process where specific ions in a feed-water stream are transferred into an exchange medium called "resin" and exchanged for different ions of equal charge. When the ion-exchange process is used to treat water only for removal of hardness, it is generally known as "water softening." When the ion-exchange process is used to treat water for the removal of ions to produce pure water, it is often referred to as "deionization" (DI) or "demineralization."

The deionization/demineralization process uses different types of resin to exchange first anions and then cations resulting in the removal of all ions from feed water when the process is carried to completion. When all of the ionic components involved in water are removed by ion exchange, the water is said to be "deionized" or "demineralized." The ion-exchange process is also used to remove dissolved inorganics. Water softening only exchanges some types of ions for others that are less detrimental for the intended end use of the water. Table 11-7 lists the common anions and cations typically found in water. Ion exchange will not remove significant amounts of organics, bacteria, particles, colloids, or turbidity.

Table 11-7 Typical Cations and Anions Found in Water

Cations	Anions
Calcium	Carbonates
Magnesium	Bicarbonates
Sodium	Sulfates
Potassium	Chlorides
Iron	Nitrates
Manganese	Silica

Regenerable ion exchange "Regenerable ion exchange" is a batch process where ions in raw water are transferred onto a resin medium in exchange for other ions bonded to that medium as the raw water percolates through it. This is accomplished by having the ions in the raw water adsorbed onto a bed of exchange resins and replaced with an equivalent amount of another ion of the same charge. This action continues until the medium has reached its exchange capacity, where it is no longer capable of exchanging ions. Water softening and deionization are the most common of the ion-exchange processes.

There are two general types of deionizers: working and polishing. The working type is used for the initial removal of the bulk of ions from feed water or as only an ion-exchange process (such as hardness removal) if the purification is a single process. The polishing type is used to purify feed water after an initial run through a working ion-exchange system.

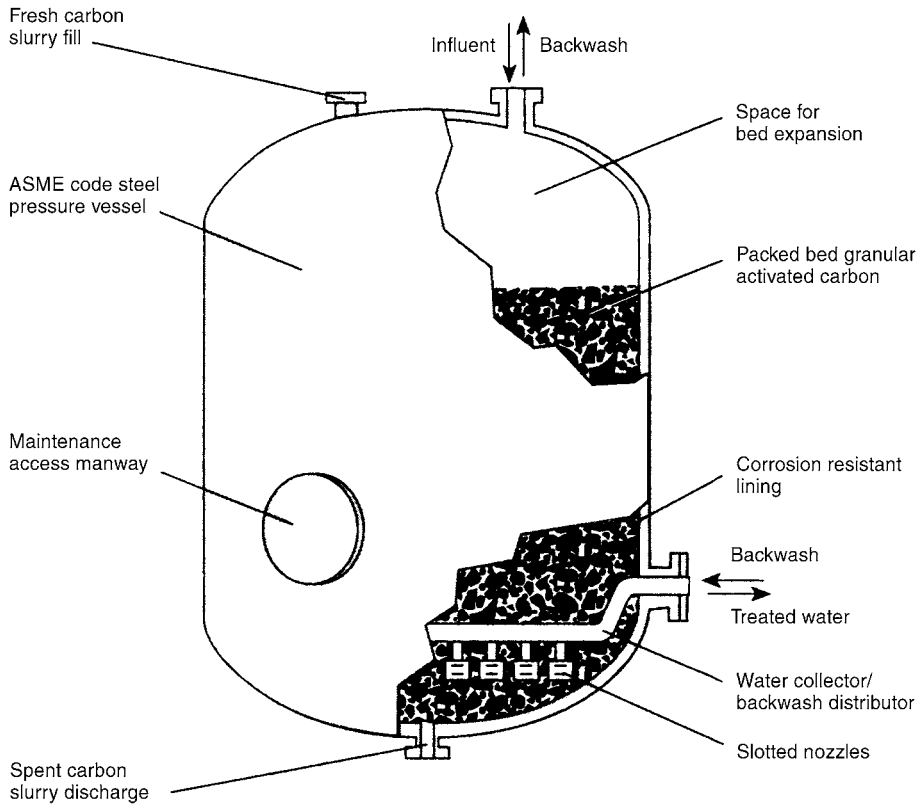


Figure 11-5 Schematic Detail of Large-Scale, Granular-Activated Carbon Filter

Resins Resin-exchange media include natural inorganic aluminum silicates (sometimes called "zeolites" or "green sands"); bentonite clay; and synthetic, gelatinous and synthetic, organic resins. Most processes use the synthetic resins. Resins are graded by purity and consistency in size of resin.

Resin is manufactured in the form of a large number of spherical beads, typically about 0.4 mm in diameter. These beads have weakly bonded ions present on their surfaces used for the exchange process. Because the process must exchange ions of the same charge, ion-exchange resins are composed of either anion or cation exchange resins.

Manufacturers are constantly making new resins for different ion-removal purposes. This is a constantly changing technology.

Traditional deionization exchanges cations with hydrogen, H^+, ions (an acid) and anions with hydroxyl, OH^-, ions (a base). Although not 100% effective, these two exchange processes together remove cations and anions from water and the remaining H^+ and OH^- ions combine to form water. When all of the ionized impurities are removed, the water is said to be "deionized," which is also referred to as "demineralized."

There is a large number of ion-exchange resins available. Each resin is formulated to obtain optimum performance for different impurities. The affinity for different ions in solution is termed "selectivity coefficients." The number of charges (valence) available on a particular ionic medium is a major factor in the selection of specific resins to remove the desired impurities and is based on an analysis of raw water. The resins are contained in a vessel, often referred to as a "column." The actual resin bed could be supported by a mat of graded gravel, screen-wrapped pipe, or perforated plates, which also act to evenly distribute feed water over the entire resin bed. The resin beads in the vessel also create an effective depth filter. This filtering action leads to fouling and unpredictable operating runs because of an accumulation of particulates.

Anion resins could be either a strong or a weak base. An often-used anion resin is divinyl benzene, a gelatinous bead. Anion resin type 1 premium has a very close tolerance of bead size. Anion resin type 1 regular is generally used for maximum silica reduction. Resin type 2 is used most often, it is generally used unless type 1 is specifically requested. There is a difference in cost and a difference in capacity between the two resins. In general, the higher cost of the type 1 resin is considered acceptable to obtain a more efficient and longer-lasting resin. Weak-base exchangers are not effective in the removal of carbon dioxide or silica. They remove strong acids more by adsorption than by ion exchange. The end result is the same, and the efficiency of weak-base regeneration for acid-salt removal is far superior to that of strong-base material for the same job. Thus, weak-base units are superior when the feed water is high in sulfates and chlorides.

The two most often-used cation-exchange resins are strong acid or weak acid. Strong cation resins remove all cations, regardless of the anion with which they are associated. These resins have a moderate exchange capacity and require a strong acid regenerant, such as hydrochloric or sulfuric acid.

The deionization process can be arranged as either a two-step (dual-bed) or single-step (mixed-bed) process. In the dual-bed process, one vessel contains the anion-exchange resins and a second vessel the cation-exchange resins. In the mixed-bed unit, a single vessel contains a mixture of both resins. The dual-bed arrangement produces a water less pure than that produced by a mixed bed but has a greater removal capacity. A typical mixed bed contains 40% cation resins and 60% anion resins. Dual beds are easier to regenerate. It is not uncommon to have a dual-bed exchanger, often referred to as a "working exchanger," installed before a mixed bed to remove the bulk of the impurities then have the mixed bed, often called a "polishing exchanger," further purify the water to the desired high purity. A typical single-bed ion-exchange unit is illustrated in Figure 11-6. A typical dual-bed ion-exchange unit is illustrated in Figure 11-7. A typical mixed-bed ion-exchange unit is illustrated in Figure 11-8. The piping and valve arrangements of different manufacturers may differ from those shown.

Regeneration cycle The ion-exchange process is reversible. As the water continues to pass through the ion-exchange resin beds over time, the number of ions on the resin beads available for exchange declines and gradually is exhausted. This process starts at the entry of the water to the vessel and progresses down the bed. When the resins have reached the limit of exchange, the bed is said to have reached its "exchange capacity." It is then necessary to take the column out of service to be regenerated.

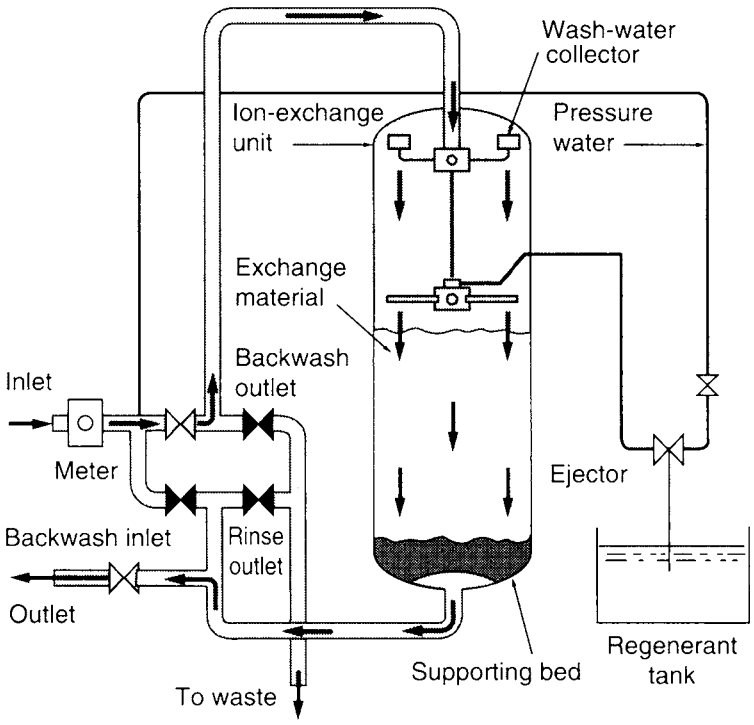


Figure 11-6 Typical Single-Bed Ion Exchanger

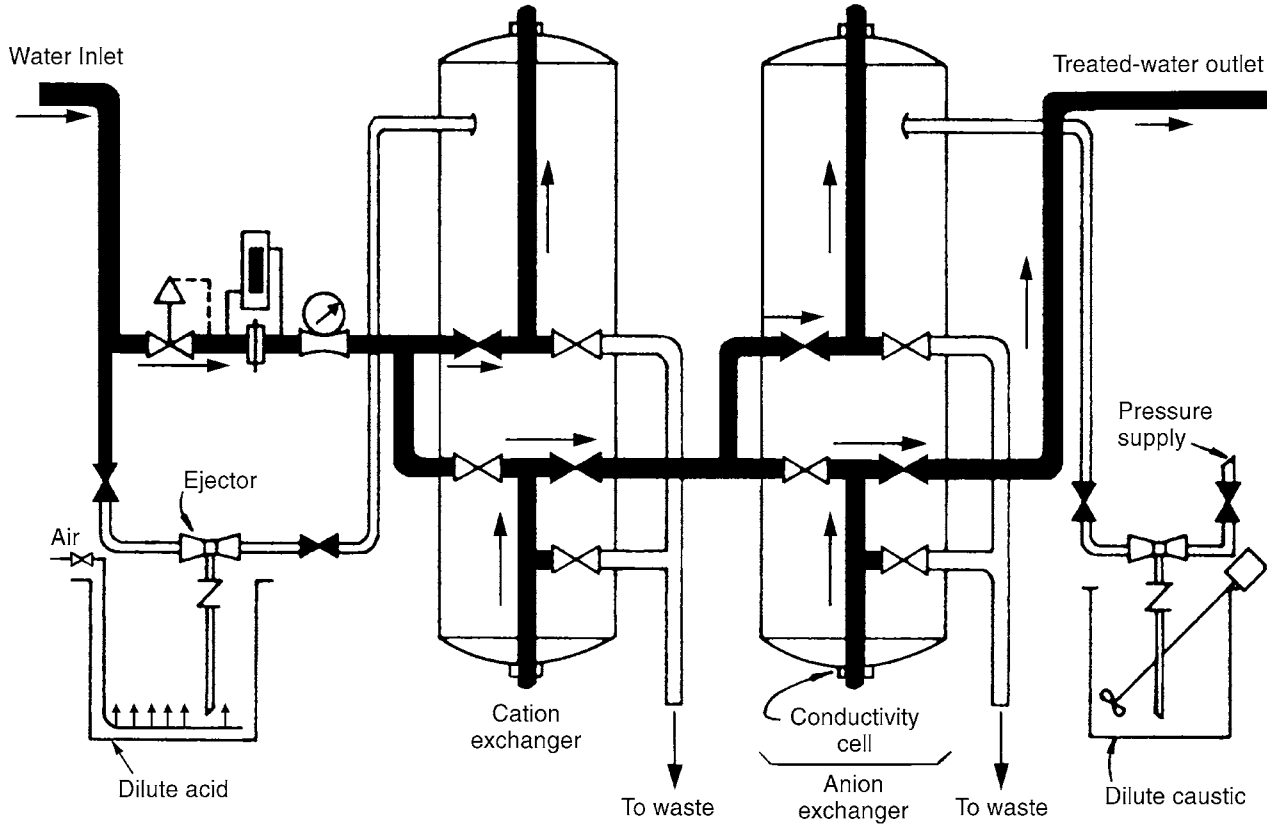


Figure 11-7 Typical Dual-Bed Ion Exchanger

"Regeneration," which is the reverse of deionization, is the term used for the displacement of the ions removed from the feed water. Regeneration generally consists of three steps: (1) backwashing, (2) application of regenerating solution, and (3) rinsing. Regeneration can be performed either co-currently (in the same direction as the flow of feed water) or counter-currently (in the opposite direction of the flow of feed water). All of the water used for regeneration must be routed to a drain of adequate size. In addition, the acid and caustic must be neutralized prior to discharge into a public sewer system. It is common practice to combine the acid and caustic waste streams to neutralize the effluent to the greatest extent possible. Additional acid or caustic may have to be added to the final effluent to produce a pH acceptable to the local authorities. *Note:* Sufficient safety precautions need to be taken when handling regeneration chemicals.

Backwashing is a counter-current operation accomplishing two purposes. The first is to remove any particulates that have accumulated in the resin bed and on the beads. The second is to regrade the resin beads sonew beads are on top of the bed, which is where the heaviest duty from the beads is required. This is done by having the resin bed expanded from its normal, packed condition by the reverse flow of water. The manufacturer establishes the required flow rate of backwash that should be maintained. A flow rate too high will blow resin out of the tank and into the drain. The flow rate of water should be enough to scrub the beads together, increasing the cleaning action. A greater-than-recommended flow will only waste water and provide no additional benefits.

The two chemicals used to regenerate cation resin beds are either a 93% solution of sulfuric acid or a 30 to 32% solution of hydrochloric acid (HCl), also called "mureatic acid." As they flow through the columns, they replace the retained cations with hydrogen ions from the acid. Hydrochloric acid is used most often because it has the greatest efficiency, and only ¼ of the amount of sulfuric acid is used. Sulfuric acid is much lower in cost and is used when there is a large quantity of resin to be regenerated, which makes its lower cost practical. The chemical used most often for regenerating anion resins is a 40% mixture of sodium hydroxide, which replaces the retained anion ions with hydroxyl ions. For mixed-bed units, the resins must be separated prior to regeneration.

The quality of the chemicals used for regeneration has an important effect on the maintenance of exchange capacity. Although chemically pure ingredients are not required, some contaminants found in these chemicals collect on the resins and eventually cause difficulty in operation.

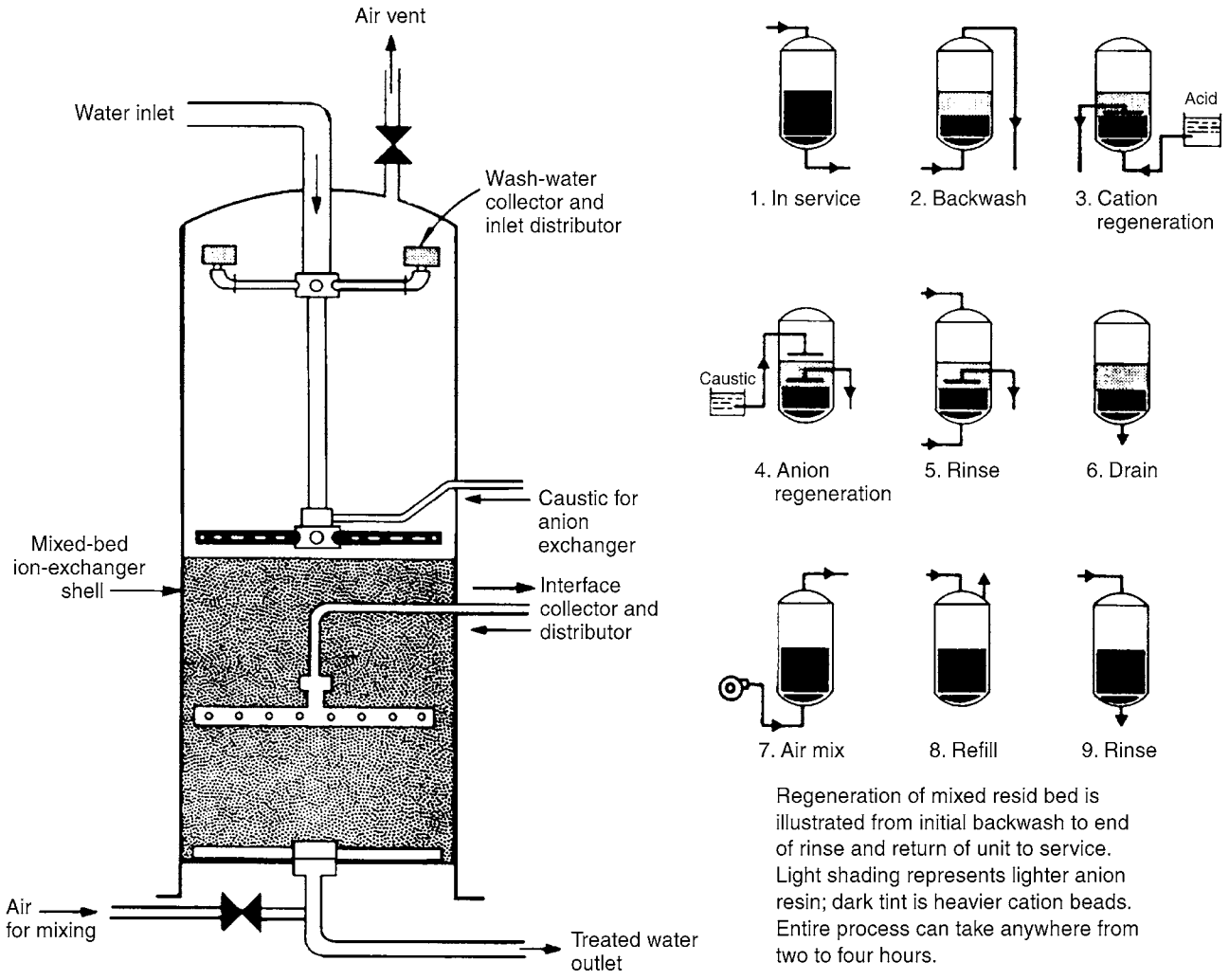


Figure 11-8 Typical Mixed-Bed Ion Exchanger

Technical-grade acids, which are free of oils and other organic materials, are acceptable for the regeneration of cation resins. They should be 66° Baume, free of suspended matter, and light in color. They should mix freely with water and not form any precipitate. Acid-containing inhibitors should not be used. Sulfuric acid is usually the most economical choice for large-scale use. Hydrochloric acid should be technical grade and a minimum of 30% HCl by weight (18° Baume) and shall not contain excessive amounts of iron and organic materials. HCl obtained by the salt-aid or hydrogen-chlorine process have been found satisfactory. HCl obtained by the hydrolysis of chlorinated organic chemicals should be avoided, particularly if used to treat potable water.

Anion-exchange resins are regenerated with 76% sodium hydroxide, which shall be low in iron, chlorides, and silica to avoid fouling the strong-base anion exchangers. Weak-base anion exchangers are regenerated most economically with technical-grade, flake sodium hydroxide. Strong-base exchangers are best regenerated using nylon or rayon-grade sodium hydroxide, also 76%. If purchased in a 40% solution, the same grade previously indicated should be used. All caustic shall have a maximum of 2 ppm chlorates.

The flush cycle is the shortest step. It is a co-current process whose purposes are to flush away any remaining residue of the regeneration liquids to drain and to repack the bed in preparation for the new run.

The entire regeneration cycle typically takes about 1 hour. If the process requires continuous operation, a duplex set of equipment is installed so one is in use while the other is being regenerated.

To estimate the frequency of regeneration, first, from literature provided by the manufacturer, determine the exchange capacity, in grains, of the selected resin bed. Next, from the analysis of the raw water, find the average level of TDS, and convert this figure into grains per gallon (liter). Dividing the flow rate, in gallons (liters), into the grain capacity of the resin bed gives the time it takes to saturate the resin bed

before regeneration is required. As mentioned above, the designer needs to consider the ionic or molecular composition of the regeneration waste.

Service deionization "Service deionization" is not another form of deionization but, rather, a different type of equipment arrangement. With the regenerable type, the deionization (DI) equipment is permanent and the regeneration is done on site by operating or maintenance personnel. They must handle and store the chemicals used for regeneration. With the service type, the supplier replaces cartridges of exhausted resins with regenerated ones.

The service DI system uses individual cartridges or tanks for the anion, cation, and mixed beds. When the individual cartridges are exhausted, they are replaced by the supplier with recharged units on site and the exhausted cartridges are removed to be regenerated at the supplier's premises. This arrangement considerably reduces the initial cost of the equipment, eliminates the need to store chemicals, and frees the operating or maintenance personnel from the time required for regenerating the units. In addition, it saves water that does not have to be used for backwash. The operating costs to a facility for service DI equipment are higher than they are for the permanent bed type. However, when regeneration discharge and variable production costs are considered, the cost of point-of-operation demineralization becomes attractive.

Continuous deionization Continuous deionization (CDI), also known as "electrodeionization" (EDI), is a continuous water-purification process using direct current (DC); an alternating arrangement of cation and anion-permeable membranes; and mixed-bed, ion-exchange resin. The cation and anion membranes form parallel, thin, flow compartments, alternating between concentrating and diluting compartments. The diluting compartments contain a thin layer of ion-exchange resin. Some manufacturers also use ion-exchange resin in the concentrating compartments. A single set of these components is called a "cell pair." Many sets of these cell pairs can be placed between one set of electrodes in a plate-and-frame device to achieve the desired flow output. The higher the number of these cell pairs, the higher is the flow output. This arrangement is schematically illustrated in Figure 11-9.

Feed water enters into the top of all the compartments. Under the influence of a DC electrical field, ions move from the water in the dilute stream, through the ion-exchange resin, toward the electrode with the opposite charge. Cations move toward the cathode, through the cation-permeable membrane, and into the adjacent concentrate stream. Anions

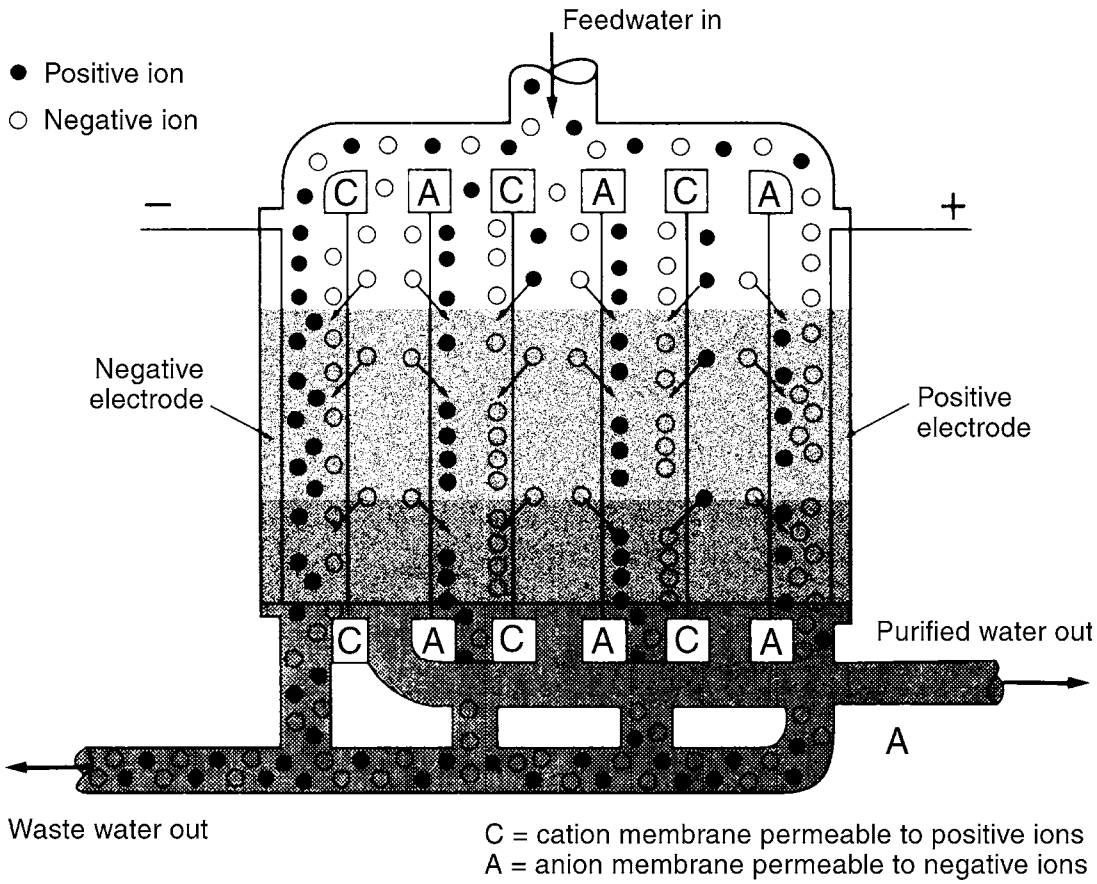


Figure 11-9 Schematic Operation of a Continuous Deionization Unit

move toward the anode, through the anion-permeable membrane, and into the adjacent concentrate stream. Deionized water exits from the bottom of the dilute stream. The alternating cation and anion-permeable membranes trap and concentrate ions in the concentrate channels. A small flow of feed water continuously rinses the concentrated ions to drain. The ion-exchange resin bed serves as a highly conductive medium through which ions flow because of the electric field. The various flow streams are hydraulically independent, allowing a high volume of high-purity water (product) and a low volume of concentrate (waste).

The resin-filled diluting compartment (cell) creates a low-level resistance path for ions. At the bottom of the diluting cell under the proper combination of flow, temperature, water conductivity, and voltage, the resins regenerate automatically without the use of added chemicals. This is commonly referred to as "electroregeneration" of the ion-exchange resins. This process is continuous and results in a steady supply of high-purity water from the diluting compartments. The continual ion removal and electroregeneration result in some significant advantages over conventional ion exchange, including no handling and disposal of hazardous regeneration chemicals, no interruptions due to exhaustion of the resins' ion-exchange capacity, and low operating costs.

CDI is sensitive to feed-water impurities, and experience has shown very few natural potable feed-water supplies can meet the required feed-water specifications without softening and additional pretreatment. Because of this limitation, most processes are now using CDI for polishing purposes after reverse osmosis (RO). The use of RO and CDI results in a complimentary combination of purification technologies, the RO removing the bulk of contaminants and the CDI polishing the water to high purity levels. Another disadvantage of CDI is the membranes and resins are incompatible with most sanitizing agents. Manufacturer specifications and guidelines should be checked and followed. However, when CDI is used in combination with RO, the RO process effectively provides efficient removal of bacteria, and the sanitization of the RO can reduce the risk of downstream bacteria growth. Furthermore, it has been reported CDI can provide water consistently low in bacteria and the CDI process can have a germicidal effect due to local pH shifts associated with electroregeneration.

Water softening "Water softening" is a process that reduces or removes dissolved impurities that cause hardness in water. This is commonly done by either of two methods: adding lime-soda ash to the raw water for very large volumes or passing the raw water through an ion-exchange process.

Lime soda addition The lime-soda-ash method uses either hydrated lime or quicklime along with soda ash. When added to water, these chemicals react with the dissolved calcium and magnesium carbonate to form insoluble compounds. These compounds precipitate out of solution and are passed through a filter to be removed. They are then discharged to drain. This process is usually carried out during the clarification process rather than separately and is reserved for large volumes of water.

Ion exchange The ion-exchange method of water softening is a cation-exchange process used to remove insoluble and scale-forming iron and other multivalent cations, which are the primary causes of hardness, and to replace them with sodium ions, which do not contribute to hardness. The removal of these impurities prevents the buildup of insoluble scale precipates on piping and the reverse-osmosis membrane. It is accomplished by passing the water through a bed of granular sodium, cation-exchange resin. This process is commonly called "sodium cycle ion exchange."

The resin bed typically occupies about 2/3 of the tank. The other 1/3 is needed for expansion of the resin bed during backwash. A generally accepted range of between 0.4 and 3 gpm/ft^3 (50 and 380 L/min/m^3) of resin is used to determine the volume of resin and the cycle time of the unit.

Microbial growth inside the unit is a concern in softening systems used for pharmaceutical and some laboratory purposes. The water softener is regenerated with a brine solution, which does not destroy bacteria. The liquid brine solution storage-and-regeneration equipment also allows microbial growth in storage tanks exposed to the atmosphere. An alternative is to use a dry storage system, which generates salt solution from water mixed with salt pellets only when necessary for regeneration. This controls microbial growth better than wet systems, but constant maintenance is required to monitor the brine tank. The quality of the salt in all systems should be periodically determined to ensure there are "no added substances" present.

The regeneration cycle is similar to that previously discussed. The difference is salt is used to regenerate the resin bed. Industrial water softeners use rock salt for economy. Rock salt, because of its high mineral content, requires a special tank called a "desolver" to dissolve the rock salt in water prior to use. The water softener is similar to the schematic single-bed ion exchanger illustrated in Figure 11-6.

Ion-exchange system design considerations Leakage" is the presence of undesired ions in the final treated water. One of the major decisions that must be made when selecting an ion-exchange system is allowable leakage. The

amount of leakage is a function of the completeness of regeneration of the resin. For water softening, generally accepted leakage amounts range between 0.1 and 1 ppm. Since total regeneration of the resin bed is inefficient and very costly, most water softeners operate at ½ to 2/3 of the ultimate capacity of the softener. There is sodium leakage from cation exchangers and silica leakage from anion exchangers. Normally, mixed-bed units have negligible leakage.

In general, for high-purity applications, a single pass cannot give adequate purification of the water stream; therefore, a polisher is necessary. A mixed-bed ion-exchange system, when used as a polisher, has, in general, a 74% lower initial cost than a two-bed system. A single-pass RO system is about equal to a two-bed ion-exchange system.

Usually, if the water demand for a facility is less than about 40 gpm (151 L/min), the greatest benefit will be derived from the simpler, less costly equipment with higher operating costs. For this quantity, it is common to have a mixed-bed unit without a degasifier, which is not required. For systems with a requirement of 200 gpm (757 L/min) or more, the majority of the systems installed will have multiple-bed units and a degasifier. Manufacturers must be contacted for specific system and resin selection and required equipment.

Where applicable, the use of weakly acidic and weakly basic resins minimizes chemical costs and reduces losses to waste because of the high regenerative capacity.

There are some problems, such as microbial growth, associated with water softeners. Sanitation is usually accomplished during regeneration. Iron buildup in the unit could pass through to downstream purification equipment unless operating personnel constantly monitor the water quality.

Membrane Filtration and Separation

"Membrane filtration and separation" is a general term for a water-purification process that removes contaminants from feed water by means of a thin, porous barrier called a "membrane." When used as a filter, a membrane is capable of removing impurities of a much smaller size than other types of filters. Filters of this nature are often called "ultrafilters" and "nanofilters."

A semipermeable membrane limits the passage of selected atoms and/or molecules in a specific manner. Membrane filtration and separation, when used to produce pure water, is characterized by having the feed water flow parallel to the membrane (often called "tangential flow"). Not all of the feed water is recovered. Many of the membranes used are also available as depth filters and in single thickness are used as disk filters. There are two general categories of membrane filtration: reverse osmosis using a semipermeable membrane and filtration using ultrafiltration and nanofiltration membranes.

Reverse osmosis Reverse osmosis (RO) is a broad-based water-purifying process involving osmosis and ionic repulsion.

Osmosis is the spontaneous passage of a solvent (such as water) through a semipermeable membrane until there is an equal concentration of solute molecules (impurities such as sodium chloride) on both sides of the membrane. This membrane is called "semipermeable" because it allows the solvent to diffuse, or pass through, but is impervious to the solute.

In the natural osmosis process, when two solutions of different concentrations are separated by a semipermeable membrane, water molecules from the less concentrated solution will spontaneously pass through the membrane to dilute the more concentrated solution. This occurs until a rough equilibrium is achieved. The driving force is a difference of pressure, called the "osmotic pressure" or "concentration gradient," that exists across the membrane and is based on the degree of concentration of contaminants. This pressure is what drives the flow of solvent. The flow, or flux, will continue until the osmotic pressure is equalized, which then results in a higher pressure on the concentrated solution side equal to the osmotic pressure.

Reverse osmosis is the flow of solvent in the direction opposite the direction of flow of natural osmosis. If enough pressure is applied to the more concentrated solution, which in these discussions is water, pure water is diffused through the membrane leaving behind the bulk of the contaminants. This concentration of contaminants is continuously flushed to drain, and thereby removed from the system. The purified water is called "permeate" and the contaminant containing water "reject" or the "reject stream." In some cases, the reject stream is referred to as "salt." The performance characteristics of the selected membrane determine how large a system is required. The flow rate is measured in membrane flux. "Membrane flux" is a measurement of the flow rate of permeate that will pass through a given area of the membrane at a specific temperature and pressure. The ratio of purified-water flow to the feed-water flow is called "recovery." Most applications require a minimum 40% recovery rate to be considered practical. Rejection characteristics are expressed as a percent of the specific impurities removed and depend on ionic charge and size.

Membrane module configurations There are four types of membrane module configuration used for RO applications: hollow fiber, spiral wound (SWRO), tubular (TRO), and plate and frame. Spiral wound is the most commonly used configuration. In each

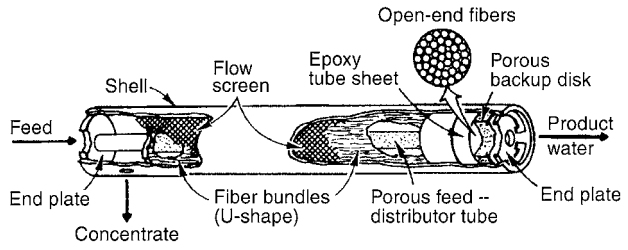


Figure 11-10 Hollow-Fiber Reverse-Osmosis Configuration

design, maximum turbulence is necessary to avoid concentration polarization.

Hollow-fiber reverse osmosis The hollow-fiber configuration, illustrated in Figure 11-10, consists of a perforated tube manufactured from ceramic, carbon, or porous plastic with inside diameters ranging from 6 to 1 in. (8 to 25 mm). It requires rigid support when mounted inside the pressure vessel. Feed water could be introduced into either the center or the outside, depending on the manufacturer of the RO module. Fouling resistance is low.

Spiral-wound reverse osmosis (SWRO) This configuration, illustrated in Figure 11-11, typically achieves a large surface area per unit volume. In this design, a flat membrane is formed around a fabric spacer closed on three sides with the open side terminating in a perforated produce water tube. The unit is placed in a pressure vessel. Feed water permeates through the membrane and flows radially inside the enclosure toward the product tube.

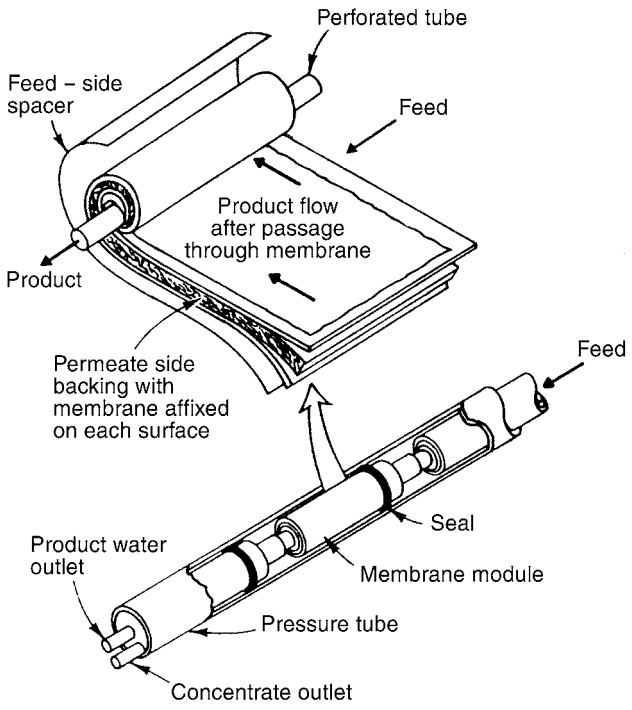


Figure 11-11 Spiral-Wound Reverse-Osmosis Configuration

Tubular reverse osmosis (TRO) This configuration, illustrated in Figure 11-12, consists of a perforated tube manufactured from ceramic, carbon, or porous plastic with larger inside diameters than the hollow-fiber configuration. The membrane is installed on the inside of the tube. A number of tubes are installed inside a pressure vessel. Feed water enters the tube and permeates through the membrane to be collected on the outside. The feed-water channels are much more open than those of the SWRO and less subject to fouling.

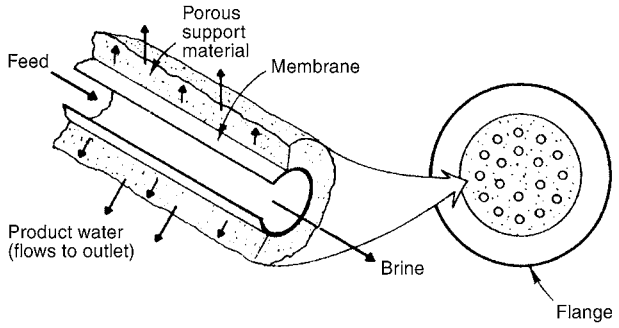


Figure 11-12 Tubular Reverse Osmosis Configuration

Plate and frame This configuration, illustrated in Figure 11-13, consists of a membrane fixed to a grooved plastic or metal plate with several plates stacked together in a frame that includes feed water and drain ports. As the feed water flows across the membrane surfaces, the purified water penetrates the membrane and gathers along the frame for collection. The retentate continues to flow and could be recirculated or directed to drain.

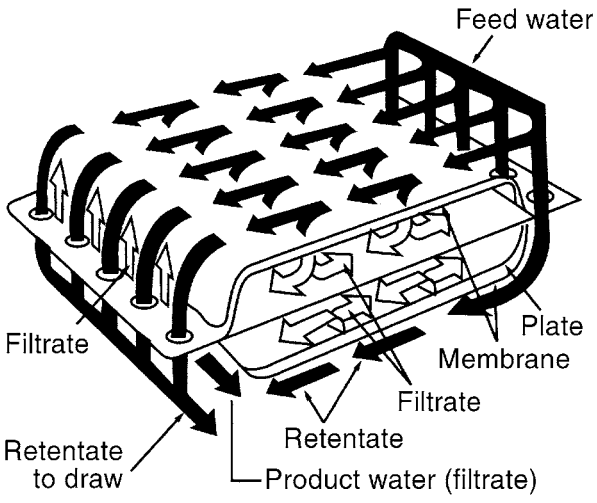


Figure 11-13 Plate-and-Frame Reverse-Osmosis Configuration

Table 11-8 Comparison of Reverse-Osmosis Polymers

	Thin Film Composite	Polyamide	Cellulose Acetate	Cellulose Triacetate	Polysulfone
pH stability	2–12	4–11	2–8	4–7.5	3–11
Chlorine tolerance	Fair–poor	Poor	Good	Fair–good	Good
Biological resistance	Good	Good	Poor	Fair–good	Good
Temperature limit for stability, °F (°C)	122 (45)	95 (35)	95 (35)	86 (30)	95 (35)
Typical rejection ionic species (%)	>90	>90	90	90	90
Flux	High	Low	Low–medium	Low–medium	High

This configuration is mostly used for filtration and rarely for RO systems. The packing density is low and the resistance to fouling is very high. It is used for small to medium volumes, generally less than 20 gpm (76 L/min).

Membrane selection System performance is determined by considering the following factors, which influence the capacity of the individual membranes selected:

1. Operating pH.
2. Chlorine tolerance.
3. Temperature of the feed water.
4. Feed-water quality, usually measured as SDI.
5. Types of impurity and prior feed-water treatment.
6. Membrane flux.
7. Number of operating hours.
8. Resistance to biodegradation and ability to be sanitized.
9. Rejection characteristics. Typical RO systems remove the following contaminants to the following levels:
   Inorganic ions 93–99%
   Dissolved organics > 99%
   (>300 molecular weight)
   Particulates > 99%
   Microorganisms > 99%

The selection of a system configuration shall be based on the following considerations:

1. Maximum recovery.
2. Fouling properties and resistance.
3. Production rate per unit volume.

Only a few polymers have the necessary characteristics to function as a semipermeable membrane:

1. Thin film composite of various polymer materials.
2. Polyamide.
3. Cellulose acetate.
4. Cellulose tricetate.
5. Polysulfone.

Typical characteristics and a comparison of these membranes are given in Table 11-8.

Cross-flow filtration Ultrafiltration and nanofiltration membranes are categorized by their pore size. Ultrafiltration membrane pore sizes range from 0.001 to 0.02 μm. Nanofiltration membranes have pore sizes allowing the passage of solids to 10,000 molecular weight, or daltons. The 10,000-dalton cutoff is recommended for the complete removal of pyrogens.

Typical recovery rates for ultrafilters range between 95 and 98%, with the remainder flushed to drain.

The membranes are manufactured by bonding the membrane onto a porous, supporting substrate and then configuring it into elements. These filters are usually used as a pretreatment for the removal of colloids, bacteria, pyrogens, particulates, and high-molecular-weight organics. Spiral wound and hollow fiber are the two most often-used configurations.

Microbial Control

Chemicals The most often-used disinfection method is the addition of oxidizing or nonoxidizing chemicals. Chemicals could be either biocides, which are substances that kill microbes, or biostats, which prevent the further growth of microbes. Commonly used chemicals are chlorine and chlorine compounds, hydrogen peroxide, and acid compounds.

To be effective, the chemical must have a minimum "contact time" in the water. In addition, a residual amount of the chemical must be present to keep its effectiveness against organisms.

Chemicals add impurities to the water and are not generally suitable for a pure-water environment. They mostly are used to disinfect potable and process water and equipment and are injected directly into the fluid stream by means of a metering pump. When present in the feed water used for purification, they must be removed. Chlorine may produce trihalomethanes.

Ultraviolet radiation Ultraviolet (UV) radiation is an in-line process. UV light is generated using mercury vapor lamps. There are two different wavelengths available that produce the intensity and energy output necessary for the intended germicidal-treatment requirements. Federal standard 209E and aseptic guidelines issued by the FDA provide some guidance for the use and application of UV irradiation.

The 254-nm wavelength operates in the germicidal region, sterilizing by destroying bacteria, mold, viruses, and other microorganisms. This wavelength is preferred for pure-water systems; it significantly reduces the multiplication of organisms.

The 185-nm wavelength operates in a high-energy spectrum of electromagnetic quantum packet, photon radiation (light) band. The energy available has the ability to break down organic molecules and compounds to carbon dioxide and water by the photo-oxidation process. It slowly breaks the bonds in organic molecules by direct radiation and also oxidizes organisms by the formation of hydroxyl radicals. The UV spectrum is illustrated in Figure 11-14.

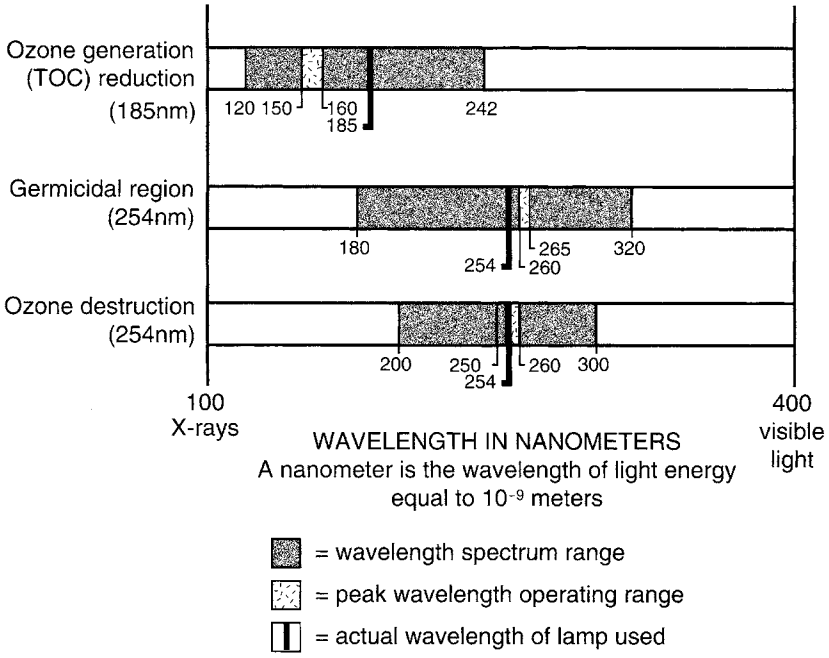


Figure 11-14 UV Wavelength Spectrum

A flow rate of approximately 2 fps (0.6 m/s) is a general industry standard for the effective sanitation of purified water. The flow rate through the UV device should be reduced compared to the circulation loop to extend the necessary contact time. The recommended location for the UV device is prior to the deionization equipment.

Problems include generation of ions that lower the resistivity of water and the possible leaching of silica from the quartz sleeve of the UV device. Glass, plastic, rubber, and similar materials exposed to UV radiation will, over time, crack, etch, discolor, and flake. Tests have shown only 50% of the energy used by the bulb is actually transmitted to the water and, in time, 25% of the output will be lost compared to a new bulb.

Filtering A filter removes organisms from the fluid stream. Generally accepted practice is to use a 0.2-μm absolute filter for the removal of bacteria. Although the effectiveness of this practice is questioned by some authorities, recommended current practice is to use a membrane with an absolute rating (cutoff) of 10,000 daltons. Cartridge filtration is the most commonly used method of filtration.

Heat Heating to 175°F (80°C) effectively sanitizes water under pressure. The heating can be accomplished by using steam, electric, or other types of heat exchangers. It is common practice to circulate purified water at this temperature and use heat exchangers to lower the water temperature at each point of use if necessary.

Ozone Ozone (O_3) is an oxidizing gas generated from gaseous oxygen or catalytically from water. The most often-used method of producing ozone is by a corona-discharge generator, which converts the oxygen in air to ozone. The air is passed between two electrodes where an electrostatic discharge across the gap converts oxygen to ozone. A typical schematic drawing of a corona-discharge generator is illustrated in Figure 11-15.

It is a common misconception the ozone created by the bulbs in mercury vapor lamps is imparted to the water. The engineer should remember when 185-nm systems are employed as a treatment process the bulbs are enclosed in—indeed, have to be enclosed in—quartz sleeves. Though it is true the 185-nm bulbs are used to generate ozone, the bulbs are in a chamber where they are exposed to oxygen-rich air. The ozone created in that chamber is then induced into the aqueous stream as a method of stream sanitation.

The ozone system consists of a feed-gas-treatment unit, an ozone generator, a water-ozone contact mechanism, and a destruction unit to eliminate any residual ozone.

1. *Feed-gas treatment.* The gas reaching the generator must have all particles larger than 0.3 μm and 95% of those larger than 0.1 μm removed. In addition, aerosols, moisture, and hydrocarbons shall be removed as required by the manufacturer. This purification is usually supplied as part of a package.
2. *Ozone generator.* The three basic types of generator are the Lowther plate unit, Otto plate unit, and tube unit. They differ only in the manner in which they are cooled. Ozone generators use large amounts of electrical power, generally between 15 and 26 kWh/kg of O_3.

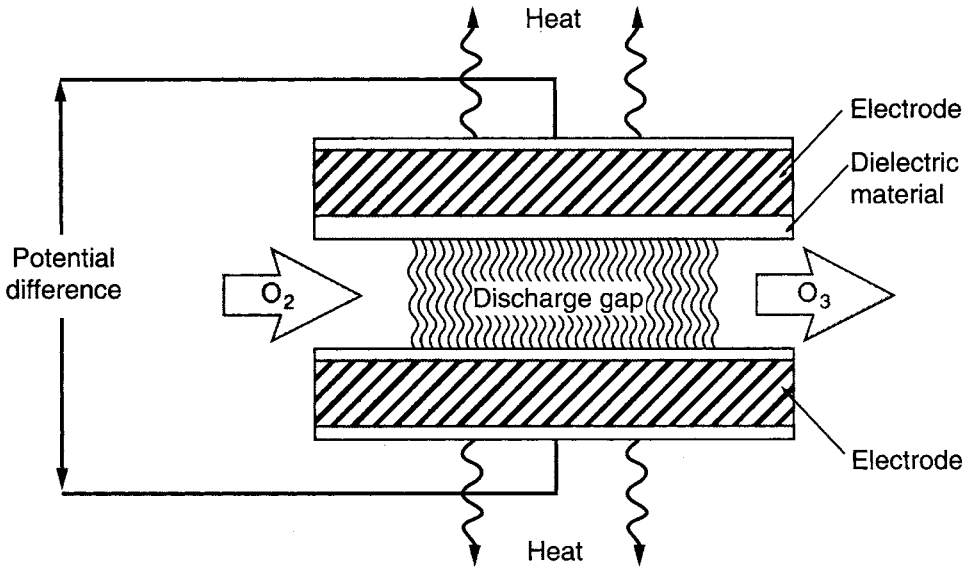


Figure 11-15 Principle of Corona-Discharge Ozone Generator

3. Ozone and water are mixed in direct contact with one another by the use of static or mechanical mixers, injectors, or columns that optimize the dissolution of the gas.
4. Depending on the generator, ozone concentrations can vary from 100 to 3000 ppm. Because high concentrations are harmful to humans and metals, the ozone should not be allowed to escape to atmosphere without being treated to a level below 0.1 ppm. Destruction can be accomplished by catalytic, thermal, and activated carbon. Thermal units operate at a temperature of 572°F (300°C) and generally require a 3 to 5-min contact time to be effective.

The mechanism for ozone oxidation is through generation of hydroxyl radicals. The gas is directly injected into the water stream.

Problems include the ozone system's inability to oxidize all organic compounds; also it is slow acting and in some cases will form stable and refractory compounds.

WATER TREATMENT

This subsection describes the various methods and equipment used to treat water for various purposes.

Utility Water Treatment

Water from wells, rivers, lakes, and streams is commonly used for cooling and washing purposes, among others. Clarifying and treating the water to meet the purity requirements of the proposed end use requires good monitoring and quick reaction to raw and treated water fluctuations. If the water is to be recirculated, the treatment methods are more stringent than if it is not. If the water is to be discharged into the environment, local codes must be adhered to with regards to allowable chemical amounts present in the waste water to avoid the need for waste treatment.

Initial filtering If the supply is from surface water, a coarse or fine screen is usually placed at the intake to keep out fish and other large debris. Coarse screens are usually ½-in. (1.27-cm) diameter bars with a clear opening of 1 to 3 in. (2.54 to 7.62 cm). Fine screens could have openings of approximately ⅜ in. (0.95-cm) square, with the water velocity through the screen limited to about 2 fps (0.6 m/s). If the quantity of water is small enough, basket strainers can be used. In climates where freezing may occur, the inlet should be placed far enough below the low-water level to prevent freezing.

Clarification After initial filtering, clarification is required to obtain water that meets the standards for the proposed use. The selection of the clarifier is based on the volume of water to be treated and the final quality desired. If the volume of water is small and the raw water is not very turbid, filters may be used.

Biological control To control microorganism fouling of the system, microorganisms must be destroyed if possible, inactivated to keep them from reproducing, and removed from the water stream. This is usually accomplished by chlorination, filtration, UV radiation, ozone generation, and special adsorbents.

Chlorination is the least costly and most often-used method. The action of chlorine requires a specified contact time and the establishment of a residual chlorine amount. A range of 0.5 to 1.0 ppm is generally accepted for typical waters.

Water softening Water softening should be considered to reduce the hardness in the utility water system when the system is used for recirculated cooling purposes.

Boiler Feed-Water Conditioning

In a boiler, energy in the form of heat is transferred across a heat-transfer surface from a fuel source to the water used for making steam. When subject to elevated temperature and pressure, the composition of the raw boiler-water supply undergoes radical changes.

The effects of dissolved gases are magnified. The dissolved minerals may deposit a scale on the transfer surface that affects the heat-transfer process.

The result is a reduction in the heat-transfer rate, a reduction in the flow rate, and increased damage from corrosion. A wide range of treatment methods is available, depending primarily on the impurities found in the raw water, the operating pressure of the boiler, and the makeup rate of water. These methods could be mechanical or chemical—the addition of chemicals to prevent deposits, inhibit corrosion, or neutralize impurities detrimental to the proposed end use of the water and the use of dispersants to keep particulates in suspension.

The treatment starts with an accurate feed-water analysis. This is compared to final treatment objectives established by the user and the boiler manufacturer. The degree of removal is determined by the difference in the two analyses. Recommended standards for boiler feed-water and steam quality are given in Table 11-9.

A boiler-water treatment program shall accomplish the following:

1. Reduce or remove hardness to control scale by either mechanical (external) or chemical (internal) treatment.
2. Maintenance of proper levels of alkalinity to ensure proper chemical reactions can occur.
3. Control dissolved oxygen and carbon dioxide through deaerating and the addition of an oxygen scavenger.
4. Maintenance of proper levels of conditioners so the suspended solids remain in suspension and can be easily eliminated through blowdown.
5. Optimum boiler blowdown.

The mechanical removal of hardness is most often accomplished by water softening using an ion-exchange process, where the insoluble calcium and magnesium ions are replaced with highly soluble sodium ions. A commonly used resin is a strong acid resin in sodium form often referred to as "zeolite." Real zeolite is a naturally occurring mineral no longer widely used because of its higher cost. Its use introduces artificial resins that are more efficient for most uses.

The adjustment of pH is accomplished by the injection of dilute sulfuric or hydrochloric acid or sodium hydroxide or sodium carbonate. This requires close monitoring.

Feed-water oxygen and carbon dioxide are normally removed with deaerators before the feed water enters the boiler. In addition to mechanical deaeration, it is recommended a chemical oxygen scavenger be added to the water to quickly eliminate any remaining traces of oxygen. Many scavengers are in use but the most frequently used scavengers are sulfites (up to 1000 psig [6895 kPa]) and compounds of hydrazine. Hydrazine is being replaced by diethylhydroxylamine (DEHA), carbohydrazide, hydroquinone, and isoascorbic acid.

Chemicals can be added to the boiler feed water for two purposes. One is to keep the hardness-causing salts in solution where they will not cause scaling. The second is to precipitate them out of solution to allow the particulates to be disposed of during blowdown. There are many effective materials, generally blends of component chemicals. Those most often used are polymers and phosphates and carbonates that are designed to optimize the precipitation of calcium, magnesium, and iron. Modern treatment has made hardness deposits much less common but iron deposits more common because of the return of condensate to the boiler.

Table 11-9 Recommended Boiler Feed-Water Limits and Steam Purity

Drum Pressure, psig (kPa)	Range TDS[a] Boiler Water (ppm max.)	Range Total Alkalinity[b] Boiler Water	Suspended Solids Boiler Water (ppm max.)	Range TDS[c] Steam (ppm) (max. expected value)
Drum-Type Boilers[a]				
0–300 (0–2068)	700–3500	140–700	15	0.2–1.0
301–450 (2075–3103)	600–3000	120–600	10	0.2–1.0
451–600 (3110–4137)	500–2500	100–500	8	0.2–1.0
601–750 (4144–5171)	200–1000	40–200	3	0.1–0.5
751–900 (5178–6205)	150–700	30–150	2	0.1–0.5
901–1000 (6212–6895)	125–625	25–125	1	0.1–0.5
1001–1800 (6902–12 411)	100		1	0.1
1801–2350 (12 418–16 203)	50		n/a	0.1
2351–2600 (16 210–17 926)	25		n/a	0.05
2601–2900 (17 933–19 995)	15		n/a	0.05
Once-Through Boilers				
1400 and above	0.05	n/a	n/a	0.05

Source: American Boiler Manufacturers Association.

Note: n/a = not available.

[a] Actual values within the range reflect the total dissolved solids (TDS) in the feed water. Higher values are for high solids, lower values are for low solids in the feed water.

[b] Actual values within the range are directly proportional to the actual value of TDS of boiler water. Higher values are for the high solids, lower values are for low solids in the boiler water.

[c] These values are exclusive of silica.

Boiler blowdown is the bleeding off of some water from the boiler. When steam is generated, impurities are left behind from the feed water converted to steam; in time, these accumulate. When the level of impurities becomes too high, a portion of the water is discharged to drain. This is called "blowdown." Blowdown could be intermittent or continuous.

Cooling-Water Conditioning

This subsection discusses basic principles used for controlling scale, corrosion, and biological fouling of water used in evaporative cooling towers and condenser systems.

The basic reason for the treatment of cooling water is to keep any dissolved solids from depositing onto any piping or equipment. This is accomplished by preventing the dissolved solids from reaching the saturation point. This is usually expressed as the cycle of concentration of the water, which compares the dissolved solids in the feed water with the dissolved solids content of the circulating water. As an example, if the feed water has a TDS of 100 ppm and the circulating water has a TDS of 300, a cycle of concentration of 3 has been reached. The cycle of concentration is reduced by bleed off (blowdown) from the system.

Scale The basic treatment for scale in cooling-water systems is to add inhibitors that keep the scale from depositing on the walls of the pipe. They are similar to those used for boiler-water treatment but with the addition of surfactants, which change the surface characteristics of the pipe to prevent deposition and aid in removal if deposits occur.

Corrosion "Corrosion" can be broadly defined as an electrochemical process. Corrosion takes place when an electrical potential is possible between two surfaces common to an electrolyte. The factors impacting corrosion in aquatic systems include:

1. Dissolved oxygen.
2. Total dissolved solids.
3. Alkalinity and pH.
4. Total hardness.
5. Temperature.
6. Flow velocity.
7. Types of metal used in the process.
8. Condition of the interior surface of the plumbing system.
9. Extraneous electrical current.
10. Bacteria.

Simple tools used to predict the propensity of an aqueous solution to be corrosive are the Langelier, Stiff & Davis, and Ryznar indexes. Corrosion treatments consist of:

1. pH control.
2. Chemical inhibitors.
3. Oxygen scavengers like hydrazine, sodium bisulfate, and morphine.
4. Ensuring proper flow rates by correct size selection of metal pipe.
5. Sacrificial anode.
6. Polishing and passivation of interior surfaces.
7. Biocide treatment.

These shall be recommended by the manufacturer of both the chemicals and the equipment to ensure compatibility. The pH of the circulating water is usually controlled to a point near 7.5 to decrease its scale-forming tendency. The addition of a dilute acid is the most often-used method of control. A corrosion inhibitor often adds compounds that increase the tendency of scale to occur; therefore, a balance must be reached.

Biological fouling Microbial control is achieved with the addition of biocides, either oxidizing or non-oxidizing depending on their chemistry and killing action. Ozone is also commonly used.

Biocide treatment is intended initially to shock microbes with a heavy dose, then the concentration of the compounds is allowed to fall to a level of 25% of the initial dose. This is a generally accepted lower limit below which the biocide is not considered effective. Often, because of the presence of several different strains of microbes, more than one biocide may be required. A contact time approved by the chemical manufacturer is required.

These chemicals are added by means of a chemical feed pump discharging directly into the piping system. The levels must be closely monitored with alarms established by performance indicators based on operating experience.

Potable Water Treatment

Water used for human consumption or intended to be part of food products must be treated to comply with the Safe Drinking Water Act (SDWA), the Surface Water Treatment Rule (which is a part of the SDWA), and local regulations. Substances that affect the quality of potable water are classified in four major headings:

1. *Physical*. Physical characteristics, such as color, turbidity, taste, and odor, are often related to the appearance of the water. Physical quality is usually corrected through the use of various types of filter.
2. *Chemical*. The chemical characteristics of water are related to dissolved minerals (mostly hardness), gases, and organics. The chemical quality of water is adjusted by the use of water softeners,

Table 11-10 Water-Treatment Technology for Small Potable Water Systems

Technology	Advantages	Disadvantages
Filtration		
Slow sand	Operational simplicity and reliability, low cost, ability to achieve greater than 99.9% Giardia cyst removal.	Not suitable for water with high turbidity, requires large land areas.
Diatomaceous earth (septum filter)	Compact size, simplicity of operation, excellent cyst and turbidity removal.	Most suitable for raw water with low bacterial counts and low turbidity (<10 ntu), requires coagulant and filter aids for effective virus removal, potential difficulty in maintaining complete and uniform thickness of diatomaceous earth on filter septum.
Reverse-osmosis membranes	Extremely compact, automated.	Little information available to establish design criteria or operating parameters, most suitable for raw water with turbidity <1 ntu, usually must be preceded by high levels of pretreatment, easily clogged with colloids and algae, short filter runs, concerns about membrane failure, complex repairs of automated controls, high percent of water lost in backflushing.
Rapid sand/direct filtration package plants	Compact, treat a wide range of water quality parameters and variable levels.	Chemical pretreatment complex, time-consuming; cost.
Disinfection		
Chlorine	Very effective, has a proven history of protection against waterborne disease, widely used, variety of possible application points, inexpensive, appropriate as both primary and secondary disinfectant.	Potential for harmful halogenated byproducts under certain conditions.
Ozone	Very effective, no THMs formed.	Relatively high cost, more complex operation because it must be generated on-site, requires a secondary disinfectant, other byproducts.
Ultraviolet radiation	Very effective for viruses and bacteria, readily available, no known harmful residuals, simple operation and maintenance for high-quality waters.	Inappropriate for surface water, requires a secondary disinfectant.
Organic Contaminant Removal		
Granular-activated carbon	Effective for a broad spectrum of organics.	Spent carbon disposal.
Packed-tower aeration	Effective for volatile compounds.	Potential for air emissions issues.
Diffused aeration	Effective for volatile compounds and radionuclides.	Clogging, air emissions, variable removal efficiencies.
Advanced oxidation	Very effective.	Byproducts.
Reverse osmosis	Broad spectrum removal. disposal.	Variable removal efficiencies, waste-water
Inorganic Contaminant Removal		
Reverse osmosis	Highly effective.	Expensive waste removal.
Ion exchange	Highly effective.	Expensive waste removal.
Activated alumina	Highly effective.	Expensive waste removal.
GAC	Highly effective.	Expensive waste removal.

ion exchange, RO units, and activated charcoal units to remove organic impurities.

3. *Biological*. These characteristics are concerned with microorganisms that affect the health of the consumer. Biological treatment requires the use of biocides and biostats to eliminate and reduce the number of microorganisms present in the water and to create a residual amount of the chemical to maintain the required level of action required by code.
4. *Radiological*. This category is concerned primarily with radon in areas where the water may have come in contact with radioactive substances. Retention and aeration lower the radon count to acceptable limits in approximately 8 hours.

A synopsis of general treatment methods for small potable-water systems, including discussion of general advantages and disadvantages, is given in Table 11-10.

WATER PURIFICATION

This section discusses pure water used for laboratory and pharmaceutical purposes. The various systems are broadly defined and general guidelines for pure water production, storage, and distribution are provided.

Ultra-pure water systems used in the production of food products and electronic industries are considered process systems and are, therefore, outside the scope of this chapter. For information on suggested guidelines for water purity in the electronics industry, contact the Semiconductor Equipment Manufacturers Institute, Mountain View, California.

A total water-treatment system consists of three general, interrelated phases: pretreatment, purification, and distribution (including post treatment)

of the purified water. Purification methods include distillation, deionization, continuous deionization, membrane filtration, and other approved processes. Water for injection (WFI) water can only be produced by distillation or membrane filtration. Ultra-pure water for specific applications is often made using pure water as feed water, which is then further purified to meet the specific requirements at the point of use.

Codes and Standards

The required quality of purified water depends on the application. Various codes have specifically defined water quality for use in various industries. Among them are:

1. 21 CFR 210, current good manufacturing practice (cGMP) for drugs.
2. 21 CFR 211, cGMP for finished pharmaceuticals.
3. USP/NF 24, official water nomographs.
4. Federal Food, Drug and Cosmetic Act.

Laboratory Systems

For laboratory work, all applications do not require the same quality of water. The American Society of Testing Materials (ASTM), the College of American Pathologists (CAP), the National Committee for Clinical Laboratory Standards (NCCLS), and the Association for the Advancement of Medical Instrumentation (AAMI) have all developed standards for water used in laboratories depending on its intended use. These standards are summarized in Tables 11-11 (ASTM), 11-12 (NCCLS), and 11-13 (AAMI). The ASTM electronics-grade water standard is given in Table 11-14 for reference only.

There are three pure-water categories in the NCCLS specifications:

- *Type I*, called "reagent grade water," is used for analysis of trace matter and other critical applications. It is the purest water covered by any written standard. This water is free from organic and inorganic impurities, suspended solids, and microorganisms.
- *Type II*, called "analytical grade water," is suitable for all but the most critical procedures.
- Type III, called "general laboratory-grade water," is suitable for most qualitative analysis and equipment rinsing and as a supply for generating type I water.

There are four basic applications where high-purity water is needed in the biological laboratory: (1) water for media used in growing tissue cultures, (2) water used in media formulations for growing bacteria and other procaryotes, (3) water used to make buffer solutions are used in enzymatic reactions, and (4) water used to make solvent standards and reagents for various types of analysis.

Another grade of water called "organic free water" is often required for trace analysis of various impurities. It has no formal specification and is required to have an organic purity greater than that required for type I.

Pharmaceutical Systems

The type of water used for pharmaceutical purposes is called "USP" purified water. The name is derived from the United States Pharmacopoeia (USP) specifications for purified water, with revisions to the specification made from time to time based on current technology. There are two categories of water referred to: puri-

Table 11-11 CAP and ASTM Reagent-Grade Water Specifications

	CAP Type			ASTM Type			
	I	II	III	I	II	III	IV
Spec. conductance (μmhos/cm)	0.1	0.5	10	0.056	1.0	0.25	5.0
Spec. resistance (M$\Omega \cdot$ cm)	10	2.0	0.1	18	1.0	4	0.2
Silicate (μg/L)	50	100	1000	3	3	500	—
Heavy metals (μg/L)	10	10	10	—	—	—	—
Total organic carbon (μg/L)	—	—	—	100	50	200	—
Potassium permanganate reduction (min.)	60	60	60	—	—	—	—
Sodium (μg/L)	100	100	100	1	5	10	50
Chlorides (μg/L)	—	—	—	1	5	10	50
Hardness	neg	neg	neg	—	—	—	—
Ammonia	0.1	0.1	0.1	—	—	—	—
Bacterial growth (cfu/mL)	10	10^4	—	[a]	[a]	[a]	[a]
pH	—	—	5.0–8.0	—	—	—	5.0–8.0
CO2 (μg/L)	3	3	3	—	—	—	—

[a] Microbiological contamination: When bacterial levels need to be controlled, reagent grade types should be further classified as follows:

	Type A	Type B	Type C
Maximum heterotropic bacteria count	10/1000 mL	10/1000 mL	100/10 mL
Endotoxin, endotoxin unit (EU)	<0.03	0.25	Not applicable

Table 11-12 NCCLS Reagent-Grade Water Specifications

Characteristics	Type I	Type II	Type III
Bacterial content (colony-forming units per mL, maximum)	10[a]	1000	N/A
pH	N/A	N/A	5.0–8.0
Resistivity (25°C, MΩ/cm)	10	1.0	0.1
Silicate (mg/L max.)	0.05	0.1	0.1
Particulate matter[a]	0.22-μm filter	N/A	N/A
Organics[b]	Activated carbon	N/A	N/A

Source: Frankel 1996.

[a] Preferably, type I water should be bacteria free.

[b] These specifications are process specifications and are not measured by the end user. Additional purification may be required for selected clinical laboratory procedures, such as:

1. Preparation of water with minimal pyrogen levels for cell culture.
2. Preparation of bacteria-free water for direct fluorescent detection of bacteria as in Legionella direct fluorescent antibody testing or direct fluorescent stains of mycobacteria.
3. Preparation of water with minimal organic content for HPLC.

Table 11-13 AAMI/ANSI Water-Quality Standards

Contaminant	Suggested Maximum Level (mg/L)
Calcium	2 (0.1 meq/L)
Magnesium	4 (0.3 meq/L)
Sodium	70 (3 meq/L)
Potassium	8 (0.2 meq/L)
Fluoride	0.2
Chlorine	0.5
Chloramines	0.1
Nitrate (N)	2
Sulfate	100
Copper, barium, zinc	0.1 each
Arsenic, lead, silver	0.005 each
Chromium	0.014
Cadmium	0.001
Selenium	0.09
Aluminum	0.01
Mercury	0.0002
Bacteria	200 (cfu/mL)

Source: Association for the Advancement of Medical Instrumentation (AAMI), 1990, Hemodialysis Systems Standard. Adopted by American National Standards Institute (ANSI), 1992.

Note: "meq/L" = mole equivalent/liter

fied water (PW) and water for injection (WFI). The standard for each is given in Table 11-15.

There are four basic technologies used to produce pure water: ion exchange, distillation, membrane filtration and separation, and continuous deionization (CDI) or electrodeionization (EDI). Some of these systems are often combined. The most common combination is called Reverse Osmosis/Deionization (RODI). The degree of treatment depends on the end-user requirements, the amount and nature of the various contaminants present in the feed-water stream and of those to be removed. Knowledge of the highest levels of contaminants and the highest-purity water required cannot be overemphasized. Unless these factors are well established, the selection of any treatment method is impossible. A typical pharmaceutical water-purification flow diagram is shown in Figure 11-16.

Feed Water

Feed-water quality, which is source dependent, is the first parameter to be identified in the design of a pure-water system. The source strongly influences the pretreatment options and may dictate the treatment methods. A wide variation in types and concentrations of impurities is possible, depending on whether the feed water is obtained from a public utility or a private source, such as a well or other surface or ground-water source. Surface waters are usually high in particulates, colloids, and organics. Underground waters tend to have low levels of particulates, colloids, and organics and relatively high levels of calcium and magnesium hardness and alkalinity (bicarbonates). Source water from agricultural areas often has high levels of nitrates, phosphates, and organic pesticides. Water from public utilities has residual chlorine, fluorides, and chlorimines as well as iron oxides and other pipe-related impurities. It is important to establish or obtain historical water analysis data from different times and seasons of the year in order to properly

Table 11-14 ASTM Electronics-Grade Water Standard[a]

Assay	Grade			
	E-I	E-II	E-III	E-IV
Resistivity, minimum	>18.0[a]	17.5[b]	12	0.5
(MΩ · cm at 25°C)	> 17.0[a]	> 16.0[b]		
SiO_2 (total), max. (μg/L)	5	10	50	1000
Particle count (per mL)	1	3	10	100
Particle size limit (μm)	0.10	0.5	1.0	10
Viable bacteria, max.	1/1000 mL	10/1000 mL	10/1 mL	100/1 mL
Copper, max. (μg/L)	1	1	2	500
Zinc, max. (μg/L)	0.5	1	5	500
Nickel, max (μg/L)	0.1	1	2	500
Sodium, max. (μg/L)	0.5	1	5	1000
Potassium, max. (μg/L)	2	2	5	500
Chloride, max. (μg/L)	1	1	10	1000
Nitrate, max. (μg/L)	1	1	5	500
Phosphate, max. (μg/L)	1	1	5	500
Sulfate, max. (μg/L)	1	1	5	500
Total organic carbon, max. (μg/L)	25	50	300	1000
Endotoxins	0.03 EU[c]	0.25 EU[c]	N/A[d]	N/A[d]

Source: ASTM Standard D5127-90.

[a] Above 18ΩD · cm 95% of the time, not less than 17.

[b] 17.5 or greater 90% of the time, not less than 16.

[c] EU = Endotoxin unit.

[d] N/A = not applicable.

Table 11-15 USP XXII Purified-Water and WFI Water-Purity Standards

Component	Purified Water	Water for Injection
pH	5.0–7.0	5.0–7.0
Chloride (mg/L)	0.5	0.5
Sulfate (mg/L)	1.0	1.0
Ammonia (mg/L)	0.1	0.1
Calcium (mg/L)	1.0	1.0
Carbon dioxide (mg/L)	5.0	5.0
Heavy metals (mg/L)	0.1 as Cu	0.1 as Cu
Oxidizable Substances	**Pass USP Permanganate Test**	
Total solids (mg/L)	10.0	10.0
Bacteria (cfu/mL)	100	50.0
—FDA action limit	100 cfu/mL	10 cfu/100 mL
Pyrogen (EU/mL by LAL)	—	0.25

Source:Numerical values are interpretations of procedures listed in the *Standards in United States Pharmacopoeia,* 24th. ed.

design a system with enough flexibility to obtain the required purity under worst-case conditions.

It is an FDA requirement the feed water for USP purified water and WFI systems meet the EPA guidelines for potable water. Of particular concern is the microbial level. The water should be virtually free of coliform, which is a pathogenic marker organism. The feed water must also meet the 400 cfu/mL, the maximum value specified in USP XXIV. Another requirement is it shall contain no added substances. This is an issue that appears to be interpreted differently by individuals and organizations involved in the design of PW systems. There are systems presently in use that appear, from an overall perspective, to violate this position. Items such as the chlorination of raw water supplies, acid addition to adjust pH, and the use of ozone to control microbial growth are subject to interpretation. All of the concerns are resolved during the application phase for FDA approval and validation of the system.

Purification System Design

Specific methods of purification are capable of removing various types of impurities better than others. None can be depended on to remove all the impurities necessary to achieve the purity level required for USP purified water. It is accepted practice to use a combination of technologies, each of which is designed to remove a specific type of impurity.

The methods used to produce this water depend on the feed water supplying the facility. In most instances, feed water has a high level of some classes of contaminant. It is much more economical to pretreat that water to remove the bulk and/or the more concentrated of those impurities, then use the purification equipment to "polish" the water to the desired purity level. In some cases, the removal of individual impurities is necessary to allow the use of specific types of purification equipment.

Pretreatment Pretreatment is considered for two reasons:

1. Potential damage to the membrane selected.
2. To increase membrane filtration quality.

The need for pretreatment is determined by an analysis of the raw water supply. The decision is generally governed by the cost efficiency of the pretreatment method and whether the cost of purchasing and installing the pretreatment equipment will reduce the initial cost of the main treatment equipment and lower the operating cost of the system as a whole enough to justify its installation.

Water temperature Membrane productivity (flux) is usually rated with feed water at 77°F (25°C) and is inversely proportional to the feed-water viscosity.

When the water temperature is lower, additional membrane area is required. The flux increases with increased feed-water temperature. Heating the feed water lowers the viscosity. The water could be heated with a separate water heater or with a blending valve using domestic hot water mixed with feed water to provide the necessary temperature.

pH adjustment The selected membrane should have an optimum pH operating range. To achieve it, a dilute acid is injected into the feed water if necessary. When using drinking water standards, this problem is rarely encountered.

Filtration Filters are used to remove suspended solids originating from any source. If continuous production is required, a duplex arrangement should be installed so the filters can be backwashed or replaced with no interruption in service.

Sand and multi-media filters A common initial method for gross particulate removal from source water is a pressure multi-media sand filter, used if the concentration of suspended solids is greater than 0.2 ppm. If the concentration is lower, a 5 to10-mm cartridge filter is often used. Experience has found cartridge replacement is uneconomical compared to backwashing.

Cartridge filters These are used to remove lesser amounts of particulates prior to the central purification equipment. It is generally accepted practice to provide an in-line 5-mm cartridge depth filter to eliminate any particulates that would clog or interfere with the operation of the central purification equipment. This filter is recommended if the SDI is less than 4 and generally required if the level is more than 4. If the level is more than 4, an additional 1-mm cartridge filter is recommended downstream of the main filter. In some locations, or on some feed waters, it is practical to use a sand, multimedia filter and a cartridge filter (with the sand filter first).

Carbon filtration Following the removal of gross particulates, a granulated carbon filter is provided to remove residual disinfectants (chlorine,

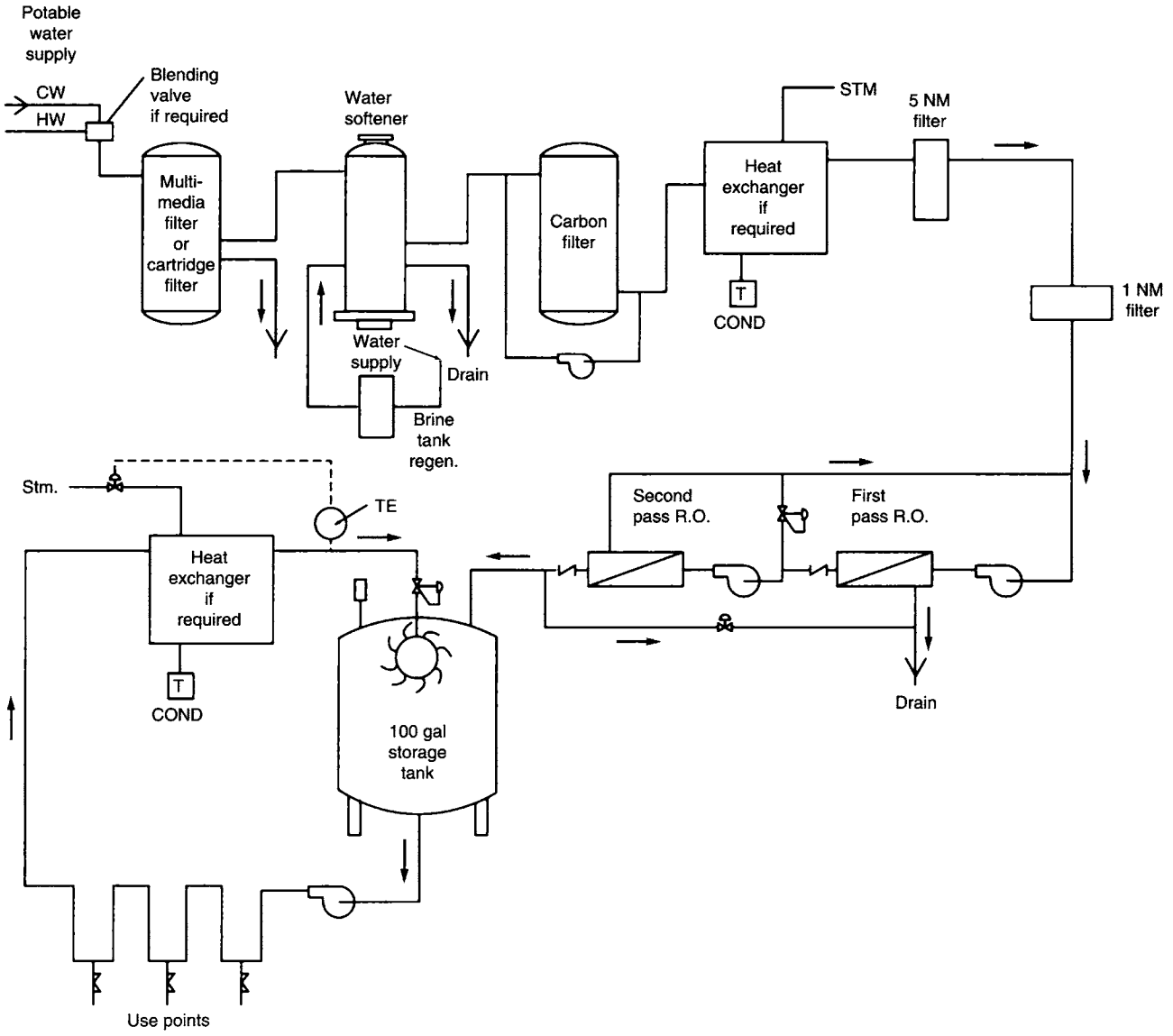


Figure 11-16 Typical Pharmaceutical Water-Flow Diagram

chlorimine, etc.), dissolved organics (oils, pesticides, surfactants, etc.), and suspended organics (humic and fulvic acids, etc.).

Flow rates through this filter are usually in the range of 1.0 to 4.0 gpm/ft^2 (3.78 to 15.14 L/min/0.093 m^2) of filter area, depending on the quantity of organics and chlorimines in the entering water. The higher the quality of water, the slower the flow rate.

Problems of carbon filters are their tendency to harbor microbial growth due to the removal of chlorine. Frequent sanitizing is necessary, usually with potassium permanganate, sodium hydroxide, or steam. If steam is selected, the tank should be constructed of 316L SS.

Water softening If the hardness is high, it is necessary to provide a water softener to reduce the calcium and magnesium present to a level required by the membrane selected. Water softening is recommended if the iron content exceeds 0.4 ppm.

The softener is another device harboring microbial growth. Sanitizing with potassium permanganate is generally used.

Biological and TOC reduction UV units and ozone generators are generally used to remove microorganisms and TOC from the feed water prior to its reaching the RO units. Materials used in the system must be compatible with these units. There is a reluctance to use any chemical to remove microorganisms due to FDA restrictions regarding adding chemicals to the feed water. However, chlorine is commonly added to disinfect the feed water because it is cost effective and can easily be removed by GAC filters.

Biocide removal The most common source of feed water for most facilities is potable water. This

water contains a residual amount of chlorine, which is necessary to comply with code for drinking-water quality. To remove this residual chlorine, a granulated, activated-charcoal filter is provided. An "organic trap" may also be required if organics are very high.

Central Purification Equipment

The basic methods used to produce high-purity water are distillation, ion exchange, continuous deionization or electrodeionization, and reverse osmosis. The method used will depend on the purity desired and limitations on initial or operating cost.

Storage The storage of water reduces the size of the purification equipment. Storage tanks could be constructed from fiberglass-reinforced plastic with an internal vial suitable for the purpose, polypropylene (high-density or cross-linked with a minimum specific gravity of 1.5), polyethylene, and stainless steel (finish specified by user or process). The bottom of the tank shall be dished or conical to aid in complete drainage. It is an established fact that high-purity water degrades in storage. Four major sources for this degradation are:

1. Water extract contamination from any container.
2. Bacteria grow and secrete waste products.
3. Organics from solvents and shedding of clothing can diffuse through the air and dissolve in the water.
4. Laboratory personnel secrete urea in perspiration and respiration that can cause the formation of ammonia in stored laboratory water.

The tank for USP water should be airtight and equipped with a non-shedding, 0.2-mm hydrophobic filter for venting. For WFI systems the tank should be type 304L or 316L SS, pressure rated to a minimum of 35 psig (241 kPa) pressure and 30 in. (760 mm) Hg vacuum, 180 grit and electro-polished. It is common practice to have a nitrogen gas blanket in the vapor space above the water in the storage tank to reduce the possibility of airborne contamination. The tank shall have a jacket to maintain a temperature of 177°F (80°C) and be insulated and provided with a rupture disk.

The discharge should be from the center bottom of the tank to allow complete circulation of the stored water. The water return should be at the top of the tank and be equipped with a spray ball or spray ring. This minimizes microbial growth by continuously washing the upper areas of the tank.

Sterilization It is common practice to provide an in-line UV sterilization device to reduce microorganisms that may be present in the water. Another often-used method is to heat purified water to a temperature of 177°F (80°C) to prevent microorganism growth, then circulate it to maintain the sterile condition. Another possibility is the installation of a filter that will remove any organic particulates.

Piping distribution network The piping material for USP water should be fabricated from either virgin polypropylene (PP), polyvinylidene fluoride (PVDF), or stainless steel (SS). Plastic pipe should be butt-joint heat fused, and SS pipe should be orbital welded. Piping material for WFI water should be SS, 180 grit, and electro-polished. Fittings shall have extended ends for orbital welding. All couplings shall be sanitary tri-clamp. Insulation shall be nonchloride bearing and designed for a temperature of 176°F (80°C). Velocity in the system should be approximately 6 to 9 fps (1.83 to 2.74 m/s) for supply from the storage tank to the system and 3 to 6 fps (0.91 to 1.83 m/s) in the return leg. Piping system design and pump selection is critical to ensure the correct velocity throughout the whole loop. The following is a "rule of thumb" formula used to select the correct pipe diameter:

$$V = \frac{\text{gpm}\left(\frac{L}{s}\right) \times 0.4085}{ID^2}$$

or

$$ID = \left[\frac{\text{gpm}\left(\frac{L}{s}\right) \times 0.4085}{V}\right]^{1/2}$$

where

V = Velocity, fps (m/s)
ID = Actual inside diameter, in. (mm)

(*Note*: Check for actual ID of various pipes based on schedules. Verify impact of various linings. Know the impact of surface finish inside pipe being considered.)

Pump selection can be made after pressure losses are calculated through the entire system. If a booster pump is required to keep the flow at the correct velocity, it is a far less costly investment than fixing a contaminated piping system.

The pipe shall be sloped at 1/8-in. (3.2 mm/m) pitch per foot to allow complete drainage of the network. Dead legs of more than 6 pipe diameters are not permitted by cGMP requirements. To prevent future plastic pipe sagging from interfering with drainage, continuous support is recommended. Using PP as a baseline, PVDF is twice the cost and SS four times the cost installed.

Valves shall be consistent with the piping materials. Prior to the RO or DI units, full-bore ball valves are recommended. In the purified loop, use SS diaphragm valves with an EPDM or Teflon diaphragm and a backing ring. Provide sample valves (usually needle type) at strategic points in the system to allow samples to be taken.

Pumps for purified water should be of sanitary design using a double mechanical seal with product

water as the lubricant for the seals. WFI pumps should be type 316L SS, 180 grit, and electro-polished. A casing drain should be provided.

System design considerations USP/WFI water is used in the pharmaceutical manufacturing process and often becomes part of the product. Because of this, all aspects of the purification system and distribution network are subject to inspection and validation by the FDA, which has the responsibility to determine if the quality of water used is adequate.

The FDA has specific guidelines for selection of stills and RO equipment used for production of WFI. In contrast, PW systems can utilize different types of purification equipment, since the microbial and chemical quality can vary depending on the proposed use of the water.

The purpose of any guidelines or standards is to verify all pertinent purity requirements of the equipment and distribution system conform to current good manufacturing practice (cGMP), are capable of consistently producing water of the required quality, and are capable of delivering water to the use point that meets the acceptance criteria for water coming in contact with product. This investigation also includes verification the purification equipment selected is capable of producing water of the required purity; the quality of installation for the distribution network produces a piping network capable of delivering water of the required quality to all outlets; and the continuing quality of system operation, maintenance, and ongoing testing will consistently provide water of the desired purity.

REFERENCES

1. Blake, Richard T. *Water treatment for HVAC and potable water systems.* New York: McGraw-Hill.
2. Brown, J., N. Jayawardena, and Y. Zelmanovich. 1991. Water systems for pharmaceutical facilities. *Pharmaceutical Engineering Magazine*. July/August: 14-23.
3. Cartwright, Peter S. 1994. Reverse osmosis and nanofiltration system design. *Plumbing Engineer*. March: 45-49.
4. Collentro, W.V. 1992. Pharmaceutical water (Parts 1 & 2). *Ultrapure Water Magazine*, November/December.
5. Denoncourt and Egozy. 1986. Trace level analysis of high purity water. *Ultrapure Water Magazine* July/August.
6. Dow Chemical Corp. *Water conditional manual*.
7. Dunleavy, M. 1991. Membrane technologies in the power industry. Paper presented at The Ninth Annual Membrane Technology/Planning Conference and Second High-Tech Separations Symposium, November, Newton, Massachusetts.
8. Frankel, M. .2002, Facility piping system handbook. New York: McGraw-Hill.
9. Gorry, M., P. Amin, and D.W. Richardson, Sr. 1994. Take the guesswork out of demineralizer design. *Chemical Engineering Magazine*. March: 112-116.
10. Janoschek, R., and G.C. du Moulin. 1994. Ultraviolet disinfection in biotechnology: Myth vs practice. *BioPharm Magazine*, January/February: 24-27.
11. Meyrick, C.E. 1989. Practical design of a high-purity water system. *Pharmaceutical Engineering Magazine*. September/October: 20-27.
12. Nalco Chemical Co. *The Nalco water handbook*. 2d ed. New York: McGraw-Hill.
13. Nussbaum, O.J. 1992. Treating cooling water. *Heating, Piping, Air Conditioning Magazine*. February: 67-63.
14. Otten, Gerald. 1992. Measuring water purity by specific resistance. *American Laboratory Magazine* July.
15. Parekh, B.S. 1991. Get your process water to come clean. *Chemical Engineering Magazine*. January: 71-85.
16. Sendelbach, M.G. 1988. Boiler water treatment. *Chemical Engineering Magazine.* August: 127-132.
17. Stenzel, Mark H. 1993. Remove organics by activated carbon adsorption. *Chemical Engineering Progress Magazine* April: 36-43.
18. Tanaka, T., et al. 1984. Disinfection of escherichia coli by using water dissociation effect on ion exchange membranes. In *Proceedings of the European-Japan Congress on Membrane and Membrane Processes*, June.
19. Yeh, K.L., and S.H. Lin. 1993. Looking to treat wastewater? Try ozone. *Chemical Engineering Magazine*. May: 113-116.
20. Paul, D. Pharmaceutical Waters, Ultrapure Water Magazine, 1999, pp 61-62

TRY ONE STOP SHOPPING

for your entire pump and control needs

and gain peace of mind with our 24/7 Emergency Service.

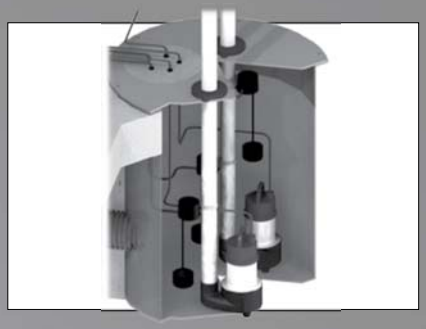
Domestic Water Booster Systems

Control Systems

Self Priming Systems

Housed Booster Systens

Break Tanks



Sump Pump Systems

For almost 50 years, Metropolitan Industries, Inc. has been the pumping world's single source for superior quality pumps, control systems, prefabricated systems and ancillary equipment for both the water and wastewater industries. We have the knowledge, experience and capability to tackle any pumping application related to the pumping industry.

We will back up our work with 24/7 service to give you that peace of mind you deserve.

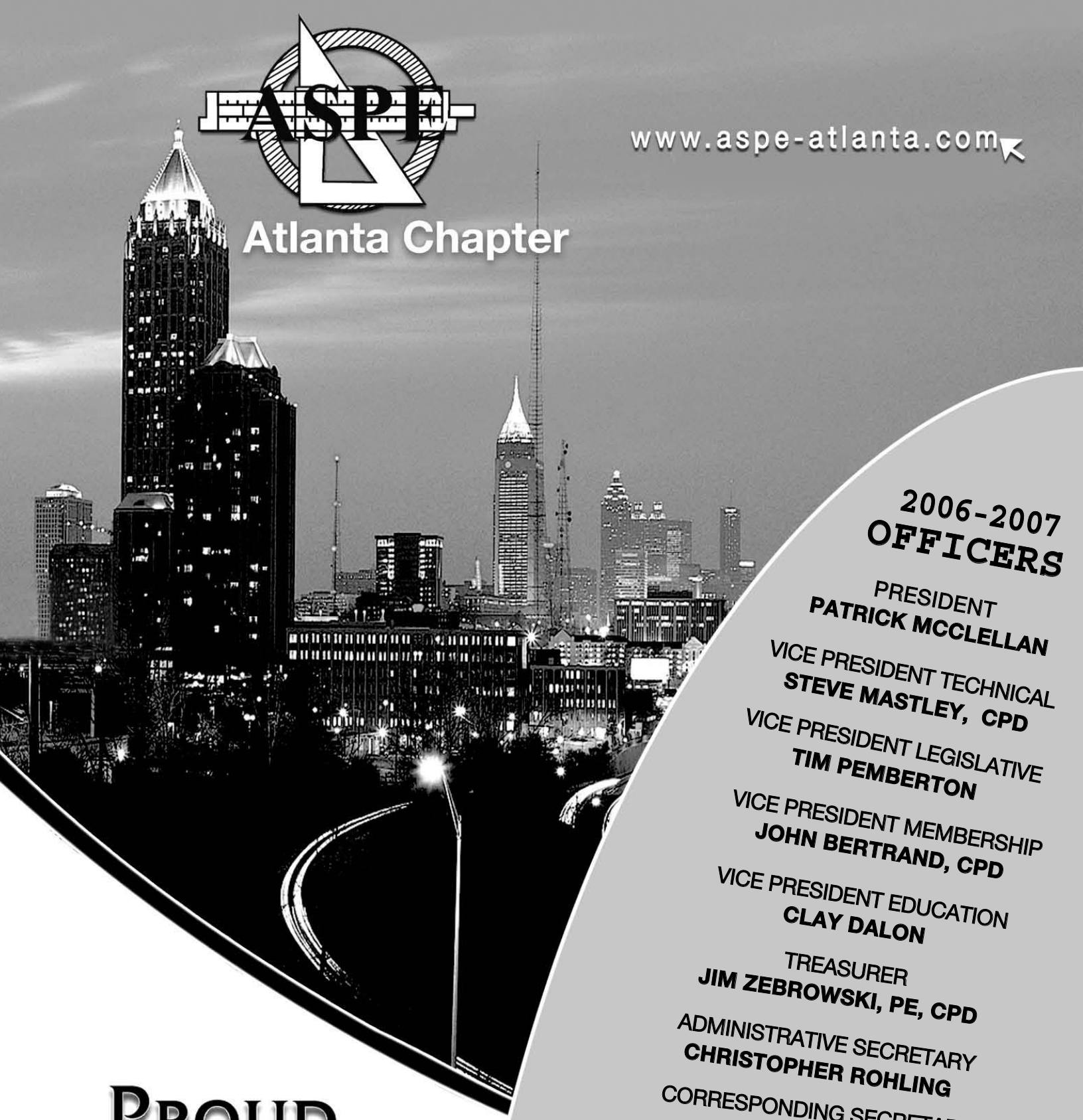
Choose Metropolitan for your next water or wastewater project and see how convenient one stop shopping can be!

Celebrating 50 Years of Service

The Pumping World's One Stop Shop

Metropolitan Industries, Inc.

37 Forestwood Drive, Romeoville, IL 60446
815-886-9200 • Fax 815-886-6932
www.metropolitanind.com



ASPE

Atlanta Chapter

www.aspe-atlanta.com

PROUD MEMBERS SINCE 1969

2006-2007 OFFICERS

PRESIDENT
PATRICK MCCLELLAN

VICE PRESIDENT TECHNICAL
STEVE MASTLEY, CPD

VICE PRESIDENT LEGISLATIVE
TIM PEMBERTON

VICE PRESIDENT MEMBERSHIP
JOHN BERTRAND, CPD

VICE PRESIDENT EDUCATION
CLAY DALON

TREASURER
JIM ZEBROWSKI, PE, CPD

ADMINISTRATIVE SECRETARY
CHRISTOPHER ROHLING

CORRESPONDING SECRETARY
JEROD MACKERT

AFFILIATE LIAISON
DOUG DYSON

CHAIR., BOARD OF GOVERNORS
STEVE MASTLEY, CPD

HISTORIAN
PAM IMMEKUS

WEBMASTER
JEROD MACKERT

12 Special-Waste Drainage Systems

INTRODUCTION

This chapter describes and discusses the collection and criteria necessary for the design of various special-waste drainage systems for liquid effluent other than discharge from sanitary and storm water sources. Except for the neutralization of acid effluent, the treatment methods are outside the scope of this chapter.

These systems are separated into categories with similar characteristics rather than grouped as discharge from specific facilities. The systems discussed are:

1. Acid-waste systems.
2. Radioactive-waste systems.
3. Biological and infectious-waste systems.
4. Chemical-waste systems.
5. Fire-suppression water drainage.

Each of these waste systems has unique properties that must be separately addressed. These systems generally route the waste from fixtures and equipment into a facility waste-treatment system, with the treated effluent discharging directly into the public sanitary-drainage sewer system. Very often, untreated waste is stored on site and collected by approved waste-removal contractors for disposal.

Unless specifically noted otherwise, all of the waste streams are assumed to have the approximate flow characteristics of water. Pipe sizing criteria are based on this assumption.

Refer to Vol. 2, Chapter 4 of the Plumbing Engineering Design Handbook (PEDH) a.k.a. Data Book for information on storm-drainage piping systems and to Vol. 2, Chapter 1 for information on sanitary-drainage piping systems.

CODES AND STANDARDS

There are two general jurisdictional bodies that regulate different aspects of special-waste systems. The first are local and regional authorities, who create and enforce plumbing and health codes. These include the local authorities charged with the review and approval of plumbing systems' design and discharge into the public sewer system. Although they are concerned with regulating the size and design of plumbing systems within a building, they also restrict the introduction of any type of waste into the sanitary sewer that may degrade the public sewer piping system or is incapable of being easily treated in the public waste-treatment facility.

The second, which have far more stringent regulations, are the various agencies concerned with protecting workers, the public, and the environment from the discharge of toxic substances. Included in this group are federal, state, and local authorities responsible for preventing toxic discharge of any substances considered harmful into the general environment, public sewers, and public treatment systems. Such discharges can occur either as a result of spills and accidents or by deliberate, illegal discharge. To prevent such discharge, it is common practice for these agencies to inspect facilities, mandate on-site facility treatment systems, and require the use of double-wall piping and leak detection to prevent and mitigate any leakage from piping.

Other regulations, such as current good manufacturing practice (cGMP) from the Food and Drug Administration (FDA), the regulations of the federal Environmental Protection Agency (EPA), and facility validation protocols, are constantly being revised due to technological and design changes.

It is recommended the services of an experienced environmental consultant, who is familiar with the latest applicable rules and regulations and their interpretations, be consulted for system compliance with the maze of regulations.

SYSTEM APPROVAL REQUIREMENTS

There is a distinction between drainage effluent that can be "locally" treated within a building (such as by biological waste sterilization, pH adjustment of

chemical waste, or oil separation) and other effluent that requires a larger and more complex waste-treatment system outside a building on site. Acceptance of such local treatment can be obtained only after conferences with the authorities responsible for issuing contamination limits for such a discharge. If the local treatment system provides the appropriate level of contaminant removal, direct discharge into the public sanitary sewer is acceptable. If the levels of contaminant removal are beyond the capability of such local treatment, a more sophisticated system that demonstrates removal of contaminants to the levels desired by the authority having jurisdiction must be chosen.

Any special drainage system effluent routed for treatment inside a facility or on site does not require examination or approval by the local plumbing official. If any effluent is routed to the public sewer system for eventual treatment, however, the discharge must conform with local regulations for maximum concentrations of any contaminant or pH levels. If the only required method of treatment is pH adjustment prior to discharging into the building sanitary drainage system or public sewer system, most authorities have requirements for acid drainage systems that must be followed. A pH value of 4.0 is generally viewed as the lowest acceptable level for direct discharge into a public sewer system.

PIPE MATERIAL AND JOINT SELECTION CONSIDERATIONS

Important factors in the selection of appropriate pipe material, gaskets, jointing methods, and other piping components for any special drainage system are cost, temperature of the effluent, the kind of chemicals, and the concentration of each that will enter the pipe. For some systems, the smoothness of the pipe interior or the lack of a crud trap are also important factors. This also applies to any associated vent system.

Selection is accomplished by first establishing the flow rate, temperature range, and concentration and composition of all effluent and chemicals that are expected. All pipe manufacturers have published chemical compatibility charts that give the effects of various chemicals on that particular pipe and recommendations for acceptance using these chemicals. For conditions not listed on these charts, the designer should make direct contact with the manufacturer of the material creating the anticipated conditions and ask for technical assistance.

When the compatibility of various pipe systems is the same, the total installed cost and possible ease of assembly are the deciding factors.

PIPE SIZING CONSIDERATIONS

System design is concerned only with the adequacy of the pipe to carry away the design flow. System configuration usually requires traps to be provided on fixtures and floor drains and the venting system conform to good plumbing design practice, which limits the pressure inside the system. All the elements of system design are left to the judgment of the design engineer.

The various plumbing codes generally use only satisfactory performance as a sizing guide for special-waste system pipe sizing, compared to specific drainage requirements mandated for sizing sanitary drainage systems. A common exception is for laboratory fixtures, which may require the drainage and vent systems to be sized on a fixture-unit basis.

The reason for the lack of code requirements is because special drainage systems do not have a predictable or documented usage history, as do standard plumbing fixtures in sanitary drainage systems. Equipment drainage, spills, discharge from production facilities, and discharge from fixtures within the facilities are not always planned. They occur mostly at random intervals dictated by cleaning, production, maintenance schedules, and, often, accidents.

In addition, special drainage systems completely within the property of the facility do not fall under plumbing code requirements for piping size or design, although they may fall under the jurisdiction of agencies such as the EPA. Because of these factors, the special drainage piping system is sized on the basis of "good engineering practice," which uses system slope, composition of the effluent, and expected flow rates rather than fixture units.

From each point in the system, the flow rate and pitch of the piping must be known to size the pipe. Pipe size should be determined based on the following criteria:

1. Effluent has the characteristics of water. (If the effluent contains large concentrations of solids, the pitch should be adjusted accordingly.)
2. The drainage system is sized on the basis of gravity drainage and maintenance of a minimum velocity of 2 feet per second (fps) (0.61 m/s), using the anticipated maximum flow rate and pitch of the pipe at each point of design and a maximum velocity of 10 fps (3.05 m/s) if the waste contains any solids.
3. Gravity drainage pipe size is based on flow rate, slope, and velocity. Refer to Table 12-1 to find the velocity and size of pipe based on flow rate and slope. Depending on the system, piping should be sized to flow between ½ to ¾ full to allow for unexpected larger discharges, future changes, and accidents.

PH DEFINITION

Any dissolved impurity in water separates to form negatively and positively charged atoms called "ions." Negative ions are called "cations" because they migrate to the cathode, and positive ions are called "anions" because they migrate to the anode.

All acid compounds consist of hydrogen combined with an acid radical. In a mixture of acid and water, hydrogen ions result. pH is a measurement of the hydrogen ion concentration of a solution. Since the balance of hydroxyl (cation) and hydrogen (anion) ions must be constant, changes in one ion concentration produce corresponding changes in the other. The pH value is calculated from the logarithmic reciprocal of the hydrogen ion concentration in water. The pH scale ranges from 0 to 14, with 0 being acid and 14 being alkaline; 7.0 is neutral. A change of one unit represents a tenfold increase (or decrease) in strength. pH is not a measure of alkalinity.

GENERAL SYSTEM DESIGN CONSIDERATIONS

It is good practice to separate each of the different systems inside the facility or building to a point outside the building so the individual services can be isolated and allowed to be tested and sampled as may be required in the future by any local or national authority. Another reason is the system may, at some point in the future, require separate treatment because of a new substance that may be discharged.

One of the more constant aspects of special drainage systems is future change. In time, the processes will change, equipment will be more efficient, facilities will become larger, and technology will be improved so the effluent will be different than it is at the time a system is originally designed. This change must be allowed for. It is common practice to size the drain one size larger than the design figures indicate or not to size the drain line to the exact point on the sizing chart indicated by the figures, especially where there is a probability of future expansion.

Consideration should be given to selecting a pipe size slightly larger than required for the immediate flow rate or a material capable of resisting a greater selection of chemicals than necessary at the time of design. This must be verified with the client, of course, to ensure the extra cost incurred by these options is acceptable.

ACID-WASTE DRAINAGE AND VENT SYSTEMS

General

An acid-waste drainage system collects and transports liquid wastes with a pH lower than 7.0 from laboratory fixtures, equipment, and all areas of a facility for discharge into an appropriate treatment facility or the sanitary drainage system after local treatment. The vent system equalizes flow in the drainage system in the same manner it does in a sanitary drainage system.

For the purposes of this chapter, acid waste is divided into two general categories: laboratory waste and industrial waste. Laboratory waste consists primarily of dilute and concentrated mixtures of liquid chemical substances of mineral and organic origin and water. Many types of acid are usually present. Laboratory waste is discharged from sinks, cup sinks, fume hoods, and other similar fixtures and equipment. Discharge from floor drains, autoclaves, and glass washers, and condensed water from various sources are also included.

Acid waste from industrial facilities consists of waste from accidental spills originating from tanks and piping, and anticipated waste discharged from equipment into drains. Very often, the drainage piping has to carry any of the acids used as part of the process. Where spills are directed into holding tanks, the drainage piping, tanks, pumps, and piping necessary to convey the effluent to treatment facilities is normally part of the plumbing engineer's responsibility.

The most important considerations in the selection of piping, valves, drains, and tanks for acid are the concentration and temperature of the acid. Acid waste water from chemical and other facilities must be neutralized to a pH of 4.0 or higher prior to discharge into the sanitary system.

Health and Safety Concerns

All grades and concentrations of acids can cause severe damage to the eyes and tissues of the body. Contact with the eyes can cause blindness. Contact with the skin causes irritation and burns. Inhaling the mist or vapors can cause lung irritation or burns. Ingestion destroys tissues of the mouth, throat, and stomach.

Extreme care should be exercised in the handling and cleanup of all acids. This mandates emergency drench equipment to be provided immediately adjacent to all hazards and locations where spills and other accidents could occur. If several people are normally present at a hazardous location, multiple pieces of drench equipment should be provided. Where fumes may be given off, emergency breathing apparatus must be provided.

For the laboratory environment, emergency showers shall be provided immediately outside every room. Where rooms are adjacent, a single shower is acceptable. Floor drains are not required but prevent the floor surrounding the shower from becoming wet and hazardous. Every room shall have an emergency

Table 12-1 Drainage Pipe Sizing

Pipe size	Grade		½ Full			⅔ Full			Full		
			Discharge		Velocity	Discharge		Velocity	Discharge		Velocity
(in.)	(in./ft)	(%)	(gpm)	(cfs)	(ft/s)	(gpm)	(cfs)	(ft/s)	(gpm)	(cfs)	(ft/s)
2	⅛	1.0	7	0.02	1.3	10	0.02	1.5	13	0.03	1.3
	¼	2.1	9	0.02	1.8	14	0.03	2.0	18	0.04	1.8
	½	4.2	14	0.03	2.9	22	0.05	3.2	28	0.06	2.9
	1	8.3	20	0.05	4.0	32	0.07	4.5	40	0.09	4.0
3	⅛	1.0	18	0.04	1.7	29	0.06	1.9	36	0.08	1.7
	¼	2.1	26	0.06	2.4	41	0.09	2.7	51	0.11	2.4
	½	4.2	40	0.09	3.7	64	0.14	4.1	80	0.18	3.7
	1	8.3	57	0.13	5.3	90	0.20	5.9	114	0.25	5.3
4	⅛	1.0	39	0.09	2.0	61	0.13	2.2	77	0.17	2.0
	¼	2.1	55	0.13	2.8	87	0.20	3.1	110	0.25	2.8
	½	4.2	87	0.20	4.5	138	0.31	5.0	174	0.39	4.5
	1	8.3	123	0.28	6.3	194	0.44	7.1	245	0.55	6.3
6		0.5	79	0.18	1.8	124	0.28	2.0	157	0.35	1.8
	⅛	1.0	1 10	0.25	2.5	174	0.39	2.8	220	0.49	2.5
		1.5	135	0.30	3.1	213	0.47	3.5	269	0.60	3.1
	¼	2.1	157	0.35	3.6	248	0.55	4.0	314	0.70	3.6
		2.5	175	0.39	4.0	277	0.62	4.5	350	0.78	4.0
	⅜	3.1	193	0.43	4.4	305	0.68	4.9	386	0.86	4.4
		3.5	207	0.46	4.7	327	0.73	5.3	413	0.92	4.7
	½	4.2	225	0.50	5.0	355	0.79	5.6	449	1.00	5.0
	⅝	5.2	247	0.55	5.6	391	0.87	6.3	494	1.10	5.6
	¾	6.3	270	0.60	6.1	426	0.95	6.8	539	1.20	6.1
	⅞	7.3	292	0.65	6.6	461	1.03	7.4	583	1.30	6.6
8		0.2	108	0.24	1.6	170	0.38	1.8	215	0.48	1.6
		0.4	153	0.34	2.0	241	0.54	2.2	305	0.68	2.0
		0.6	191	0.43	2.4	302	0.67	2.7	382	0.85	2.4
		0.8	236	0.53	2.9	372	0.83	3.2	471	1.05	2.9
	⅛	1.0	247	0.55	3.2	391	0.87	3.6	494	1.10	3.2
		1.5	303	0.68	3.8	479	1.07	4.3	606	1.35	3.8
	¼	2.1	348	0.78	4.5	550	1.22	5.0	696	1.55	4.5
		2.5	392	0.88	4.9	621	1.38	5.5	785	1.75	4.9
	⅜	3.1	427	0.95	5.4	674	1.50	6.0	853	1.90	5.4
		3.5	449	1.00	5.8	710	1.58	6.5	893	2.00	5.8
	½	4.2	494	1.10	6.2	780	1.74	6.9	987	2.20	6.2
	½	4.5	516	1.15	6.6	816	1.82	7.4	1032	2.30	6.6
10		0.2	211	0.47	1.7	334	0.74	1.9	422	0.94	1.7
		0.4	303	0.68	2.4	479	1.1	2.7	606	1.35	2.4
		0.6	359	0.80	2.9	568	1.3	3.2	718	1.60	2.9
		0.8	438	0.98	3.5	692	1.5	3.9	875	1.95	3.5
	⅛	1.0	472	1.05	3.8	745	1.7	4.3	943	2.10	3.8
		1.5	561	1.25	4.5	887	2.0	5.0	1122	2.50	4.5
	¼	2.1	651	1.45	5.3	1029	2.3	5.9	1302	2.90	5.3
		2.5	741	1.65	5.7	1170	2.6	6.4	1481	3.30	5.7
	⅜	3.1	808	1.80	6.4	1277	2.8	7.2	1616	3.60	6.4
		3.5	853	1.90	6.8	1348	3.0	7.6	1706	3.80	6.8

eyewash inside the room, usually mounted on a sink or free standing if sink mounting is not practical.

Where vapor is possible, fog nozzles using water to suppress the vapor and foam systems to prevent vapor from rising should be considered.

Common Types of Acid

Acids are widely used chemicals in the chemical processing industry. The most commonly used acids are:

Sulfuric acid (H_2SO_4) Sulfuric acid, among the most commonly used acids, is commercially available in many concentrations and as various percentages of oleum. "Oleums" are sulfuric acids containing sulfur trioxide dissolved in the acid, which are called "fuming" grades. Generally recommended piping materials for these acids at low temperatures (140°F [60°C] and lower) and up to 90% concentration are PVC (polyvinyl chloride), CPVC, PP, PVDF, ETFE, and HDPE plastic; glass; alloy 20; duriron; and FRP (fiberglass-reinforced plastic) piping with special resins. At 90% and higher concentrations, carbon steel schedule 80 is often used. Stainless steel is generally unsuitable, except for oleum with less than 10.3% concentration. Vent lines should be of the same material used for the drain line.

Valve types include ball, gate, and diaphragm, with gate valves being the most commonly used. For low pressures and temperatures suitable for specific plastic pipes, plastic is often used. For higher tem-

Table 12-1(M) Drainage Pipe Sizing

Pipe size	Grade		½ Full			⅔ Full			Full		
			Discharge		Velocity	Discharge		Velocity	Discharge		Velocity
(mm)	(cm/m)	(%)	(L/s)	(m3/s)	(m/s)	(L/s)	(m3/s)	(m/s)	(L/s)	(m3/s)	(m/s)
50	1.04	1.0	0.44	0.57	0.40	0.63	0.57	0.46	0.82	0.85	0.40
	2.08	2.1	0.57	0.57	0.55	0.88	0.85	0.61	1.14	1.13	0.55
	4.16	4.2	0.88	0.85	0.88	1.39	1.42	0.98	1.77	1.70	0.88
	8.32	8.3	1.26	1.42	1.22	2.02	1.98	1.37	2.52	2.55	1.22
80	1.04	1.0	1.14	1.13	0.52	1.83	1.70	0.58	2.27	2.27	0.52
	2.08	2.1	1.64	1.70	0.73	2.59	2.55	0.82	3.22	3.12	0.73
	4.16	4.2	2.52	2.55	1.13	4.04	3.96	1.25	5.05	5.10	1.13
	8.32	8.3	3.60	3.68	1.62	5.68	5.66	1.80	7.19	7.08	1.62
100	1.04	1.0	2.46	2.55	0.61	3.85	3.68	0.67	4.86	4.81	0.61
	2.08	2.1	3.47	3.68	0.85	5.49	5.66	0.94	6.94	7.08	0.85
	4.16	4.2	5.49	5.66	1.37	8.71	8.78	1.52	10.98	11.04	1.37
	8.32	8.3	7.76	7.93	1.92	12.24	12.46	2.16	15.46	15.58	1.92
150		0.5	4.98	5.10	0.55	7.82	7.93	0.61	9.91	9.91	0.55
	1.04	1.0	6.94	7.08	0.76	10.98	11.04	0.85	13.88	13.88	0.76
		1.5	8.52	8.50	0.94	13.44	13.31	1.07	16.97	16.99	0.94
	2.08	2.1	9.91	9.91	1.10	15.65	15.58	1.22	19.81	19.82	1.10
		2.5	11.04	11.04	1.22	17.48	17.56	1.37	22.09	22.09	1.22
	3.12	3.1	12.18	12.18	1.34	19.25	19.26	1.49	24.36	24.36	1.34
		3.5	13.06	13.03	1.43	20.63	20.67	1.62	26.06	26.05	1.43
	4.16	4.2	14.20	14.16	1.52	22.40	22.37	1.71	28.33	28.32	1.52
	5.2	5.2	15.59	15.58	1.71	24.67	24.64	1.92	31.17	31.15	1.71
	6.3	6.3	17.04	16.99	1.86	26.88	26.90	2.07	34.01	33.98	1.86
	7.3	7.3	18.43	18.41	2.01	29.09	29.17	2.26	36.79	36.82	2.01
200		0.2	6.81	6.80	0.49	10.73	10.76	0.55	13.57	13.59	0.49
		0.4	9.65	9.63	0.61	15.21	15.29	0.67	19.25	19.26	0.61
		0.6	12.05	12.18	0.73	19.06	18.97	0.82	24.10	24.07	0.73
		0.8	14.89	15.01	0.88	23.47	23.51	0.98	29.72	29.74	0.88
	1.04	1.0	15.59	15.58	0.98	24.67	24.64	1.10	31.17	31.15	0.98
		1.5	19.12	19.26	1.16	30.22	30.30	1.31	38.24	38.23	1.16
	2.08	2.1	21.96	22.09	1.37	34.71	34.55	1.52	43.92	43.90	1.37
		2.5	24.74	24.92	1.49	39.19	39.08	1.68	49.53	49.56	1.49
	3.12	3.1	26.94	26.90	1.65	42.53	42.48	1.83	53.82	53.81	1.65
		3.5	28.33	28.32	1.77	44.80	44.75	1.98	56.35	56.64	1.77
	4.16	4.2	31.17	31.15	1.89	49.22	49.28	2.10	56.60	62.30	1.89
		4.5	32.56	32.57	2.01	51.49	51.54	2.26	65.12	65.14	2.01
250		0.2	13.31	13.31	0.52	21.08	20.96	0.58	26.63	26.62	0.52
		0.4	19.12	19.26	0.73	30.22	31.15	0.82	38.24	38.23	0.73
		0.6	22.65	22.66	0.88	35.84	36.82	0.98	45.31	45.31	0.88
		0.8	27.64	27.75	1.07	43.67	42.48	1.19	55.21	55.22	1.07
	1.04	1.0	29.78	29.74	1.16	47.01	48.14	1.31	59.50	59.47	1.16
		1.5	35.40	35.40	1.37	55.97	56.64	1.52	70.80	70.80	1.37
	2.08	2.1	41.08	41.06	1.62	64.93	65.14	1.80	82.16	82.13	1.62
		2.5	46.76	46.73	1.74	73.83	73.63	1.95	93.45	93.46	1.74
	3.12	3.1	50.98	50.98	1.95	80.58	79.30	2.19	101.97	101.95	1.95
		3.5	53.82	53.81	2.07	85.06	84.96	2.32	107.65	107.62	2.07

peratures and pressures, alloy 20 is preferred. In all cases, because of differences in manufacturing, pipe vendors should be consulted as to the suitability of materials for specific acid piping service.

Centrifugal pumps constructed of SS alloy 320 with Teflon packing are in common use. Other manufacturers use FRP and plastic pumps. Also available are metallic pumps lined with plastic or glass. Temperature limits should be carefully checked for material suitability.

Spills of concentrated acids from tanks onto floors and equipment should be washed off and flooded with water, which is then routed to the acid drainage system for neutralization. Tanks used to contain this spillage should be of a suitable plastic. Since water reacts rapidly with the acid and splatters, caution should be exercised. Heat and fumes are also given off. Breathing the fumes causes throat and lung injury. Where this situation is possible, suitable emergency breathing apparatus should be provided. An emergency shower should be provided in the immediate vicinity of acid storage and pipe routing.

Sulfuric acid is nonflammable, but it is highly reactive. Below a concentration of 75% it reacts with carbon steel and other metals to form hydrogen. It is particularly hazardous when in contact with carbides, chlorates, nitrates, fulminates, picrates, and powdered metals. In higher concentrations it will ignite combustible materials, such as oily rags and

sawdust. Dry chemicals or carbon dioxide are the fire-suppression methods of choice.

Because of the danger of fumes, oleum spills should be contained by curbs and the liquid diverted away from the area of a spill to a containment area, where the liquid can be neutralized. The resulting liquid should be absorbed with diatomaceous earth, expanded clay, or other nonreactive material. This material should be carted away for suitable disposal.

Phosphoric acid (H_3PO_4) Phosphoric acid is available in concentrations of between 75 and 87%. Recommended pressure piping is SS type 316 extra low carbon (ELC) and CPVC Sch 80. The drainage and vent piping, valves, and pumps are similar to those used for sulfuric acid. The Occupational Safety and Hazard Administration (OSHA) has limits for human exposure to this acid.

Precautions for spills and safety and health concerns are similar to those for sulfuric acid.

Hydrochloric acid (HCl) Hydrochloric acid, also known as "muriatic acid," is available in four strengths, designated as degrees Baume (an equivalent notation of specific gravity).

Piping materials for drainage and vent piping, valves, and pumps are PVC, CPVC, PP, polyvinylidene fluoride (PVDF), glass, high silicon cast iron (HIS), or fiberglass-reinforced plastic (FRP). Precautions and procedures for spills and safety and health concerns are similar to those for sulfuric acid, except that caustic soda should not be used because hydrochloric acid reacts with this chemical.

Nitric acid (HNO_3) Nitric acid is available in three grades, designated by the percent of concentration by weight: 56-70, 70-84, and 97.5-100%.

Recommended pressure piping material for concentrations up to 95% is 304L SS. CPVC is acceptable up to 70% concentrations at 73°F (22.8°C). Above this concentration, aluminum piping is recommended. Pumps for concentrations up to 95% should be constructed of 304L SS. Above this concentration, titanium, aluminum type 3003 or silicon iron are commonly used. Recommended materials for gate, ball, plug, and globe valves are 347 SS or 304L SS. Drain lines should be glass.

Precautions and procedures for spills and safety and health concerns are similar to those for sulfuric acid, except temperature and humidity have an effect on the reaction of nitric acid on such metals as copper, brass, and zinc. Nitric acid reacts violently with organic substances, occasionally causing explosions. A self-contained breathing apparatus is required for approaching spills because of the emission of nitrogen oxides, commonly called "nitrous fumes," which are extremely hazardous.

Hydrobromic acid (Hbr) Hydrobromic acid is commercially available in two concentrations: 70 and 99.95%.

Recommended pressure piping materials are glass and rubber-lined steel pipe, PVC, PE (poly ethylene), and PTFE (polytetrafloroethylene). In addition to the pressure piping, glass pipe could be used for drainage. Valves are often ball and plug type with PVC, PE, and PTFE lining. Rubber-lined pinch valves are commonly used. Pumps are similar to those used for sulfuric acid, with the addition of Hastelloy B material.

Precautions and procedures for spills and safety and health concerns are similar to those for phosphoric acid, but the vapors are much more hazardous. This acid reacts with metals and produces explosive hydrogen gas.

Perchloric acid ($HClO_4$) Perchloric acid is available in a concentration of 69-72% strength and is the strongest of all the inorganic acids.

Recommended pressure piping materials are glass and PTFE, and CPVC Sch 80. Drain lines can be glass or CPVC Drainage DWV. Valves are often ball-and-plug type manufactured from PTFE and duriron. Pumps manufactured from PTFE are the most commonly used.

Precautions and procedures for spills and safety and health concerns are similar to those for phosphoric acid, except when heated to 150°F (69°C), perchloric acid can cause objects not normally considered combustible, such as rubber gloves and human skin, to burst into flames.

Selection of Laboratory Waste Piping and Joint Material

The majority of the effluent from an "average" laboratory consists primarily of water and acid. If toxic to the staff, chemicals used for experiments are usually confined to fume hoods. The designer should obtain information regarding the extent and concentration of all the chemicals expected to be used in the laboratory from the end user.

The most cost-effective above-the-floor piping from laboratory fixtures is generally fire-retardant polypropylene with either heat-fused socket or "screwed mechanical" type joints, or CPVC DWV with special solvent cement. Other acceptable materials are glass with compression joints and high-silicon cast iron with caulked or compression gasket joints. Although PVC has the lowest initial cost, they also have a limited range of chemical compatibility, with PVC having a low temperature rating. PTFE is resistant to the widest variety of chemicals and has the highest temperature rating and highest cost. CPVC is suitable to 210 ° F (98.9 °C), and is resistant to a wide variety of chemicals, but has a higher cost.

Piping underground, subject to local codes, could also be polypropylene with heat-fused socket joints

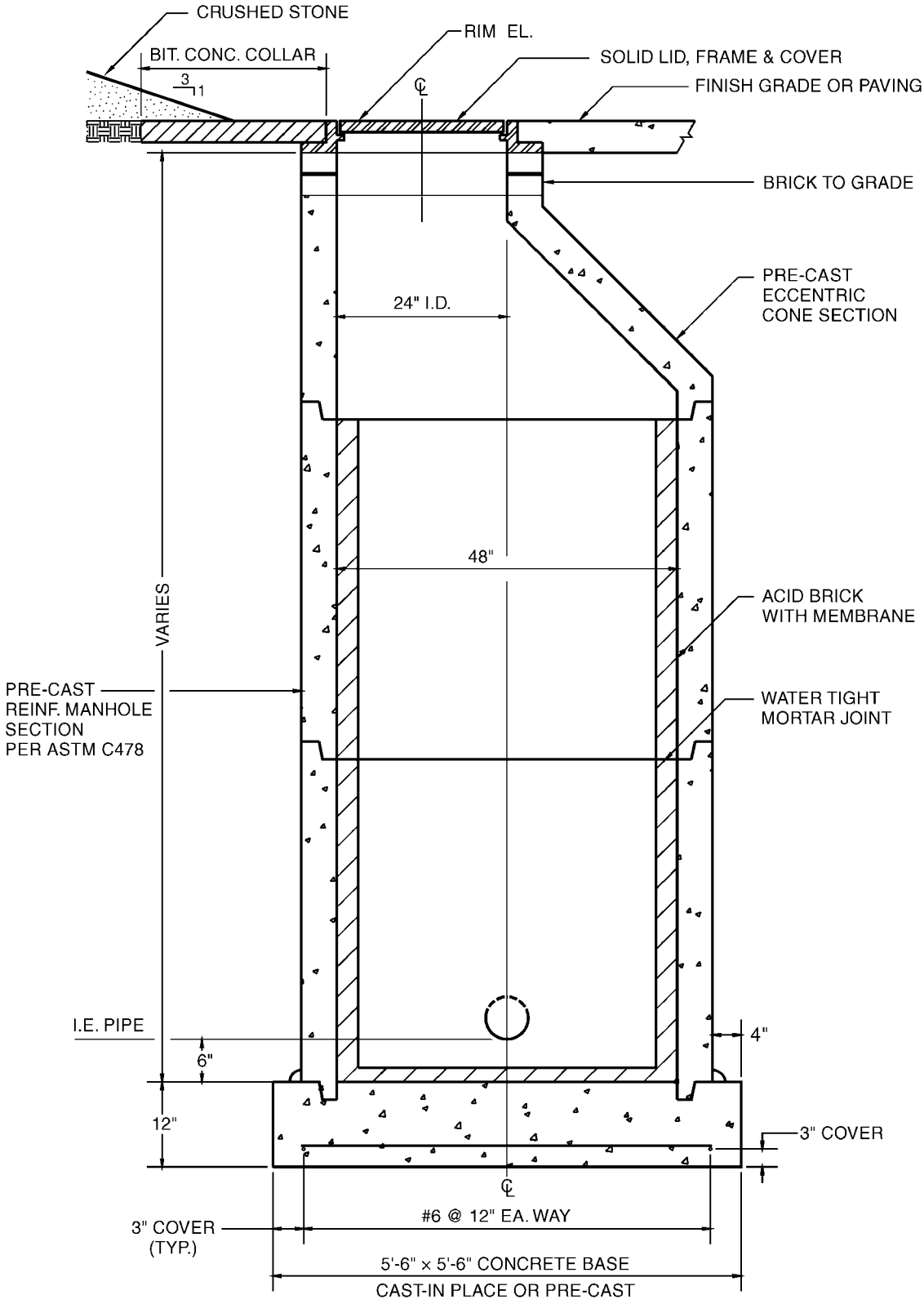


Figure 12-1 Typical Acid-Resistant Manhole

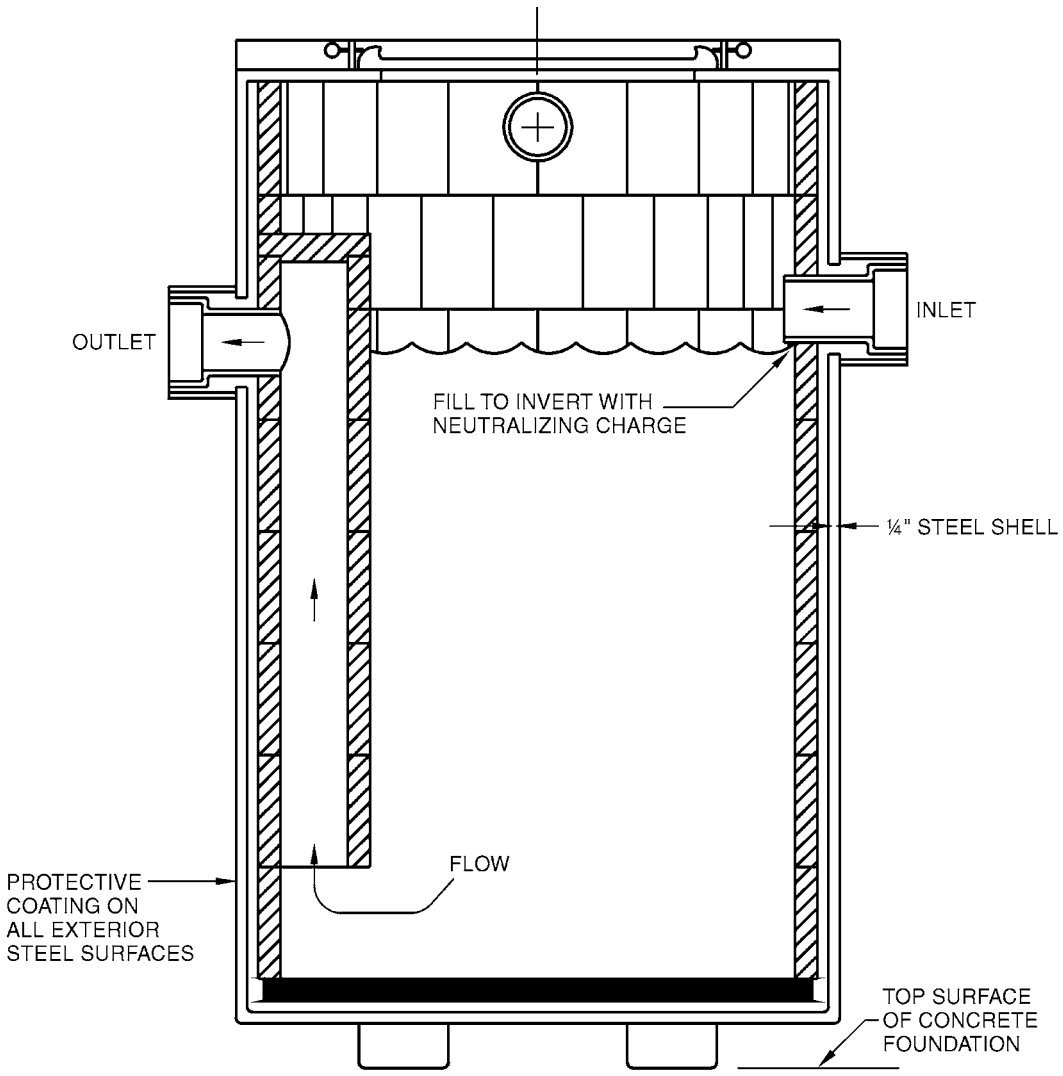


Figure 12-2 Typical Large Acid-Neutralizing Basin

or high-silicon cast iron with compression gasket joints. Glass piping should be encased in a sleeve of polyethylene for protection.

Vent pipe shall be the same material as the drain pipe. The vent shall be carried up to above the roof level. Vent piping penetrating the roof shall not be glass. An adapter should be used and any other acceptable acid-resistant pipe material should be provided through the penetration.

System Design Considerations

General system design considerations for the laboratory drainage system shall be the same as those for the sanitary drainage system, including placement of cleanouts. Each fixture shall be individually trapped and vented. Clean water, such as is discharged from air compressors and other condensate drains, can also spill into the laboratory drainage system when convenient. Because of possible stoppages that could flood all the piping, the entire laboratory waste system shall be of the same acid-resistant piping material.

Where the only waste discharge is from laboratory fixtures, the use of fixture-unit schedules for pipe sizing is acceptable, except simultaneous use should be factored into the sizing process. When the effluent is expressed in gallons per minute (gpm) (liters per second [L/s]) from a known discharge, base the size on this gpm (L/s) and the equivalent gpm (L/s) from the fixtures. The pipe shall be sized using the pitch and a ¾-full pipe.

The laboratory drainage and vent system shall be separate from all other systems until the effluent is adequately treated; it may then be combined on the site with other waste lines. If a manhole is required in the acid waste line, it should be acid resistant. A typical acid-resistant manhole is illustrated in Figure 12-1.

Acid Waste Treatment

All acid waste requires neutralization to a pH of between 7.5 and 4.0 before it is permitted to be discharged into any public sewer for disposal. Commonly accepted practice permits local authorities to

allow primary-treated effluent to discharge directly into the public sanitary sewer system after only pH treatment. The most often-used primary procedures are direct, continuous contact with limestone chips in an acid-neutralizing basin or continuous or batch treatment in an automated neutralization system utilizing chemical feed neutralizing.

An acid-neutralizing basin operates on the principle of a chemical reaction between the acid and the limestone chips. Each basin shall be designed by the manufacturer to allow sufficient contact time for the chemical reaction to accomplish complete neutralization based on the maximum flow rate anticipated. Average figures show 100 lb (45 kg) of limestone chips treat 97 lb (44 kg) of sulfuric acid and 75 lb (34 kg) of hydrochloric acid. Effluent consisting mostly of sulfuric acid should be treated with dolomite limestone chips.

For general laboratory waste, several methods of treatment using limestone chips are available. For single isolated sinks, an acid-neutralizing trap should be considered. For a small number of sinks in a cluster, a shelf-mounted, small-diameter basin could be used. It should be confined to treating the discharge of acids from a small number of fixtures and in remote locations or for individual sinks where the timely maintenance needed to fill the basin may be questionable. Larger basins, such as the one illustrated in Figure 12-2, are available to treat the effluent from a large number of laboratory sinks. If the discharge of oil or grease is expected in the laboratory waste stream, the installation of an interceptor basin before the acid sump is recommended. Some objectionable contaminants can coat individual chips and prevent proper chemical action to neutralize the acid.

For a larger number of fixtures or equipment and where treatment by limestone chips alone is not practical, a system consisting of single or multiple basins and/or a mixing tank should be installed. If this is located at a low level, a pump is required to bring the discharge up to the level of the sewer. A sophisticated arrangement of probes, chemical feed pumps, level indicators, and alarms is required. An agitator or mixer may be installed in the basin to mix the acid with the caustic. The addition of a recorder may be desired. The acid-neutralizing system operates on the principle of automatically adding proper amounts of caustic to the incoming acid waste, thereby neutralizing the acid. The probe is connected to an automatic caustic feed pump that introduces the proper amount of neutralizing liquid into the basin or mixing tank. The most commonly used neutralizing chemical is caustic soda. Continuous treatment may also require additional downstream sensing probes and chemical additive locations to ensure the discharge is within acceptable limits. Figure 12-3 illustrates a typical continuous waste-treatment system. Various manufacturers have numerous proven and successful methods of acid treatment.

It is good engineering practice to have the discharge from the neutralizer separately routed into the sanitary house drain outside of a building for dilution prior to discharge into the public sewer. This may also be necessary in order for local authorities to monitor the waste stream without having to enter a building.

For preliminary determination of the number of sinks required for average laboratories, allow 1 sink for each 200 ft^2 (18.6 m^2) of laboratory area. Each sink will discharge 1 gpm (3.8 L/min). Cup sinks will discharge 0.5 gpm (1.9 L/min). For a maximum flow rate, assume 50% of the sinks could discharge simultaneously.

RADIOACTIVE WASTE DRAINAGE AND VENT SYSTEM

General

Commercial facilities can be characterized by low quantities and levels of radioactive waste, and therefore, have a lesser set of regulatory requirements than nuclear power plants. Because of the small amount of radioactive material present at commercial type facilities, larger storage and treatment systems are not provided, and severe safety requirements are not necessary. Facilities having higher quantities of radioactive material and levels of radiation fall under a different, much more stringent set of regulatory requirements than commercial or institutional projects. For such facilities, the submission of documentation for the protection of the public and workers in the event of an accident are considerably more complex. The principles of drainage system design apply to all kinds of system.

The requirements for handling radioisotopes in laboratories are essentially no different than the requirements for handling toxic chemicals or pathogens, with the exception of providing radiation shielding if necessary. The ideal goal is to totally eliminate the exposure of workers, staff, and the general public. Since this is not realistic, it is required not only to prevent overexposure but to keep any exposure to radiation as low as is reasonably achievable. The design shall implement criteria that eliminate or reduce to allowable levels the radiation exposure of workers and maintenance personnel and prevent exposure of the general public to unacceptable amounts of radiation by waterborne radioactive waste ("radwaste").

The Nature of Radiation

"Radioactivity" is the spontaneous emission of "harmful" particles from the unstable nucleus of an atom. There are many intermediate steps in the

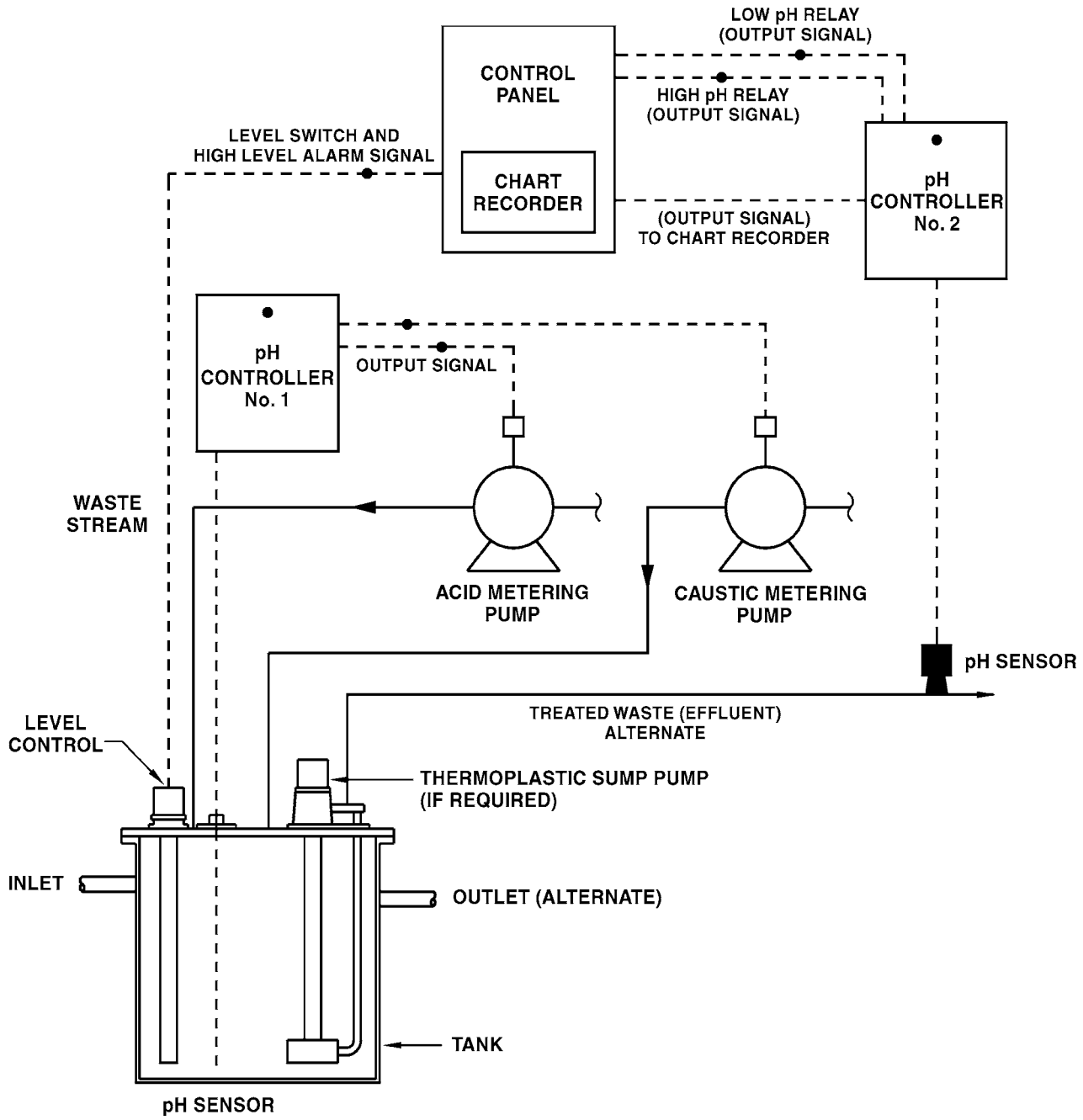


Figure 12-3 Typical Continuous Acid-Waste Treatment System

stabilization cycle, including the formation of other, less complex, radioactive byproducts called "isotopes." These byproducts, in turn, decay to form other unstable isotopes as the cycle continues. The end result is a highly stable element. For example, the end product of uranium is lead. One of the intermediate byproducts of uranium is radon.

"Radiation" is a general term meaning any or all of the following; alpha rays, beta rays, gamma rays, neutrons, x-rays, and other atomic particles. There are three general classifications of radiation of concern, namely, alpha, beta, and gamma. Alpha radiation is actually a helium atom with a high velocity. Beta radiation is an electron with a high velocity. Gamma radiation is a particle similar to a photon, which is light. Alpha and beta radiation can generally be stopped by the skin or clothing, paper, or another similar, light material. Alpha loses energy very quickly in air and is no practical concern for distances greater than 12 in. (305 mm). High-energy beta radiation is commonly contained by only 1 in. (25 mm) of solid, dense plastic. Beta is denser, carries more energy greater distances than alpha, and will burn bare skin and, in particular, damage the eye but will generally

not penetrate into the body to cause any internal damage. The greatest danger with beta radiation is to the eyes, particularly when the eye is directly exposed close to the source.

Gamma radiation is electromagnetic in nature. It carries the most energy and therefore is the most dangerous to humans. Its wavelength is shorter than light waves. When generated, it is similar to x-rays and behaves in a manner similar to light waves. When released from a source, gamma rays have a mass and velocity that has a measurable energy potential.

Radiation Measurement

"Radioactivity" is a general term used for the total release of radiation of all types from a source. Its measurement is in disintegrations per second (dps). This measurement is possible for gamma radiation because in most radioactive materials dps also produces a known amount of gamma radiation. However, the best manner of measuring gamma radiation is to measure the energy it produces per kilogram (pound) of air. Because the instruments needed to measure radiation in this way are very expensive, it is not widely used outside of the laboratory. The so-called Geiger-Mueller counter is the most common device for measuring radiation. It measures the penetration of the particles entering into a tube, where the particles react with a gas in the tube creating a measurable electrical charge. If an amplification device is used, it can be heard in the form of static. The more modern instruments have a digital readout.

Units of radiation Particulate radiation is measured by the number of disintegrations per unit of time. A curie (c) is equal to 3.7×1010 dps. One millicurie (mc) is 0.001 c, or 3.7×107 dps. One rad is defined as the dose corresponding to the absorption of 100 ergs/gram of tissue. A Roentgen measures ions carrying a total of 2.58×104 coulombs (C) of electrical energy.

Since the term "radiation" is a general one, a more specific method must be used to measure its effect on humans. The measurement is called a "dose" and is defined as the total quantity of radiation absorbed by the body or any portion of the body. Much of the time, the dose is modified by reference to a unit of time. This differs from radioactivity because all radiation is not absorbed by the body.

A "rad" is a measure of the dose to body tissue in terms of energy absorbed per unit mass. Gamma radiation is the type of radiation most commonly measured this way.

The most important measurement is the "radiation equivalent to man," or "rem." A "rem" is the measure of ionizing radiation passing through or absorbed by the body in terms of the biological effect relative to a dose of 1 roentgen of x-rays. The relation of the rem to other dose units depends upon the actual biological effect to the particular part of the body being studied and the actual conditions and amount of time of the irradiation. One rem is the equivalent of 1 roentgen due to x or gamma radiation, and also 1 rad due to x, gamma, or beta radiation. One rem of high-flux neutrons is roughly equivalent to 14 million neutrons per square centimeter (cm^2) incident to the body.

Allowable Radiation Levels

Many scientists believe there is no exact radiation level that is certain to cause any individual permanent harm. Many other scientists believe there is no level that is harmless.There is no agreement on the level. There is a term called "background level of radiation" that exists all over the world. The most common source of this is the sun, and it is called "cosmic radiation." In addition, many substances, such as fly ash from burning organic fuels (particularly coal), granite, and many other natural substances contain trace isotopes of elements, emit radiation. One of the most common of these trace elements is carbon 14, used by scientists to date many materials.

The Nuclear Regulatory Commission (NRC) is a governmental body that has the responsibility of establishing criteria for the field of radioactivity. These criteria appear in the federal government's *Code of Federal Regulations*.

All personnel working at any site that has a possibility of exposure to radiation are required to wear some type of exposure detection device that gives an accurate determination of their actual exposure. The photographic badge is the most common and is used where sensitivity is required. A pen-shaped device called a "dosimeter" is commonly used where there is less need for accuracy. It is used where instant determination of dose is necessary.

An "unrestricted area" is any area within a facility that is not specifically controlled for the purpose of protecting any individual from radiation or radioactive materials. A "restricted area" is access controlled. Another term, "environs," may also be used to describe areas adjacent to a restricted or high-radiation area.

A high-radiation area is defined as any accessible area within a facility capable of allowing the body to receive 100 millirem (mrem) of radiation in a 1-h period.

Shielding

The purpose of shielding is to reduce or eliminate radiation emanating from any source within the facility. The most effective material has the greatest density, so lead has been universally used for this purpose. Another commonly used material is concrete. The difference in shielding thickness between concrete and lead is the following: 1/6 in. (4 mm) of lead is the equivalent of 12 in. (305 mm) of concrete. The basic

philosophy is that the use of concrete as a structural element of the building serves double purposes as a very good shielding material. It is up to the Radiological Safety Officer (RSO), whose responsibilities we discuss later, to determine the type of shielding and its placement to lower radiation in specific areas. Radiation travels in a straight line; therefore, if a tank or a length of pipe has to be shielded, the proper manner is to form a labyrinth, so the shine from the tank can't escape in a straight line.

The materials most commonly used for shielding purposes are concrete and sheet lead. Other materials that have proven effective are (a) lead-lined concrete blocks, (b) lead-lined lath for plaster, and (c) lead-lined panels and gypsum boards.

The barriers set up to reduce radiation levels are primary barriers, which are the first line of defense, and secondary barriers, which are used to eliminate leakage radiation and scattered radiation where it may possibly exist.

Radioactive Materials

Radioactive materials are used for the following five general categories of work:

1. Imaging sciences.
2. Diagnostic purposes.
3. Treatment purposes.
4. Industrial uses.
5. Research.

Almost all of the materials used are isotopes. An "isotope" is a form of an element with a different (or excess) number of neutrons in its nucleus. Because of this difference, the atom is unstable. These isotopes are identified by their "atomic weight," which is the weight of the number of neutrons and protons in the nucleus.

There are a great number of isotopes in use today. Some of the more common are:

- Iodine 131 (8-day half-life).
- Phosphorus 32.
- Technetium 99 (6-hour half-life).
- Calcium 45.
- Carbon 14.
- Strontium 90.
- Radium 226.

Since given amounts of radioactive material remain active for different periods of time, it is not possible to predict when any material will become completely stable. The method used is to determine when a specific material loses half of its radioactivity is called its "half life."

System Design Criteria

The approval process and application requirements The use of any radioactive material requires the licensing of the site for a specific purpose, quantity, and amount of radioactive material. Application for this license is made to either the NRC or a particular state. Those states that have elected to adopt NRC regulations and provide their own staff for the purpose of issuing and approving licenses are called "agreement states." In some cases these states make additional regulations of their own. Those states relying on the NRC to review and issue licenses are "non-agreement states." The application is made to the appropriate party.

The duties of the Radiological Safety Officer (RSO) include administration, monitoring personnel exposure limits, and controlling any release of radionuclides to the sewer system. In addition, it is usually the RSO who works with engineers in the design phase of the facility to ensure the piping runs and all other mechanical work will result in a low exposure to people within the facility. For the most part, this work is aimed at ensuring facility personnel do not exceed the maximum permissible radiation dose allowed under the applicable codes for any particular type of radioactive material present and non-staff members are not subject to unacceptable levels of radiation. The RSO is also responsible for the following:

1. Teaches facility staff about the potential dangers.
2. Keeps the necessary records for the facility.
3. Keeps inventory of material and records disposal.
4. Is responsible for concentration of materials at the facility.
5. Assists engineer in the design of mechanical systems.
6. Designates areas within the facility to be restricted.

General design criteria The prime consideration in the design of any facility is controlling the exposure of personnel to radiation, a concept called ALARA, an acronym for "as low as reasonably achievable." This requires, in the design of the facility, every reasonable method to limit the possible exposure of personnel inside the facility and to keep the presence of radioactivity in any unrestricted area to a figure as low as reasonably achievable must be considered. Among the things that must be taken into account are the current state of technology, the economics of further improvements in relation to the benefits to the public health and safety, and other socioeconomic considerations relating to the utilization of radioactive material in the general public interest. The designer

of the facility must also make a reasonable effort to eliminate residual radiation. One of the overriding concepts is the "worst case" possibility, where the worst possible combination of circumstances is used to determine the possible level of radiation and the period of time of the exposure. This concept should not be overused, and a general rule is to have only one "accident" at a time. As an example, a serious spill and a fire would not be considered as likely to occur simultaneously.

Pipe material selection The pipe selected for the radioactive drainage system depends upon the type of radiation and the level of radioactivity expected, which, in turn, depend upon the amount and type of radioactive material at the facility. In general, an ideal radwaste drainage pipe should have the following properties:

1. It must be nonporous.
2. It must be easy to clean and decontaminate.
3. It should be acid resistant.
4. It should be non-oxidizing.
5. The joints should not form a crud trap.
6. Joint materials must not be affected by radiation exposure.

It is possible in very high radiation areas to have a pipe affected by the radiation present. The oxides of the pipe can become radioactive or the pipe itself can be weakened. Plastic piping is not acceptable for radiation-waste systems due to the possibility the plastic may be affected by the radiation. Another possibility is the weakening of elastomeric seals or gaskets because of high levels of radiation. For this reason, Teflon is never used where anything more than a very low level of radiation is present. Other materials should be investigated as to their suitability for use for the levels anticipated.

All the commonly used materials (cast iron, ductile iron, copper, steel, and glass) and the joints normally used to put pipes together fall far short of the ideal. However, all of them are suitable for low-level waste and radioactive source materials found in facilities with a low level of radiation. It is only when the radiation levels of the waste materials get into the "high radiation" level category that they fail one or more of the conditions listed above. As a result, stainless steel with welded joints has emerged as the material of choice for all "industrial" type waste products. Type 316L is the type most commonly used.

A welded joint is the only type of joint to meet the criterion for not allowing a crud trap. The orbital welding process is often used since it produces the cleanest interior weld surface. The proper weld end preparation is critical to proper welding and must be diagrammed or described in the specifications.

There are two types of joint used for drainage pipe: butt welding and socket welding. "Butt welding" is a term used to describe two pipes placed end to end and joined with no overlapping. A "socket weld" describes the process by which one pipe is placed inside the other and only one end of the exposed pipe is actually welded around the exterior of the pipe. This is like a coupling, with only the joint on the outside of the pipe welded. In general, only pipe 2 in. (50 mm) and less is socket welded. Pipe this small (2 in. [50 mm] and under) is called "small bore pipe."

Specifications for, and approval of, the entire welding process for both shop welding and field welding is necessary. It is also necessary to qualify welding personnel to ensure they have sufficient training and knowledge to produce a weld of the required quality called for in the specifications. The qualifications of welding personnel are difficult to assess. High-temperature, high-pressure pipe is covered by ASME codes that specify the selection of successive welding type passes, filler metal composition, joint preparation, movement and handling of the pipe, tack welding and clamping, welding currents, metal deposit rates, and weld inspection. None of these code requirements applies to welded nonpressure drainage pipe. If the engineer does not have the knowledge to specify the minimum requirements for welders and the welding process, it could be left up to the contractor who has the job to determine the correct specifications for the project and recommend them to the engineer for approval. When this is done, the contractor establishes minimum criteria that will qualify any individual for welding on this particular project. It is then up to the contractor to test a welder's ability to make sound welds under the actual working conditions and using the same equipment expected to be used on the job and certify that person as being qualified. These criteria should be reviewed by the engineer for acceptability. It is common practice to use an outside, knowledgeable third party for this review process.

The defects in welded piping must be found and corrected. All of them arise from the fact that the weld does not actually create a monolithic piece of pipe. The flaws are cracks or voids in the joint. The testing methods are of the non-destructive type (NDT). The methods are:

1. Visual inspection of the weld.
2. Dye penetration.
3. Magnetic testing.
4. Ultrasonic testing.
5. X-ray.

General design considerations Human or animal waste, even that contaminated with radioactivity, is exempt from all NRC regulations, requiring

only compliance with local codes as far as disposal, sizing, and all other criteria applicable to standard drainage systems. There are also many isotopes exempt from regulations regarding disposal into the public sewer.

Another requirement is the liquid radwaste to be discharged shall be diluted with the ordinary waste effluent from the rest of the facility before being discharged to the public sewer system. This usually requires the radwaste piping first be kept separate from the rest of the facility's effluent, but combined together before leaving the building for discharge into a public sewer. There are no restrictions regarding the combining of any radwaste together with the rest of the facility's effluent are permitted to be discharged separately. A method should be provided, such as a valved outlet from both the radwaste line and the combined discharge, for the RSO to take a sample of the radwaste stream if desired.

The pitch of the piping should be kept as steep as possible in order to empty the pipe quickly and to allow a scouring action to keep the radioactive solids in suspension.

It is common practice to have high levels of radiation confined to glove boxes or protected fume hoods. The small amount of liquid waste produced from this equipment should be stored in shielded containers below the equipment and removed periodically. If the storage of larger quantities of low-level radwaste is required, the waste is piped to a holding tank. A common holding time is ten half-lives of the effluent. Usually, radwaste is stored for disposal on the site, outside of a building and where easy transfer of the liquid is possible. The removal must be done by licensed waste-disposal contractors who remove the waste from the holding tank into a special truck, which transports the liquid waste to a designated site suitable for disposal of low-level waste. The solid wastes, such as gloves, wipes, and the like are stored in special containers, which are removed to the disposal area with the liquid radwaste.

Floor drains are normally not desired in laboratories. If there is a spill of radioactive material, it is wiped up by hand using absorbent material, and the solid containing the spill is put in a special radwaste holding container within the lab. If a floor drain is installed, it should be constructed of stainless steel. For testing purposes and to close off a drain when it is not expected to be used, each drain should be supplied with a closure plug. If there are areas where a spill is possible, the floor must be pitched to a floor drain. A generally accepted value for the pitch of the floor is 1 in./20 ft. (2.54 cm/6.10 m). The thickness of the slab must be closely coordinated because the slab is thinnest at the drain and made thicker at the ends of the area served to make up the pitch. It is not practical to cast the slab evenly and add a topping, because there is a tendency to chip the topping and possibly have a radioactive spill get under the top coating. Since the slab depth is greater the longer the run to the drain, it is necessary to indicate the top of the drain elevation at each drain. This also makes it easier for the shop fabricator to make up accurate pipe spools.

Drains also require special treatment. They should also be manufactured of stainless steel. There will be different types of drain in different areas, and they may be installed at different elevations. Because of this and the probability the piping will be made in spools (preassembled sections of piping), it is a good idea to number all the individual drains on the design drawings. A box next to each drain can be used to provide information regarding type, number, and elevation.

Since fittings are a natural crud trap, running piping in, under, over, or adjacent to unrestricted areas in a facility should be avoided. If this is not possible, the line should be placed where additional shielding can be added, either at the time of construction or after the start of actual use, when the RSO may determine by survey additional shielding is necessary. Much of the time, the ability to take the joint apart and flush out any crud is an advantage. Any of the popular joints for no-hub or grooved pipe are acceptable, as well as those for glass pipe if that is used in a laboratory for chemical resistance.

The designer should be generous with cleanouts. They may be needed to flush out the line to reduce spot high radiation rather than rodding it out.

Infectious and Biological-Waste Drainage Systems

Biological waste has the same basic characteristics as other types of laboratory and production facility waste, but with the addition of biohazardous material. "Biohazardous material" is material suspended in the waste stream with live organisms that, if not contained, have the potential to cause infection, sickness, and other very serious diseases. This waste may be discharged by gravity and under pressure from many sources, including:

1. Fermentation tanks and equipment.
2. Process centrifuges.
3. Sinks, both hand-washing and process.
4. Containment area floor drains.
5. Janitor closet drains.
6. Necropsy table drains.
7. Autoclave drains.
8. Contaminated condensate drains.

Containment is the method used to isolate and confine biohazardous material. The facility equipment

and design shall conform to acceptable and appropriate containment practices based on the hazard potential. A containment category is used to describe an assembly of both primary and secondary preventive measures that provide personnel, environmental, and experimental protection. "Primary barriers" are specific pieces of equipment such as the biological safety cabinet (which is the biologist's equivalent of the chemist's fume hood) and glove boxes. "Secondary containment" refers to features of the facility design surrounding and supporting the primary containment. These features are described and classified in publications of the National Institutes of Health (NIH), in Bethesda, Maryland, among others.

The classifications for biological containment in laboratories consist of four biosafety levels, BL1 through BL4. Publications describe the work practices, equipment, and BL selection criteria based on the activity of a particular laboratory. If the laboratory or production facility produces or uses greater than 2.6 gal (10 L) involving viable organisms, the facility may become large scale (LS). This is noted as "BL2 LS."

Manufacturing standards shall conform to good large-scale production (GLSP) standards. The same standards apply to both small and large-scale facilities.

Facility type of work is outlined later in this chapter in a very abbreviated and simplified form.

Codes and Standards

Mandated guidelines and regulations include the following:

1. OSHA blood-borne pathogen regulations.
2. NIH guidelines for the use of recombinant microorganisms
3. FDA cGMP regulations.
4. CDC/NIH (Center for Disease Control/National Institute of Health) guidelines for biosafety in microbiological and biomedical laboratories.

Biological safety levels The laboratory containment levels described in the Centers for Disease Control/National institutes of Health (CDC/NIH) guidelines for biosafety in microbiological and biomedical laboratories are summarized as follows:

Biosafety level 1 (BL1) containment This is the typical biological research facility classification for work with low-hazard agents. Viable microorganisms not known to cause disease in healthy adults are used at this level. Work activity is done on an open bench and any hazard present can be controlled by using standard laboratory practice. Standard features consist of easily cleaned, impervious bench surfaces and hand-wash sinks, and the work area is separated from general offices, animal rooms, and production areas. Contaminated liquid and solid waste shall be treated to remove biological hazards before disposal. Wastes containing DNA materials or potentially infectious microorganisms shall be decontaminated before disposal. Facilities to wash hands are required in each laboratory.

Biosafety level 2 (BL2) containment Facility construction for this level is similar to that for BL1 except the microorganisms may pose some risk and safety cabinets are often present. Equipment and work surfaces shall be wiped down with a suitable disinfectant. Sinks shall be scrubbed daily with a chlorine-containing abrasive and flushed with a suitable disinfectant. All liquid waste shall be immediately decontaminated by mixing it with a suitable disinfectant.

Nearly all laboratories operate under levels 1 or 2 containment. At these levels, the facility is engaged in research, diagnostic, or production activities thought to pose little or minimal risk to workers.

Biosafety level 3 (BL3) containment Level 3 activity involves organisms posing a significant risk or represent a potentially serious threat to health and safety. Biosafety cabinets are required and all penetrations to outside the facility must be sealed to prevent leakage. These seals must be capable of being cleaned. Liquid waste is kept within the laboratory or facility and steam sterilized prior to discharge or disposal. Vacuum inlets must be protected by appropriate filters and/or disinfectant traps. Laboratory animals require special housing or, if conventional housing is used, personnel must be appropriately protected with full suits and respirators. A hand-washing sink routed to sterilization shall be located adjacent to the facility exit. Vents from plumbing fixtures must be filtered.

Biosafety level 4 (BL4) containment This is a rarely used classification; activities in this type of facility require a very high level of containment. The organisms present have life-threatening potential and may initiate a serious epidemic disease. All of the BL3 requirements apply. In addition, showers shall be provided for personnel at the air lock where clothes are changed upon entry or exit.

A bio-waste treatment system shall be provided within the facility to sterilize liquid waste.

Liquid-Waste Decontamination System A "liquid-waste decontamination system" (LWDS) collects and sterilizes (decontaminates) liquid waste. Effluent containing potentially hazardous bio-matter is collected in a dedicated drainage system generally discharging by gravity into a sump below the floor level within the facility. From the sump, effluent is pumped into a "kill tank" where the actual sterilization occurs. A "kill tank" is a vessel into which steam or chemical disinfectant is injected to kill any organism. The kill-tank system shall be qualified to the same biosafety level as the facility it

receives discharge from. The kill-tank system must be a batch process since time is needed to complete the sterilization and decontamination, based on the process used.

System components In addition to piping, an LWDS consists of the sump or tank to receive contaminated discharge from the drains and equipment of the facility, a pump to move the contaminated effluent from the sump and up into the kill tank(s), and the kill tanks will decontaminate and sterilize the effluent to a point permitting disposal into the same system used for the sanitary waste from the facility—generally a public sanitary sewer.

Sump pit The sump pit into which the effluent drains shall have a gasketed, waterproof cover. The controls are similar to those provided on a plumbing sump pump and shall be capable of being chemically or steam sterilized. The sizing of the pit is done in conjunction with the sizing of the pump so the pump stays on for a minimum of 1 min to avoid short cycling and and protect the equipment. Other possibilities, such as having the pit contain one batch of product if necessary, may be considered.

Kill-tank assembly The kill tank consists of a duplex-tank arrangement, allowing one batch to be decontaminated while the other is filling. The size of the tanks vary based on the individual facility, but common practice is to have each tank capable of containing one day's effluent plus the chemicals used for decontamination. Another consideration is to have sufficient size to hold a catastrophic spill. There is usually an agitator to mix the effluent with the deactivation chemicals. In addition to the kill tanks, tanks containing disinfectant chemicals to be injected are required. A fully automatic control system must be provided to ensure the timely addition of the required chemicals in the correct amounts and for the required duration for deactivation of the bio-matter. Alarms and status shall be displayed in an appropriate panel located in a facility control room or other area, which shall be provided.

Drainage system and components The drainage system must be closed, which requires sealed floor drains and valved connections to equipment when not in use. Since the HVAC system maintains a negative pressure, it is important the traps on all floor drains have a seal 2½ in. (65 mm) deeper than the negative difference in air pressure. The traps of floor drains shall be filled with a disinfectant solution when not used, to eliminate the possibility of spreading organisms between different areas served by the same connected sections of the piping system.

The drainage piping material is based on the expected chemical composition of the effluent and the sterilization method. If the local authorities determine the bio-waste is hazardous, a double-contained piping system with leak detection may be required. Stainless steel or PTFE pipe is usually chosen where higher-temperature effluent may be discharged or steam sterilization may be required. PVC, CPVC, polypropylene, or lined FRP pipe can be used where effluent temperatures are lower and also where chemicals will provide the method of sterilization.

If waste from pressurized equipment is discharged into a gravity system, the system must be adequately sized to carry away the waste at the proposed flow rate with pipe flowing ½ full, and adequate vents must be provided to equalize the internal pressure and ensure the pipe is always at atmospheric pressure.

Valves shall be diaphragm type and capable of being sterilized using the same method used for the pipe. After appropriate decontamination, the kill-tank effluent shall be discharged to drain. This effluent must be treated prior to discharge into a public sewer system for disposal.

Vents Vents from pipe, fixtures, sealed sump pits, and kill tanks must be filter sterilized prior to leaving the system using a HEPA or a 0.2-μ filter.

In the event of an accident, OSHA has rules to aid personnel responding to emergencies involving any hazardous material.

System design considerations The treated discharge from any containment treatment shall be separately routed to the sanitary system outside the building to allow for monitoring and sampling.

CHEMICAL-WASTE SYSTEMS

General

Industrial-waste drainage systems can contain a wide variety of water-borne wastes, among them chemicals, solvents, suspended solids, and flammable liquids, as well as waste water, many of which are considered hazardous. The purpose of the industrial-waste drainage system is to collect and transport these wastes from inside a facility to a point on site where disposal or treatment can be accomplished.

Codes and Standards

A great body of regulations affect the design of any industrial drainage system. Among them are the federal Clean Water Act (CWA) and Resource Conservation and Recovery Act (RCRA), which are administered by the federal Envirenmental Protestion Agency (EPA) as well as state and other local agencies. The local authorities are also empowered to create regulations that are stricter than federal regulations. Where production and manufacturing facilities discharge waste, it is a general practice to engage the services of professionals experienced in waste-water treatment and environmental issues to ensure compliance with all of the latest applicable regulations and an acceptable treatment system.

The major regulatory factor to be considered is the determination if any particular waste stream is hazardous. If so, protective measures, such as double-contained piping systems and leak detection may be required.

Pipe Material and Joint Selection

Because of the vast diversity of manufacturing processes, it is impossible to make any general characterization of industrial waste water. It is common to have various areas within a plant or industrial complex discharging different types of effluent with greatly varying characteristics.

The largest quantity of effluent in an industrial facility originates from drains. Drains receive discharge from production equipment, floor wash down, process and production machines, and other equipment, such as compressors and boilers. The floor drain and the discharge pipe from the drain must be capable of resisting chemicals discharged from the production equipment. Selection of the most appropriate piping material can only be accomplished if the nature of the effluent, both present and future, is known and can be allowed for.

An often-used material is vitrified clay sewer pipe because of its resistance to most chemicals. Manholes are lined, as is shown in Figure 12-1.

System Design Considerations

The design of the drainage system is dependent on the location, composition, and quantity of discharged effluent from all sources. The layout and engineering of a piping network requires ingenuity and attention to detail.

Selection of the type and location of floor drains is a major aspect of drainage system design. The following are general guidelines for locating and selecting the drains:

1. Wet floors are to be avoided. Drains should be located next to equipment and be large enough to allow multiple discharges to spill easily over them without requiring a run of pipe over the floor or having to spill on the floor and run to the drain. If large flow rates are expected, a large drain should be selected.
2. The use of long trench drains in areas where a number of pieces of equipment are placed creates easy access to all the various drains from the equipment. This arrangement is usually less costly than multiple drains.
3. In many cases, the discharge from equipment may be under pressure because of the head of water in the piece of equipment, such as occurs when a tank is emptied. The drain should be large enough in physical size to accept the largest expected flow. The size of the discharge pipe must be large enough to accept the maximum quantity flowing full by gravity without overflowing. An air gap shall be provided to prevent pressurizing the gravity drainage system.
4. To accept the largest number of multiple, small-sized drainage lines from equipment, a funnel type of drain should be provided. The top of the funnel should be as close to the floor as reasonable in order for an air gap to be provided between the top of the floor drain and the end of the equipment drain. This air gap shall be twice the diameter of the drainage line.
5. Adequate cleanouts must be provided in drain lines. In lines that are at the ceiling of high floors, the cleanouts should be extended to the floor above to avoid the need for maintenance personnel to climb ladders to clean stoppages.
6. The minimum size drain line under the slab or underground should be 2 in. (50 mm). Floor drains should be a minimum size of 4 in. (100 mm).
7. Adequate venting of the drainage line must be provided to allow for smooth flow. The vents shall be connected to the top of the drain line in order either to allow air at the top of the pipe to be vented out (when there is a slug of liquid) or to admit air required by the flow of water or due to a partial vacuum created by the liquid flowing full. Vents shall be a minimum size of 2 in. (50 mm). If the room is pressurized to avoid contamination, the trap depth should be 2 inches (50 mm) longer than the amount of pressurization.
8. Local regulations may require the use of double-contained piping to prevent potential leakage from discharging into the environment. A leak-detection system should be provided that annunciates leakage.

FIRE-SUPPRESSION WATER DRAINAGE

For industrial facilities, the water used to suppress a fire could become contaminated with the products and raw materials it comes in contact with. It is required for any water, such as sprinkler and fire-hose discharge, having the possibility of being contaminated in this manner be routed to holding basins for analysis and possible treatment before being discharged into the environment. If there is no material capable of causing contamination, no special consideration is necessary except to protect other areas of the facility from possible flooding.

System Description

The drainage system consists of the drains, located in such a manner to intercept the flow of fire water; the drainage piping; a holding basin on site to contain and treat the total volume of water; and the necessary

treatment system that will neutralize the water prior to its discharge into the environment.

The amount of water discharged from the fire-suppression system is far greater than the amount of waste water discharged from the facility under normal operating conditions. Overflow floor drains large enough to take the design flow rate shall be installed at points that will intercept the water before it flows out of doorways or drive bays and route it to holding basins. The placement of these overflow drains shall be selected to intercept all of the water discharged and prevent it from damaging other parts of the facility or escaping away from the property or into the ground.

The drainage piping is sized based on flow rate and pitch from the facility to the detention basin. The effluent is essentially clear water with a few solids,with possible contamination of the waste water from whatever is stored in the area where the fire was present. The flow rate of water required to be disposed of is determined by first calculating the sprinkler water density over the area used for hydraulic calculations. Add to this the flow rate from the number of fire standpipe hose streams possible. Velocity in the drainage pipe is not a major consideration because the system will be rarely used. A shallow pitch will give a low velocity potentially resulting in the deposit of some material that could be flushed out after the event of the fire. A high velocity will not affect the life of the piping system because of the short amount of time the system will be in operation. Pipe size is selected based on the actual pitch of the pipe and the capacity flowing full. Refer to Table 12-1.

Venting of the system is required in order to allow free flow of the effluent. Each individual drain need not be vented, but each branch should have a loop vent of at least 2 in. (50 mm) in size. The vent could be connected to the sanitary vent system or carried through the roof independently.

The pipe material selected shall be compatible with the possible chemicals it may carry.

FLAMMABLE AND VOLATILE LIQUIDS

Federal, state, and local regulations have established standards for the discharge of volatile liquids, particularly oil, into storm-water and sanitary sewers. These standards vary, and the responsible enforcement and code authorities must be consulted to determine the level of treatment required.

The most common flammable liquid is oil. The hazard created is either one of safety (since the vapors could create an explosive condition, the oil will float on water and could be set on fire) or health (where the breathing of the vapors is dangerous to health and toxic if ingested by humans).

The common characteristic of all volatile liquids is they are lighter than water. Their removal from water, therefore, is similar to the removal of oil outlined below.

Oil in Water

Oil is considered immiscible which means it will not be disolved in water. Since it cannot be disolved; oil in water exists in several forms:

1. Free oil.

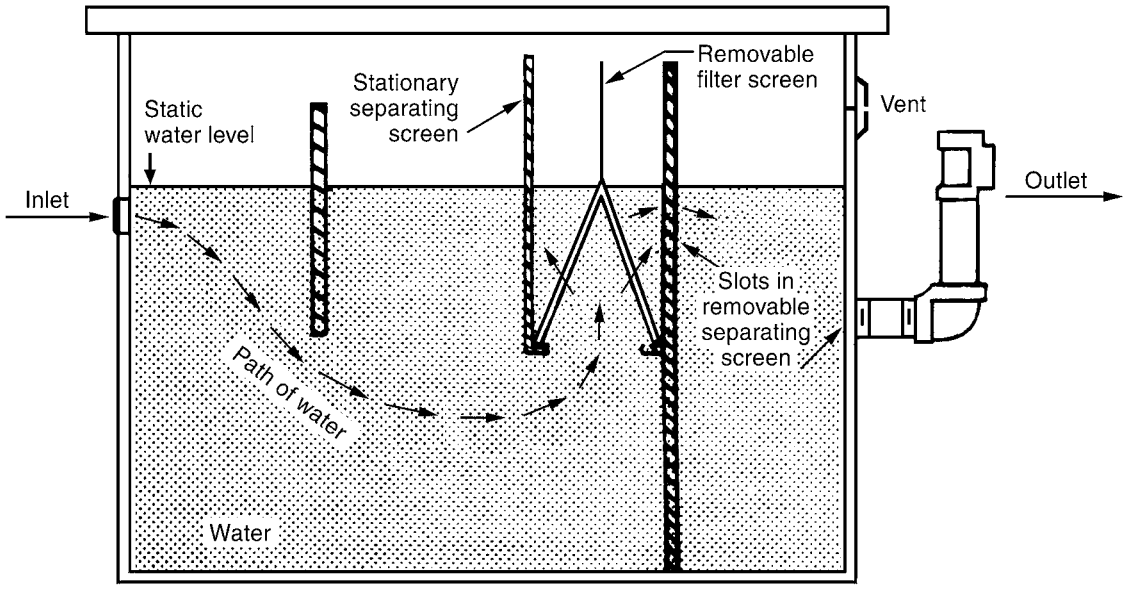


Figure 12-4 Typical Oil Interceptor

(*Source*: Courtesy of Rockford Co.)

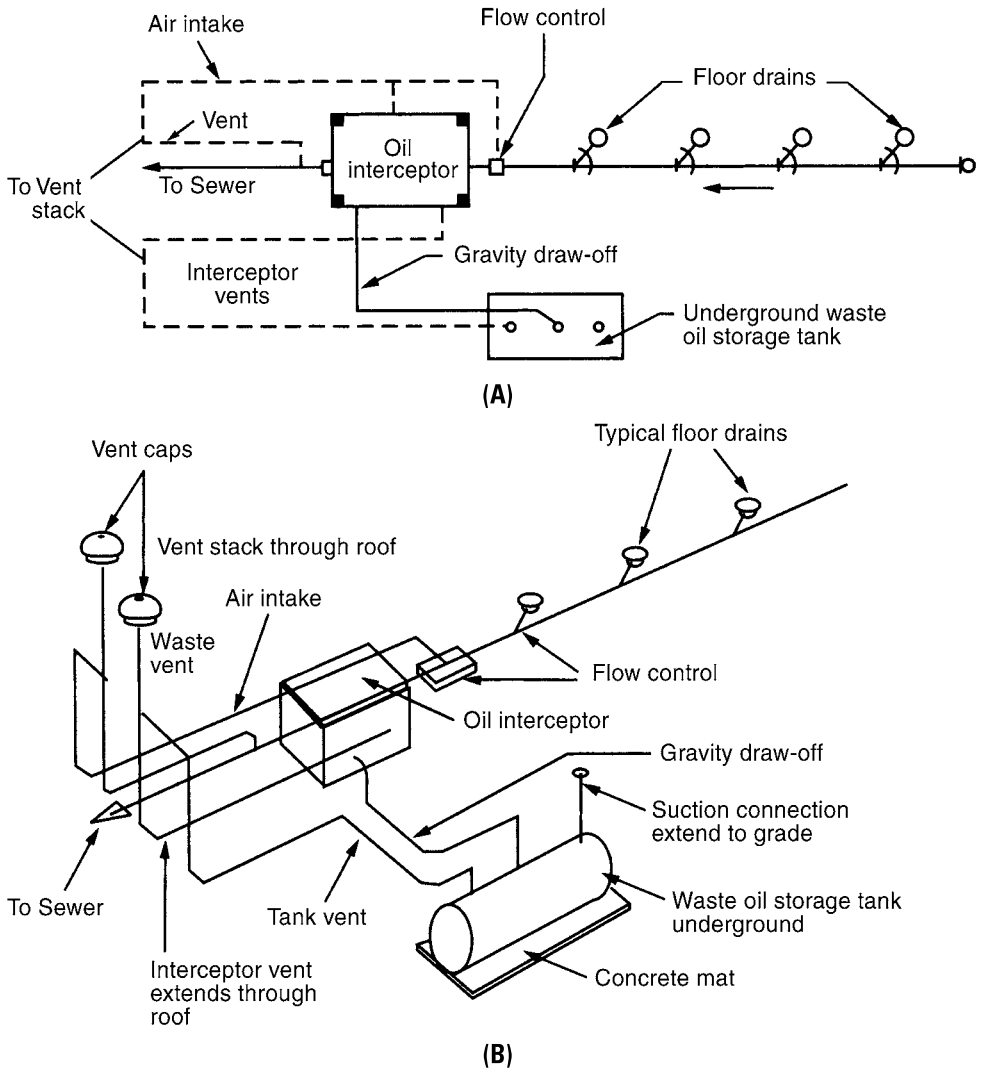


Figure 12-5 Typical Gravity Draw-Off Installation (A) Plan and (B) Isometric

(Source: Frankel 1996)

2. Mechanically dispersed oil is fine droplets ranging in size from microns to fractions of an inch (millimeter). These droplets are stable due to electrical charges and other forces but not due to the presence of surface active agents.
3. Chemically stabilized emulsions are fine droplets that are stable due to surface active agents.
4. Dissolved and dispersed oil is suspended in such a small size (typically 5 μ or smaller) that ordinary filtration is not possible.
5. Oil-wet solids are oils which adhere to the surfaces of solids such as particlates or sediment.

Methods of separation and treatment Oil spills and leaks are best treated in their most concentrated state, which is at their source or as close to their source as is reasonable. The primary methods used to separate and remove free oil and oil-wet solids are flotation and centrifugation. Secondary treatment, such as chemical treatment/coalescence and filtration, is then used to break up oil water emulsions and remove dispersed oil. Finally, tertiary treatment, such as ultrafiltration, biological treatment, and carbon adsorption will remove the oil to required levels prior to discharge. This chapter discusses only the general principles of the primary and secondary separation methods and devices.

The American Petroleum Institute (API) has established criteria for the large-scale removal of globules larger than 150 μ. In abbreviated form, they are:

1. The horizontal velocity through the separator may be up to 15 times the rise velocity of the slowest-rising globule, up to a maximum of 3 fps (0.91 m/s).
2. The depth of flow in the separator shall be within 3 ft 0 in. to 8 ft 0 in. (0.9 to 2.4 m).
3. The width of the separator shall be between 6 ft 0 in. and 20 ft 0 in. (1.8 to 6.1 m).

4. The depth to width ratio shall be between 0.3 and 0.5.
5. An oil-retention baffle should be located no less than 12 in. (305 mm) downstream from a skimming device.

Gravity separators Gravity separation is the primary and most often-used separation method. It is based on the specific gravity difference between immiscible oil globules and water. Since all volatile liquids are lighter than an equal volume of water, gravity separators operate on the principle of flotation. As the water and oil flow through the unit, the oil floats to the top and is trapped inside by a series of internal baffles. Since the oil remains liquid, it is easily drawn off.

Flotation devices For larger-scale service, the flotation of oil and oil-wet solids to the top of the flotation chamber can be increased by the attachment of small bubbles of air to the surface of the slow-rising oil globules. This is done by adding compressed air to the bottom of the flotation chamber in a special manner creating small bubbles that mix with and attach themselves to the oil globules.

Centrifugal separators For larger-scale service, the centrifugal separator is used. This device operates on the principle of inducing the combined oil and water mixture to flow around a circular separation chamber. The lighter oil globules collect around the central vortex, which contains the oil removal mechanism, and the clear water collects at the outer radial portion of the separation chamber. Methods have evolved that produce effluent water with only 50 to 70 ppm of oil, and proprietary devices exist that lower oil content to 10 ppm.

Filtration Chemical methods used to break oil/water emulsions followed by depth type filters to remove the destabilized mixture have proven effective in the removal of oil globules in a range of sizes between 1 and 50 μ. The velocity and flow rate of the mixture must be carefully controlled to allow optimum effectiveness of the system.

Smaller systems Oil separators for small flows usually take the form of a single unit consisting of a drain grating into which the effluent flows, is trapped and separated by gravity, then is diverted to an accumulator chamber to be drawn off manually or automatically. Another type of unit uses an overflow arrangement that sends the trapped oil to a remote oil-storage tank.

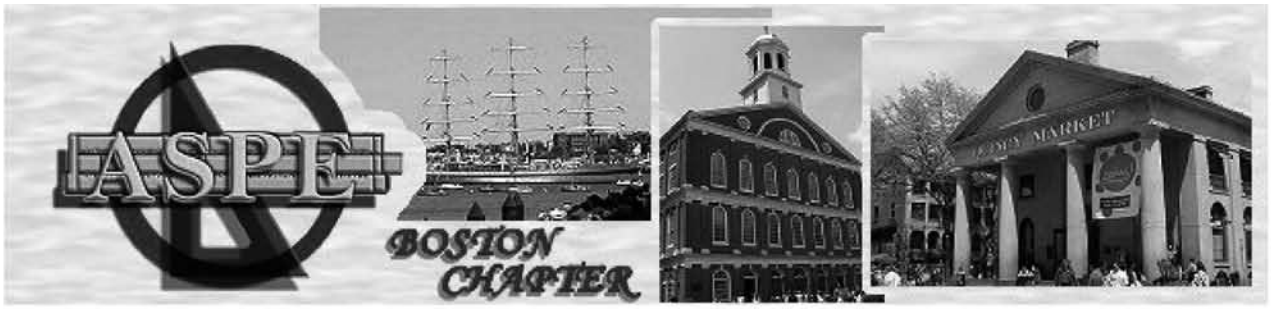
Because there is the possibility the vapor given off by the flammable liquid could ignite, it is important to provide a separator vent that terminates in the open air at an approved location above the highest part of the structure. Some codes require a flame arrestor be installed on the vent.

Most commonly used for an oil interceptor is a coated steel vessel. Gratings, if used, must have the strength to withstand the type of vehicle expected to pass over the interceptor. A collection basket may be specified where debris, such as metal chips, can be intercepted before entering the interceptor.

Refer to Figure 12-4 for an illustration of a typical small oil interceptor. Figure 12-5 illustrates the installation of a typical oil interceptor with gravity oil drawoff for multiple-floor drain inlets.

REFERENCES

1. Frankel, M. 1996. *Facility piping systems handbook*. McGraw-Hill New York City:.
2. Geogehegan, R.F., and H.W. Meslar. 1993. Containment control in biotechnology environments. *Pharmaceutical Engineering*.
3. Grossel, S.F. 1998. Safe handling of acids. *Chemical Engineering Magazine* July.
4. Kaminsky, G. Failsafe neutralization of wastewater effluent. *Plant Services Magazine* May. 1998
5. Mermel, H. 1988. pH control of chemical waste. *Heating/Piping/Air Conditioning Magazine*.



President Alfred M. Marzullo, P.E., CPD (617) 331-8714 al@marzullo.com	**Vice President Membership** James P. Harrison (781) 848-2250 jharrison@symmons.com
Vice President Technical Fredrick S. Neth, CIPE (617) 494-9090 fneth@cosentini-ma.com	**Administrative Secretary** Paul G. Galvin (508) 587-1212 paul.galvin@sloane.georgefischer.com
Treasurer John H. Pokorny (781) 762-2661 johnp@jhpokorny.net	**Education Chairman** Joseph A. Vela, Sr., CIPE, CPD (401) 339-1717 jvela-aspen@cox.net
Corresponding Secretary Patrick J. Haney (508) 238-2030 phaney656@aol.com	**Chapter Scribe/ Membership Directory** Paul R. Taylor III, CPD, CET 508-230-0260 x232 ptaylor@ber-engineering.com
Affiliate Liaison Tom J. Farrell (781) 344-1988 pumpman1988@yahoo.com	**Boston Chapter Historian** Bernard J. McCarty, P.E., CIPE (508) 830-6882

Number:	Past President's Name:	Years Served:
1st	Samuel Ussia, P.E.*	1973-1974
2nd	John J. McEvoy, P.E.*	1974-1975
3rd	Evan F. Bailey, P.E.*	1975-1976
4th	James G. Craig, CIPE	1976-1977
5th	Robert L. Hough, P.E.	1977-1978
6th	Bernard J. McCarty, P.E., CIPE	1978-1979
7th	Allen W. Sterns, P.E.	1979-1980
8th	James B. Johnston, CIPE	1980-1981
9th	Frank G. Teebagy, P.E., CIPE	1981-1982
10th	P. Joseph Sullivan, P.E.*	1982-1983
11th	Richard A. Delaney, P.E.	1983-1984
12th	Gary P. Dean, P.E.	1984-1985
13th	Michael L. Fournier, P.E., CIPE	1985-1986
14th	David J. Ferguson, P.E., CIPE	1986-1987
15th	Kevin W. Lally, CIPE	1987-1988
16th	Joseph J. Barbera, P.E., CIPE	1988-1989
17th	Roger D. Wardwell, P.E., CIPE	1989-1991
18th	Frank G. Teebagy, P.E., CIPE	1991-1992
19th	Ronald W. Howie, CIPE	1992-1993
20th	Bahig A. Kaldas, P.E.	1993-1994
21st	James N. Polando, P.E., CIPE	1994-1995
22nd	Roger G. Bernard, P.E., CIPE	1995-1996
23rd	James N. Polando, P.E., CIPE	1996-1997
24th	John P. Callahan, CIPE	1997-1998
25th	William F. Hughes, Jr., CPD	1998-2001
26th	William R. Brady, CPD	2001-2003
27th	Joseph A. Vela, CIPE, CPD	2003-2005

American Society of
Plumbing Engineers

ASPE

PITTSBURGH CHAPTER

2006

President ..... Gregorio P. Torchia, CPD
Vice President Technical ..... James T. Marsili, CIPE/CPD
Vice President Education ..... N/A
Vice President Legislative ..... Jerry Valenti, PE, CIPE
Vice President Membership ..... Michael B. Savannah
Treasurer ..... Joseph R. Starr, Jr.
Corresponding Secretary ..... Kevin M. Morrissey, GE
Administrative Secretary ..... Kevin M. Morrissey, GE

The Pittsburgh Chapter Board Members would like to thank all of its members for their continued support

KANSAS CITY CHAPTER
AMERICAN SOCIETY OF PLUMBING ENGINEERS
A NON PROFIT CORPORATION
PO Box 3553
Olathe, Kansas 66063
LOCAL CHAPTERS NOT AUTHORIZED TO SPEAK FOR SOCIETY

Please visit our web site

www.aspe-kc.com

for information about

Regular Meetings on the second Monday of every month from September through May. CEU/PDH credit is available for the technical programs and networking opportunities with Plumbing Professionals occur with a dinner format.

Technical Programs
Legislative Programs
Education Programs

Manufacturer's Product Listings by Manufacturer and by Product Category

Certified In Plumbing Design (CPD)

Plumbing Engineering Design Handbook – Four Volume Set –
One hardback volume updated each year and distributed to each ASPE member

ASPE Magazine: Plumbing Systems & Design

Bi-Annual Product Show

Annual Golf Tournament

Contact one of these Kansas City Chapter board members if you have any questions or comments:

President: Jim Brune, bruneja@bv.com
Vice-President Technical: Mike Haramia, mike.haramia@hendersonengineers.com
Vice-President Legislative: Chris Sturges, chris.sturges@hendersonengineers.com
Vice-President Membership: Tim Helmer, tim.helmer@ferguson.com
Treasurer: Anindy Nandy, anindya.nandy@larsonbinkley.com
Secretary Administrative: Joe Tobin, joe.tobin@hendersonengineers.com
Secretary Corresponding: Joe McClain, jmcclain@mackmcclain.com
Affiliate Liaison: Lilliard Richardson, lilliard.richardson@siouxchief.com

Virginia Blue Ridge Chapter

Chartered December 10, 2002

2006 – 2007 Chapter Officers and Chairmen

Mark Thayer, CIPE
President

Michael Knizley, PE, CPD
Vice-President, Technical

Mike Smith, CPD
Vice-President, Legislative

Michael Wolfe, EIT, CPD
Vice-President, Membership

Tim Roseberry, CIPE
Treasurer

Herb Edwards
Administrative Secretary

Granville Grant, CPD
Education Committee Chairman

Cheryl Overfelt
Corresponding Secretary
Newsletter Editor

Harvey Nichols, CPD
Historian

Ralph Johnson
Chapter Affiliate Liaison

Gary Parsons
Fund-Raising Chairman

Jason Price
Table Top Chairman

"Committed to advancing the science of plumbing engineering, to professional development of ASPE members and to the health, welfare and safety of the peoples of Western and Central Virginia"

Central Ohio Chapter
American Society of Plumbing Engineers

The Central Ohio Chapter of the American Society of Plumbing Engineers is dedicated to bringing everyone involved with the plumbing industry together to help expand their knowledge of the industry as a whole.

The Central Ohio Chapter has received awards from the National American Society of Plumbing Engineers for "Outstanding Performance as a Chapter" for three consecutive years.

The Central Ohio Chapter has the highest percentage of attendees at General Meetings of any chapter in the region.

OFFICERS 2006-2007

President
Mark G. Simpson, CPD
T 614.487.1650 F 614.487.8981
mark.simpson@korda.com

Vice President, Technical
David Dexter, PE, CPD, CPI, LEED AP
T 614.487.1650 F 614.487.8981
david.dexter@korda.com

Vice President, Legislative
Eric Leman, CPD
T 614.457.2696 F 614.457.4021
ewleman@heapy.com

Vice President, Membership
Chad Dupler
T 740.467.3071 F 740.467.3071
chadd@campbellequipment.com

Treasurer
D. Jason Hopkins
T 614.451.2248 F 614.451.6628
jhopkins@rdfa.com

Administrative Secretary
Dave Madsen
T 614.837.2039 F 614.837.2039
dmindrep@msn.com

Corresponding Secretary
Greg Hochstetler, PE, CEM, GBE
T 614.261.6331 F 614.261.6330
ghochstetler@speermechanical.com

Affiliate Liaison
Stevin Van Straten
T 740.927.6880 F 740.927.4545
svanstraten@RepSourceLLC.com

Index

Δ (delta), 2004 V1:14
μ (micro) prefix, 2004 V1:34
Σ (ohms), 2004 V1:33
Σ cm (ohm-centimeter units), 2000 V3:46
Σ m (ohm-meters), 2004 V1:33
% (percentages), 2004 V1:15
1-compartment sinks, 2001 V4:11
1-family dwellings, numbers of fixtures for, 2001 V4:20, 21
1-occupant toilet rooms, 2001 V4:18, 23
1-pass cooling for equipment, 2004 V1:264
1-piece water closets, 2001 V4:3
1-pipe steam systems, 2000 V3:178–180, 183, 186, 188
1-stage distillation, 2005 V2:210
1-tank residential filters, 2000 V3:134
1-time costs, defined, 2004 V1:223
1-wall tanks, 2000 V3:156
2-bed deionizing units, 2000 V3:46
2-compartment sinks, 2001 V4:11, 12
2-family dwellings, numbers of fixtures for, 2001 V4:20
2-pipe steam systems, 2000 V3:178, 180–182, 185, 186–187
2-pipe venturi suction pumps, 2005 V2:165
2-point vapor recovery, 2000 V3:163
2-pole fan-cooled electric motors, 2004 V1:196
2-step deionization (dual-bed), 2005 V2:216, 217
2-valve parallel pressure-regulated valves, 2005 V2:78
2-word expressions of functions, 2004 V1:225, 231
3-compartment sinks, 2001 V4:11, 12
5-minute storm duration, 2005 V2:57–61
10-minute storm duration, 2005 V2:57–61
10-year rainfall return periods, 2005 V2:57–61
15-minute storm duration, 2005 V2:57–61
18-8 SS, 2004 V1:141
18-8-3 SS, 2004 V1:141
28 CFR Part 36, 2004 V1:106
70:30 Cu Ni, 2004 V1:144
80/20 rule, 2004 V1:224, 258
90:10 Cu Ni, 2004 V1:144
100-year rainfall return periods, 2005 V2:57–61
1964 Alaska Earthquake, 2004 V1:161–162
1971 San Francisco Earthquake, 2004 V1:162
2406 MDPE pipe, 2001 V4:58
3408 HDPE. *See* HDPE (high density polyethylene)

A

A, X#, X#A (compressed air). *See* compressed air
A/m (amperes per meter), 2004 V1:33
A (amperes). *See* amperes
A (area). *See* area (A)
a (atto) prefix, 2004 V1:34
"A dimension," 2000 V3:187–188
A-weighted sound levels, 2004 V1:194
A-53 standard, 2001 V4:48
A-74 standard, 2001 V4:28
A-106 standard, 2001 V4:48
A-135 standard, 2001 V4:48
A-888 standard, 2001 V4:28
AAMI (Association for the Advancement of Medical Instrumentation), 2005 V2:197, 229, 230
AAU (Amateur Athletic Union), 2000 V3:151
AAV (automatic air vents), 2004 V1:10
abandoned septic tanks, 2005 V2:156
abandoned wells, 2005 V2:167
abbreviations
  International System of Units, 2004 V1:32
  plumbing and piping symbols, 2004 V1:7–13
  text, drawings, and computer programs, 2004 V1:14–16
The ABC's of Lawn Sprinkler Systems, 2000 V3:105
above-finished floor (AFF), 2004 V1:14
above-grade fountains, 2000 V3:108
aboveground piping
  inspection checklist, 2004 V1:103
  materials for, 2005 V2:13
  storm-drainage systems, 2005 V2:50
aboveground sanitary piping codes, 2004 V1:42
aboveground tank systems
  codes and standards, 2000 V3:154
  connections and access, 2000 V3:166
  construction, 2000 V3:165
  corrosion protection, 2000 V3:165
  electronic tank gauging, 2000 V3:160
  filling and spills, 2000 V3:166–167
  industrial wastes, 2000 V3:91
  leak prevention and monitoring, 2000 V3:167–168
  liquid fuel systems, 2000 V3:165–169
  materials for, 2000 V3:165
  overfill prevention, 2000 V3:167
  product-dispensing systems, 2000 V3:168
  tank protection, 2000 V3:169
  testing, 2000 V3:171
  vapor recovery, 2000 V3:168
  venting, 2000 V3:167
abrasion, 2004 V1:146, 2005 V2:16, 195

ABS. *See* acrylonitrile-butadiene-styrene (ABS)
abs, ABS (absolute), 2004 V1:14
absolute (abs, ABS), 2004 V1:14
absolute pressure, 2000 V3:200
  defined, 2004 V1:17
  in vacuums, 2005 V2:176
absolute temperature, 2004 V1:17
absolute zero, 2004 V1:17
absorphan (carbon filtration). *See* activated carbon filtration (absorphan)
absorption
  air drying, 2000 V3:204
  defined, 2004 V1:17
  rates for soils, 2000 V3:99
  trenches. *See* leaching trenches (leach fields)
absorptive silencers, 2000 V3:202
ac, AC (alternating current), 2004 V1:14
AC (air chambers). *See* air chambers (AC)
AC-DC rectifiers, 2004 V1:150, 151
acc (accumulate or accumulators), 2004 V1:14, 17
acceleration
  earthquakes, 2004 V1:159, 160
  linear, 2004 V1:33, 35
  measurements, 2004 V1:33
accelerators (dry-pipe systems), 2000 V3:11, 12–13
accelergrams, 2004 V1:159
access
  aboveground tank systems, 2000 V3:166
  clean agent gas fire containers, 2000 V3:23
  to equipment, piping and, 2001 V4:25
  underground liquid fuel tanks, 2000 V3:156–157
access doors, 2004 V1:17
accessibility, 2004 V1:17. *See also* people with disabilities
Accessibility Guidelines for Buildings and Facilities, 2004 V1:105
Accessible and Usable Buildings and Facilities, 2004 V1:105, 123, 2001 V4:2
accessories section in specifications, 2004 V1:91
accreditation of health-care facilities, 2000 V3:50
accumulate (acc, ACCUM), 2004 V1:14
accumulators (acc, ACCUM), 2004 V1:14, 17
accuracy
  in measurements, 2004 V1:32
  of pressure-regulating valves, 2005 V2:67
ACEC (American Consulting Engineers Council), 2004 V1:62
acetylene, 2005 V2:126
acfh (actual cfh), 2005 V2:131
acfm (actual cubic feet per minute)
  defined, 2000 V3:83, 200
  medical air compressors, 2000 V3:65, 66
  medical vacuum systems, 2000 V3:69
  vacuum systems, 2005 V2:177–178
acid-containing inhibitors, 2005 V2:218
acid fumes, 2000 V3:42
acid neutralization, 2000 V3:40–41, 91
acid-neutralization tanks, 2000 V3:40–41, 42
acid radicals, 2005 V2:199
acid regenerants, 2005 V2:209, 216, 217
acid resins, 2005 V2:210
acid-resistant fixtures, 2001 V4:1–2
acid-resistant floor drains, 2005 V2:15
acid-resistant piping, 2005 V2:13, 249
acid-resistant sinks, 2000 V3:37
acid vents (AV), 2004 V1:8, 17
acid-waste systems
  acid-waste treatment, 2005 V2:244–245
  continuous systems, 2005 V2:246
  health and safety concerns, 2005 V2:239–240
  health-care facilities, 2000 V3:39–40
  introduction, 2005 V2:239
  large facilities, 2005 V2:244, 245
  metering, 2000 V3:41–42
  piping and joint material, 2005 V2:242–244
  solids interceptors, 2000 V3:41, 43
  system design considerations, 2005 V2:244
  types of acid, 2005 V2:240–242
acid wastes (AW), 2004 V1:8, 17, 2000 V3:42
acidity
  in corrosion rates, 2004 V1:145
  pH control, 2000 V3:91–92
  swimming pool water, 2000 V3:146–147
  in water, 2005 V2:168, 199, 202–203
acids, defined, 2005 V2:198
acme threads, 2004 V1:17
acoustics in plumbing systems
  acceptable levels in buildings, 2004 V1:193
  acoustics, defined, 2004 V1:206
  building material acoustic insulation, 2004 V1:193
  design procedures, 2004 V1:198–200
  equipment selection, 2004 V1:200
  flow velocity, 2004 V1:198
  glossary, 2004 V1:206–210
  gurgling noises in pipes, 2005 V2:37
  introduction, 2004 V1:193
  noise and vibration control, 2004 V1:199–200
  occupied domestic spaces, 2004 V1:196
  pipe sleeves and, 2004 V1:201
  pressure and, 2004 V1:200
  pumps, 2004 V1:196–198, 201–202
  ratings for fixtures and appliances, 2004 V1:194–195, 198
  silencers on vacuum systems, 2005 V2:189
  sound power levels, 2004 V1:194
  system design, 2004 V1:200–206
  system layout, 2004 V1:202
  transmission in pipes, 2005 V2:14
  vacuum systems, 2005 V2:184
  vibration isolation, 2004 V1:202–206
  water hammer, 2004 V1:198, 201, 2005 V2:79–82
  water piping design, 2004 V1:195–196
acoustics in swimming pools, 2000 V3:129
acquisition costs
  acquisition prices defined, 2004 V1:222
  base acquisition costs, 2004 V1:223
ACR/MED pipes, 2001 V4:36
ACR piping, 2001 V4:36
acres, converting to SI units, 2004 V1:39
acrylic fixtures, 2001 V4:2
acrylonitrile butadiene rubber (ABR), 2000 V3:169
acrylonitrile-butadiene-styrene (ABS)
  defined, 2004 V1:17
  fixtures, 2001 V4:2
  pipe characteristics, 2001 V4:59–60

piping, 2005 V2:13, 14, 50, 2000 V3:48
plastic underdrains, 2000 V3:131
weirs, 2000 V3:146
activated alumina air dryers, 2000 V3:204
activated alumina water treatment, 2005 V2:228
activated carbon filtration (absorphan)
in gray-water systems, 2005 V2:30
in gray-water treatment, 2005 V2:31
illustrated, 2005 V2:215
overview, 2005 V2:211–214
pure-water systems, 2005 V2:231–232
small water systems, 2005 V2:228
well water, 2005 V2:168
Activated Carbon Process for Treatment of Wastewater Containing Hexavalent Chromium (EPA 600/2-79-130), 2000 V3:96
activated sludge systems, 2000 V3:95
active, defined, 2004 V1:151
active potential, defined, 2004 V1:151
active sludge, 2004 V1:17
active verbs in function analysis, 2004 V1:224, 225
activities in FAST approach, 2004 V1:231
actual cfh (acfh), 2005 V2:131
actual cubic feet per minute. *See* acfm (actual cubic feet per minute)
actual flow rates, 2000 V3:5, 217
actual liters per minute (aL/min), 2000 V3:69, 200
actual pressure. *See* static pressure (SP)
actuator-control valves, 2000 V3:119
ACU (air-conditioning units), 2004 V1:14
ADA. *See* Americans with Disabilities Act
ADAAG *(Americans with Disabilities Act Accessibility Guidelines),* 2004 V1:105, 106
ADAAG Review Federal Advisory Committee, 2004 V1:123
adapter fittings, 2004 V1:17
addenda in contract documents, 2004 V1:62–63
addresses of organizations and associations, 2004 V1:58–59
adiabatic processes, 2000 V3:200
adjustment section in specifications, 2004 V1:71, 92
administrative and operation costs in value engineering. *See* overhead
administrative authorities, 2004 V1:17
admiralty brass, 2004 V1:144
adp, ADP (apparatus dew points), 2004 V1:14
adsorption, 2000 V3:204
adult-sized wheelchairs, dimensions, 2004 V1:108. *See also* wheelchairs
advanced oxidation water treatment, 2005 V2:228
aerated lagoons, 2000 V3:95
aerating fountain nozzles, 2000 V3:108, 119–120
aeration, 2004 V1:17
aeration cells, 2004 V1:151
aerators
aeration treatment, 2005 V2:208, 228
lavatories and sinks, 2000 V3:33
sovent aerators, 2005 V2:17
aerobic, defined, 2004 V1:17
aerobic wastewater treatment plants, 2005 V2:157–158
AFF (above-finished floor), 2004 V1:14
AFFF foam concentrates, 2000 V3:21
after-coolers
air compressors, 2000 V3:202–203
air dryers and, 2000 V3:207
medical air compressors, 2000 V3:66
after-filters, 2000 V3:203
AGA (American Gas Association)
defined, 2004 V1:17
relief valve standards, 2005 V2:116
water heating standards, 2005 V2:124
age of water mains, 2000 V3:8
age-related disabilities, 2004 V1:107
aggressiveness index, 2005 V2:208
aging disabilities, 2004 V1:107
aging water mains, 2000 V3:8
agitators in kill tanks, 2005 V2:252
agreement documents, 2004 V1:62
agreement states, 2005 V2:248
AHJ. *See* authorities having jurisdiction
ahp, AHP (air horsepower), 2004 V1:14
AHU (air-handling units), 2004 V1:14
AI (aggressiveness index), 2005 V2:208
AIA (American Institute of Architects). *See* American Institute of Architects
air
depleted in air chambers, 2005 V2:81
free, 2004 V1:17, 2000 V3:199, 200–201
oil-free, 2000 V3:83
in pipes, 2005 V2:2
properties, 2000 V3:199
standard, 2004 V1:17–18
water vapor in, 2000 V3:200–201
air, compressed. *See* compressed air (A, X#, X#A)
air, free, 2004 V1:17, 2000 V3:199, 200–201
air, oil-free, 2000 V3:83
air, standard, 2004 V1:17
air-admittance valves, 2004 V1:43, 2005 V2:46
air binding, 2000 V3:178, 180
air-bleed vacuum controls, 2005 V2:189
air-bleed valves, 2005 V2:181
air breaks, 2004 V1:17. *See also* air gaps
air chambers (AC)
defined, 2004 V1:17
self-priming pumps, 2000 V3:142
symbols for, 2004 V1:10
water hammer arresters, 2004 V1:198, 201, 2005 V2:80–81, 81
air circuits in instrumentation, 2000 V3:199
air compressors
accessories, 2000 V3:202–203
compressed air systems, 2000 V3:201–202
dry-pipe systems, 2000 V3:12
medical systems, 2000 V3:65
pulsation, 2000 V3:205
selection factors, 2000 V3:213
sizing, 2000 V3:210–213
types of, 2000 V3:201–202
vacuum pumps, 2005 V2:180
AIR COND (air conditioning). *See* air-conditioning systems
Air-Conditioning and Refrigeration Institute (ARI), 2004 V1:46–47, 58
air-conditioning cooling towers. *See* cooling-tower water
air-conditioning engineers, 2000 V3:27–28

air-conditioning systems (AIR COND)
fixture-unit values, 2005 V2:8
pipes, 2001 V4:36
symbols, 2004 V1:14
waste heat usage, 2004 V1:131
air-conditioning units (ACU), 2004 V1:14
air-consuming devices, 2000 V3:206
air-cooled after-coolers, 2000 V3:203
air densities, calculating, 2004 V1:5
air dryers
compressed air systems, 2000 V3:203–204
deliquescent dryers, 2000 V3:207
desiccant dryers, 2000 V3:207
medical air compressors, 2000 V3:66
refrigerated air dryers, 2000 V3:207
selection, 2000 V3:204
air ducts, 2000 V3:23
air flow rates, 2004 V1:14
air gaps. *See also* air breaks; effective openings
booster pumps and, 2005 V2:73
defined, 2004 V1:17
air-gate valves, 2005 V2:189
air-handling units (AHU), 2004 V1:14, 267
air horsepower (ahp, AHP), 2004 V1:14
air intakes, 2000 V3:211
air locks, 2004 V1:201
air pressure, 2005 V2:176–178, 2000 V3:12
air purges in vacuum pumps, 2005 V2:182
air receivers, 2000 V3:205–206
air springs, 2004 V1:203, 210
air temperatures
pool heating and, 2000 V3:121
swimming pools and, 2000 V3:129
air tests
in cold-water systems, 2005 V2:103
defined, 2004 V1:18
air velocity in vacuum cleaning systems, 2005 V2:190–191
air vessels (chambers), 2004 V1:198
aircraft cable bracing method, 2004 V1:171
aircraft fuel, 2005 V2:12
aL/min (actual liters per minute), 2000 V3:69, 200
ALARA (as low as reasonably achievable), 2005 V2:248
alarm check valves, 2004 V1:13, 18, 2000 V3:9
alarm lines on sprinklers, 2000 V3:9
alarm relays, 2000 V3:24
alarms
aboveground tank leakage, 2000 V3:168
defined, 2004 V1:18, 2000 V3:83
on bulk oxygen supply, 2000 V3:62
on corrosive-waste systems, 2000 V3:40
on hazardous waste systems, 2000 V3:90
on kill tanks, 2005 V2:252
on medical gas systems
area alarms, 2000 V3:72
master alarms, 2000 V3:72
testing, 2000 V3:81
on vacuum systems, 2005 V2:180, 182
overfill prevention, 2000 V3:158, 167
pressurized fuel delivery systems, 2000 V3:162
Alaska Earthquake, 2004 V1:161–162
Albern, W.F., 2005 V2:196
alcohol-resistant AFFF foam concentrates, 2000 V3:21
algae, 2005 V2:199, 205, 2000 V3:148
algaecides, 2000 V3:150
alkalinity
alkaline solutions in corrosion rates, 2004 V1:145
boiler feed water, 2005 V2:226
dealkalizing treatment, 2005 V2:209–210
measuring, 2005 V2:199, 2000 V3:123
pH and, 2005 V2:202–203, 239, 2000 V3:91
predicting scale and corrosion, 2005 V2:206
swimming pool water, 2000 V3:147
water saturation, 2005 V2:207
allowable leakage in compressed air systems, 2000 V3:209
allowable radiation levels, 2005 V2:247
allowable vacuum system pressure loss, 2005 V2:184
alloy pipes, 2004 V1:18
alloys, 2004 V1:18
alpha ray radiation, 2005 V2:246
alt, ALT (altitude), 2004 V1:14
alteration (altrn, ALTRN), 2004 V1:14
alternate bracing attachments for pipes, 2004 V1:174
alternating current (ac, AC), 2004 V1:14
alternative collection and treatment of waste water, 2005 V2:153, 157
alternative energy solutions, 2004 V1:263–267
alternative energy sources, 2004 V1:130–131
alternative sanitary drainage systems, 2005 V2:16–19
alternative sketches in value engineering, 2004 V1:254, 255
Alternatives for Small Wastewater Treatment Systems: Cost-effectiveness Analysis", 2005 V2:162
Alternatives for Small Wastewater Treatment Systems: On-site Disposal/Seepage Treatment and Disposal, 2005 V2:162
Alternatives for Small Wastewater Treatment Systems: Pressure Sewers/Vacuum Sewers, 2005 V2:162
alternators
medical air compressors, 2000 V3:67
vacuum systems, 2000 V3:70
altitude (alt, ALT), 2004 V1:14. *See also* elevation
altitude valves, 2005 V2:172
altrn, ALTRN (alteration), 2004 V1:14
alum, 2005 V2:209, 2000 V3:147, 150
aluminates, 2000 V3:147
aluminosilicates, 2000 V3:204
aluminum, 2004 V1:139, 144, 2005 V2:199, 2000 V3:20, 145
aluminum 1100, 2004 V1:141
aluminum 2017 and 2024, 2004 V1:141
aluminum hydroxide, 2005 V2:199, 2000 V3:149–150
aluminum piping, 2005 V2:50, 2000 V3:47, 210
aluminum silicates, 2005 V2:215, 2000 V3:134
aluminum sulfate, 2005 V2:209, 2000 V3:149–150
Amateur Athletic Union (AAU), 2000 V3:151
amb, AMB (ambient), 2004 V1:14
ambient (amb, AMB), 2004 V1:14
ambient temperature, 2004 V1:18
ambulatory accessible stalls, 2004 V1:114
American Chemical Society, 2004 V1:153
American Concrete Institute, 2005 V2:64
American Consulting Engineers Council (ACEC), 2004 V1:62

American Gas Association (AGA)
codes and standards, 2005 V2:126, 127
defined, 2004 V1:17
relief valve standards, 2005 V2:116
water heating standards, 2005 V2:124
American Institute of Architects (AIA)
General Conditions of the Contract for Construction, 2004 V1:62
Masterspec, 2004 V1:71
medical-gas guidelines, 2000 V3:50
specifications format, 2004 V1:63
American National Standards Association (ANSI)
water hammer arrester certification, 2005 V2:81
American National Standards Institute (ANSI)
abbreviation for, 2004 V1:14, 18
address, 2004 V1:58, 2000 V3:97
consensus process, 2004 V1:41
gas approvals, 2005 V2:126
list of standards, 2004 V1:46
publications, 2004 V1:41
ANSI A112.6.1, 2001 V4:6
ANSI A112.18.3, 2001 V4:14
ANSI A112.19.6, 2001 V4:5, 9
ANSI A117.1-1980, 2004 V1:105
ANSI A117.1-1986, 2004 V1:105
ANSI A117.1-1998, 2004 V1:105, 106, 109–123, 2001 V4:2, 14
ANSI/ASME B16.15 Cast Bronze Threaded Fittings, 2001 V4:34
ANSI/ASME B16.24 Cast Copper Alloy Pipe Flanges and Flanged Fittings, 2001 V4:34
ANSI-ASSI: Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, 2004 V1:191
ANSI/AWWA C104/A21.4 Cement Mortar Lining, 2001 V4:32
ANSI/AWWA C105/A21.5 Polyethylene Encasement, 2001 V4:32
ANSI/AWWA C110/A21.10 Fitting, 2001 V4:32
ANSI/AWWA C111/A21.11 Rubber-Gasket Joints, 2001 V4:32
ANSI/AWWA C115/A21.15 Flanged Pipe, 2001 V4:32
ANSI/AWWA C116/A21.16 Fusion-Bonded Epoxy Coating, 2001 V4:32
ANSI/AWWA C150/A21.50 Thickness Design, 2001 V4:32
ANSI/AWWA C151/A21.51 Manufacturing, 2001 V4:32
ANSI/AWWA C153/A21.53 Compact Fittings, 2001 V4:32
ANSI/AWWA C600 Installation, 2001 V4:32
ANSI B-16.45 Sovent systems, 2005 V2:17
ANSI B3.13: Chemical Plant and Petroleum Refinery Piping, 2000 V3:95
ANSI/NFPA 30: Flammable and Combustible Liquids Code, 2005 V2:127
ANSI/NFPA Standard no. 54: National Fuel Gas Code, 2000 V3:248, 254
ANSI/NSPI-1: Standard for Public Swimming Pools, 2000 V3:125, 151
ANSI/NSPI-5: Standard for Residential, In-ground Swimming Pools, 2000 V3:151
ANSI/UL 144:Pressure Regulating Values for LPG, 2005 V2:127
ANSI Z83.3: Gas Utilization Equipment for Large Boilers, 2005 V2:127
ANSI Z358.1, 2001 V4:18
ANSI ZE 86.1: Commodity Specification for Air, 2000 V3:65, 86
ASME/ANSI B16.22 Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings, 2001 V4:37
ASME/ANSI B16.23 Cast Copper Alloy Solder-Joint Drainage Fittings, 2001 V4:45
ASME/ANSI B16.26 Cast Copper Alloy Fittings for Flared Copper Tube, 2001 V4:37
ASME/ANSI B16.29 Wrought Copper and Wrought Copper Alloy Solder-Joint Drainage Fittings, 2001 V4:45
B16.15 Cast Bronze Threaded Fittings, 2001 V4:27
B16.24 Cast Copper Alloy Pipe Flanges and Flanged Fittings, 2001 V4:27
B36.1 standard, 2001 V4:48
standard air definition, 2000 V3:200
water quality standards, 2005 V2:230
American Petroleum Institute
address, 2000 V3:97, 173
emergency vent standards, 2000 V3:167
publications
AOIRP 1004: Bottom Loading and Vapor Recovery for MC-306 Tank Motor Vehicles, 2000 V3:173
API Bulletin no. 1611: Service Station Tankage Guide, 2000 V3:173
API Bulletin no. 1615: Installation of Underground Gasoline Tanks and Piping at Service Stations, 2000 V3:173
API Specification 12D: Large Welded Petroleum Tanks, 2000 V3:95
API Specification 12F: Small Welded Petroleum Tanks, 2000 V3:95
API Standard 250: Steel Tanks for Oil Storage, 2000 V3:95
removal of globules standards, 2005 V2:255–256
separators, 2000 V3:93
American Public Health Service, 2005 V2:203
American Society for Healthcare Engineering (ASHE), 2005 V2:118
American Society for Testing and Materials (ASTM)
abbreviation for, 2004 V1:18
address, 2004 V1:58
ASTM B819 tubing, 2000 V3:77
consensus process, 2004 V1:41
electronics-grade water standards, 2005 V2:230
high-purity water standards, 2005 V2:229
list of standards, 2004 V1:41, 49–52
membrane filters, 2005 V2:204
publications
A-53 standard, 2001 V4:48
A-74 standard, 2001 V4:28
A-106 standard, 2001 V4:48
A-135 standard, 2001 V4:48
A-716 Culvert Pipe, 2001 V4:32

A-746 Gravity Sewer Pipe, 2001 V4:32
A-888 standard, 2001 V4:28
ASME/ANSI B16.23 Cast Copper Alloy Solder-Joint Drainage Fittings, 2001 V4:45
ASTM D2863: Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics, 2000 V3:85
B-16.9 standard, 2001 V4:48
B-16.11 standard, 2001 V4:48
B-16.28 standard, 2001 V4:48
B-16.50 Wrought Copper Braze Fittings, 2001 V4:45
B-29 standard, 2001 V4:49
B-42 Standard Specification for Seamless Copper Pipe, Standard Sizes, 2001 V4:34
B-43 Standard Specification for Seamless Red Brass Standard Sizes, 2001 V4:27
B-88 Specification for Seamless Copper Water Tube, 2001 V4:35
B-306 Specification for Copper Drainage Tube (DWV), 2001 V4:35
B-306 Standard Specification for Copper Drainage Tube (DWV), 2001 V4:45
B-813 Standard Specification for Liquid and Paste Fluxes for Soldering Applications of Copper and Copper Alloy Tube, 2001 V4:37
B-819 Specification for Seamless Copper Tube for Medical Gas Systems, 2001 V4:35
B-819 Standard Specification for Seamless Copper Tube for Medical Gas Systems, 2001 V4:45
B-828 Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings, 2001 V4:37
C-4 standard, 2001 V4:49
C-12 standard, 2001 V4:49
C-14 Standard Specification for Concrete Sewer, Storm Drain, and Culvert Pipe for Non-reinforced Concrete, 2001 V4:32
C-76 Standard Specification for Reinforced Concrete Culverts, Storm Drain, and Sewer Pipe, 2001 V4:32
C-296 standard, 2001 V4:26
C-301 standard, 2001 V4:49
C-425 standard, 2001 V4:49
C-428 standard, 2001 V4:26
C-443 Standard Specification for Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets, 2001 V4:32
C-599-77 standard, 2001 V4:48
C-655 Standard Specification for Reinforced Concrete D-Load Culvert Storm Drain and Sewer Pipe for Reinforced Concrete Pipe, 2001 V4:32
C-700 standard, 2001 V4:49
C-828 standard, 2001 V4:49
C-896 standard, 2001 V4:49
D-1148 standard, 2001 V4:61
D-1784 standard, 2001 V4:62
D-1785 standard, 2001 V4:62
D-2239 standard, 2001 V4:61
D-2241 standard, 2001 V4:62
D-2464 standard, 2001 V4:62
D-2466 standard, 2001 V4:62
D-2467 standard, 2001 V4:62
D-2609 standard, 2001 V4:61
D-2662 standard, 2001 V4:58
D-2665 standard, 2001 V4:62
D-2666 standard, 2001 V4:58
D-2672 standard, 2001 V4:62
D-2737 standard, 2001 V4:61
D-3139 standard, 2001 V4:62
E-33.08b Plumbing Noise, 2004 V1:194
F-477 standard, 2001 V4:62
F-876 standard, 2001 V4:61
F-877 standard, 2001 V4:61
F-1281 standard, 2001 V4:62
F-1282 standard, 2001 V4:62
reagent-grade water standards, 2005 V2:197, 229
American Society of Civil Engineers (ASCE)
contract publications, 2004 V1:62
sewer publications, 2005 V2:64
American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)
address, 2004 V1:58
cold water systems, 2005 V2:104
defined, 2004 V1:18
hot-water recirculation systems, 2004 V1:265
Legionella standards, 2005 V2:118
list of standards, 2004 V1:47
publications
Handbook of Fundamentals, 2004 V1:2, 5, 6, 40, 2000 V3:197
water heating codes and standards, 2005 V2:124
American Society of Mechanical Engineers (ASME)
address, 2004 V1:58, 2000 V3:97
air receivers, 2000 V3:205
defined, 2004 V1:18
fired and unfired pressure vessel standards, 2005 V2:124
list of standards, 2004 V1:47–48
publications
ANSI/ASME A112.6.1, 2001 V4:6
ANSI/ASME A112.18.1, 2001 V4:14
ANSI/ASME A112.19.6, 2001 V4:5, 9
ANSI/ASME B16.15 Cast Bronze Threaded Fittings, 2001 V4:34
ANSI/ASME B16.24 Cast Copper Alloy Pipe Flanges and Flanged Fittings, 2001 V4:34
ASME A17.1 Safety Code for Elevators and Escalators, 2000 V3:25
ASME/ANSI B16.22 Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings, 2001 V4:37
ASME/ANSI B16.24 Cast Copper Alloy Pipe Flanges and Flanged Fittings, 2001 V4:37
ASME/ANSI B16.26 Cast Copper Alloy Fittings for Flared Copper Tube, 2001 V4:37
ASME/ANSI B16.29 Wrought Copper and Wrought Copper Alloy Solder-Joint Drainage Fittings, 2001 V4:45
ASME Boiler and Pressure Vessel Code, 2000 V3:95
B16.15 Cast Bronze Threaded Fittings, 2001 V4:27
Fuel-Gas Piping, 2005 V2:144

relief valve standards, 2005 V2:116
American Society of Plumbing Engineers (ASPE)
ASPE Solar Energy System Design Handbook, 2004 V1:130
defined, 2004 V1:18
Domestic Water Heating Design Manual, 2005 V2:104, 2000 V3:45
medical gas station guidelines, 2000 V3:50, 51–52
publications, 2005 V2:47
American Society of Plumbing Engineers Research Foundation (ASPERF), 2004 V1:18
American Society of Safety Engineers (ASSE), 2004 V1:18
American Society of Sanitary Engineering (ASSE), 2004 V1:18
address, 2004 V1:58
ASSE 1002, 2001 V4:8
ASSE 6000 Professional Qualifications Standard for Medical Gas Systems Installers, Inspectors, Verifiers, Maintenance Personnel and Instructors, 2001 V4:45
list of standards, 2004 V1:48–49
water hammer arrester certification, 2005 V2:81
American standard pipe threads, 2004 V1:18
American Standards Association. *See* American National Standards Institute (ANSI)
American Water Works Association (AWWA)
address, 2004 V1:58
cold water systems, 2005 V2:67
defined, 2004 V1:18
list of standards, 2004 V1:52
publications
ANSI/AWWA C104/A21.4 Cement Mortar Lining, 2001 V4:32
ANSI/AWWA C105/A21.5 Polyethylene Encasement, 2001 V4:32
ANSI/AWWA C110/A21.10 Fitting, 2001 V4:32
ANSI/AWWA C111/A21.11 Rubber-Gasket Joints, 2001 V4:32
ANSI/AWWA C115/A21.15 Flanged Pipe, 2001 V4:32
ANSI/AWWA C116/A21.16 Fusion-Bonded Epoxy Coating, 2001 V4:32
ANSI/AWWA C150/A21.50 Thickness Design, 2001 V4:32
ANSI/AWWA C151/A21.51 Manufacturing, 2001 V4:32
ANSI/AWWA C153/A21.53 Compact Fittings, 2001 V4:32
ANSI/AWWA C600 Installation, 2001 V4:32
AWWA Cross Connection Control Manual, 2005 V2:104
AWWA Standard for Disinfecting Water Mains, 2005 V2:104
AWWA Standard for Disinfection of Water Storage Facilities, 2005 V2:104
C-400 standard, 2001 V4:26
C651 Disinfecting, 2001 V4:32
American Welding Society (AWS), 2004 V1:52, 58, 167
American wire gage (AWG), 2004 V1:14
Americans with Disabilities Act Accessibility Guidelines (ADAAG), 2004 V1:106
Americans with Disabilities Act (ADA)
ADAAG Review Federal Advisory Committee, 2004 V1:123
faucet flow rates, 2004 V1:135
fixture standards, 2001 V4:2
history, 2004 V1:106
overview, 2004 V1:105
Amin, P., 2005 V2:234
ammonia, 2005 V2:199, 209
amp, AMP, AMPS (ampere). *See* amperes
ampacity, 2000 V3:83
amperes (A, amp, AMP, AMPS)
ampere-hours, 2004 V1:139
amperes per meter, 2004 V1:33
measurement conversions, 2004 V1:33
symbols for, 2004 V1:14
amphoteric corrosion, defined, 2004 V1:151
amphoteric materials, 2004 V1:145
amusement parks, numbers of fixtures for, 2001 V4:19
anaerobic bacteria in septic tanks, 2005 V2:153
anaerobic wastewater treatment, 2000 V3:95
anaerobic, defined, 2004 V1:18, 151
Analysis phase of value engineering, 2004 V1:213, 224. *See also* Function Analysis phase in value engineering
analytical grade water, 2005 V2:229
anchoring equipment
anchorage forces in earthquakes, 2004 V1:186
anchors, defined, 2004 V1:191
fire-protection equipment, 2000 V3:23
illustrations of potential problems, 2004 V1:189
seismic protection, 2004 V1:163
anchoring pipes, 2005 V2:16, 63
anchors, defined, 2004 V1:18, 12004 V1:191
anechoic chambers, 2004 V1:198
anesthesia workrooms
fixtures, 2000 V3:36
health-care facilities, 2000 V3:32
medical air, 2000 V3:53
medical gas stations, 2000 V3:51
anesthetic gas management, 2000 V3:70–71
anesthetics, 2000 V3:83
anesthetizing locations, 2000 V3:83
ANG (angle). *See* angles (ANG)
ANGI (angles of incidence), 2004 V1:14
angle snubbers, 2004 V1:165
angle stops, 2004 V1:18
angle valves (AV), 2004 V1:9, 18
resistance coefficients, 2005 V2:100
angled grates in school shower rooms, 2005 V2:11
angles (ANG)
measurements, 2004 V1:33
symbols, 2004 V1:14
angles of bend, 2004 V1:18
angles of incidence (ANGI), 2004 V1:14
angular acceleration measurements, 2004 V1:33
angular velocity measurements, 2004 V1:33
animal research centers, 2005 V2:251, 2000 V3:51
animal shelters, 2005 V2:15
animal treatment rooms, 2000 V3:45
anions
anion resins, 2005 V2:201, 218
defined, 2004 V1:151, 2005 V2:197
in electromotive force series, 2004 V1:144

in ion exchange, 2005 V2:215, 216
in pH values, 2005 V2:239
annealed temper (soft), 2001 V4:37
annual costs. *See* costs and economic concerns
annular chambers in dry-pipe systems, 2000 V3:11
annular spaces in wells, 2005 V2:164, 166
anodes
anode expected life, 2004 V1:148
anodic protection, 2004 V1:151–152
defined, 2004 V1:139, 151
galvanic series of metals, 2004 V1:141
sacrificial anodes, 2004 V1:147
anodic inhibitors, 2004 V1:151
anodic potential (electronegative potential), 2004 V1:153
anodic protection, defined, 2004 V1:151–152
ANSI. *See* American National Standards Institute (ANSI)
anthracite coal filters, 2005 V2:168, 211, 2000 V3:132, 134
anthropometrics for wheelchairs, 2004 V1:109
anti-cross-connection precautions, 2005 V2:35
anti-siphon ballcocks, 2001 V4:8
anti-vortex drains, 2000 V3:117
anti-vortex grating, 2000 V3:110
apartment buildings
firefighting demand flow rates, 2000 V3:232
gas demand, 2005 V2:135, 136
hot water demand, 2005 V2:109, 110
natural gas demand, 2005 V2:135
numbers of fixtures for, 2001 V4:20, 21
apparatus dew points (adp, ADP), 2004 V1:14
appearance functions
defined, 2004 V1:225
in value engineering, 2004 V1:243
appliances. *See also* fixtures
acoustic ratings, 2004 V1:194–195, 198
codes and standards, 2004 V1:43–44
gas control valves, 2005 V2:127
gas demand, 2005 V2:128
gas regulators, 2000 V3:251
Applied Technology Council (ATC), 2004 V1:183, 191
approaches to toilet compartments, 2004 V1:114
approvals
for radioactive materials systems, 2005 V2:248
for special-waste drainage systems, 2005 V2:237–238
approved, defined, 2004 V1:18
approved testing agencies, 2004 V1:18
approximate (approx., APPROX)
approximate values, 2004 V1:32
defined, 2004 V1:14
appurtenances, in plumbing cost estimation, 2004 V1:93, 97
aquastats, 2004 V1:10, 2000 V3:112, 125
Aqueous Film-Forming Foam (AFFF), 2000 V3:21
aquifers
defined, 2005 V2:163–164
formation of, 2005 V2:163
potentiometric surfaces, 2005 V2:165
unconsolidated aquifers, 2005 V2:165
arabic numerals, 2004 V1:32
arcades, numbers of fixtures for, 2001 V4:19
Architect-engineers Turf Sprinkler Manual, 2000 V3:105
architect's supplemental instructions (ASI), 2004 V1:63
Architectural Barriers Act (90-480), 2004 V1:106
area (A)
calculating, 2004 V1:3–5
conversion factors, 2004 V1:35
measurements, 2004 V1:33
non-SI units, 2004 V1:34
symbols, 2004 V1:14
area alarms, 2000 V3:49, 72, 81
area drains, 2004 V1:18
areas of sprinkler operation, 2000 V3:16
arenas, numbers of fixtures for, 2001 V4:19
ARI (Air Conditioning and Refrigeration Institute), 2004 V1:46–47, 58
arm baths, 2000 V3:32, 35, 38
hot water demand, 2005 V2:109
Army Corps of Engineers, 2004 V1:63
arresters for water hammer. *See* water hammer arresters
arterial vents, 2004 V1:18
articulated-ceiling medical gas systems, 2000 V3:59
"as low as reasonably achievable" (ALARA), 2005 V2:248
ASA A117.1-1961, 2004 V1:105
asbestos cement piping, 2005 V2:83, 2000 V3:245
asbestos concrete piping, 2001 V4:26
ASCE. *See* American Society of Civil Engineers (ASCE)
ASHE (American Society for Healthcare Engineering), 2005 V2:118
ASHRAE. *See* American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)
Legionella standards, 2005 V2:118
ASI (architect's supplemental instructions), 2004 V1:63
ASME. *See* American Society of Mechanical Engineers (ASME)
ASPE. *See* American Society of Plumbing Engineers (ASPE)
ASPERF (American Society of Plumbing Engineers Research Foundation), 2004 V1:18
asphalt-dipped piping, 2005 V2:86
aspirating nozzles on foam extinguishers, 2000 V3:21
aspirators, 2004 V1:18, 2000 V3:38
ASSE. *See* American Society of Safety Engineers (ASSE); American Society of Sanitary Engineering (ASSE)
assembly costs, 2004 V1:222
assembly halls
numbers of fixtures for, 2001 V4:19, 21
single-occupant toilet rooms, 2001 V4:23
assisted creativity, 2004 V1:232
assisted living facilities, numbers of fixtures for, 2001 V4:20
Association for the Advancement of Medical Instrumentation (AAMI), 2005 V2:197, 229, 230
Association of State Drinking Water Administrators, 2005 V2:163
ASTM. *See* American Society for Testing and Materials (ASTM)
ASTM A53 piping, 2000 V3:254
ASTM A106 piping, 2000 V3:254
ASTs (aboveground storage tanks). *See* aboveground tank systems
ATBCB (U.S. Architectural and Transportation Barriers Compliance Board), 2004 V1:106, 107
ATC-3 (Tentative Provisions for the Development of Seismic Regulations for Buildings), 2004 V1:183, 191

Atienze, J., 2005 V2:35
atm, ATM (atmospheres). *See* atmospheres
atmospheres (atm, ATM)
  converting to SI units, 2004 V1:39
  symbols, 2004 V1:14
  vacuum units, 2005 V2:176
atmospheric pressure in vacuum, 2005 V2:175
atmospheric regulators, 2000 V3:251
atmospheric tanks
  defined, 2000 V3:153
  foam, 2000 V3:21
  venting, 2000 V3:157–158
atmospheric vacuum breakers (AVB)
  defined, 2004 V1:18
  faucets, 2001 V4:14
  irrigation sprinklers, 2000 V3:103, 104
atmospheric vaporizers, 2000 V3:61
atmospheric vents (steam or hot vapor) (ATV), 2004 V1:9
attachments, 2004 V1:191
"atto" prefix, 2004 V1:34
ATV (atmospheric vents), 2004 V1:9
Auciello, Eugene P., 2005 V2:64
auditoriums, numbers of fixtures for, 2001 V4:19, 21
augered wells, 2005 V2:164
authorities having jurisdiction
  alternative sanitary systems, 2005 V2:16
  defined, 2004 V1:17, 18, 2000 V3:83
  fire hazard evaluations, 2000 V3:2
  fire-protection system design, 2000 V3:1
  gaseous fire-suppression systems, 2000 V3:22
  manholes, 2000 V3:234
  medical gas stations, 2000 V3:56
  public sewer availability, 2000 V3:234
  swimming pools, 2000 V3:127
automatic air vents (AAV), 2004 V1:10
automatic alternators, 2000 V3:70
automatic drain valves, 2000 V3:103
automatic drains in vacuum systems, 2000 V3:70
automatic fill lines makeup-water systems, 2000 V3:124
automatic fire-detection devices, 2000 V3:13
automatic fire-protection systems, 2000 V3:1–18
  history and objectives, 2000 V3:1–2
  pipes and hangers, 2000 V3:15
automatic flushometer valves, 2001 V4:8
automatic heat-up, 2000 V3:191, 195, 196
automatic overfill prevention, 2000 V3:167
automatic overrides for irrigation controllers, 2000 V3:104
automatic skimmers, 2000 V3:146
Automatic Sprinkler and Standpipe Systems, 2000 V3:29
automatic sprinkler systems
  combined dry-pipe and pre-action, 2000 V3:15
  design density, 2000 V3:15
  effectiveness statistics, 2000 V3:2
  elevator shafts, 2000 V3:25
  fire hazard evaluation, 2000 V3:2–3
  fire pumps for, 2000 V3:25
  gaseous fire-suppression systems and, 2000 V3:22
  history, 2000 V3:1–2
  hydraulic design, 2000 V3:15–18
  materials, 2000 V3:12
  numbers of sprinklers in operation, 2000 V3:16
  pipes and hangers, 2000 V3:12, 15
  pre-action systems, 2000 V3:13
  system design, 2000 V3:2–18
  types, 2004 V1:29, 2000 V3:8–15
  water supplies, 2000 V3:3–8
Automatic Sprinkler Systems Handbook, 2004 V1:191
automatic storage water heaters, 2005 V2:111
automatic tank gauging, 2000 V3:159–160
automatic trap primers, 2005 V2:10
automotive traffic, 2005 V2:11
autopsy rooms
  fixtures, 2000 V3:35, 38
  health-care facilities, 2000 V3:32
  medical gas stations, 2000 V3:51, 58
  medical vacuum, 2000 V3:54
  non-potable water, 2000 V3:45
AV (acid vents), 2004 V1:8, 17
AV (angle valves), 2004 V1:9, 18
availability. *See* demand
available vacuum, safety factors and, 2005 V2:195
AVB. *See* atmospheric vacuum breakers (AVB)
average (avg, AVG), defined, 2004 V1:14
avg, AVG (average), 2004 V1:14
AW (acid wastes), 2004 V1:8, 17, 2000 V3:42
AWG (American wire gage), 2004 V1:14
AWS. *See* American Welding Society (AWS)
AWWA. *See* American Water Works Association (AWWA)
Ayres, J.M., 2004 V1:191
az, AZ (azimuth). *See* azimuth (az, AZ)
azimuth (az, AZ)
  solar (SAZ), 2004 V1:14
  symbols for, 2004 V1:14
  wall (WAZ), 2004 V1:14

B

B-16.9 standard, 2001 V4:48
B-16.11 standard, 2001 V4:48
B-16.15 Cast Bronze Threaded Fittings, 2001 V4:27
B-16.24 Cast Copper Alloy Pipe Flanges and Flanged Fittings, 2001 V4:27
B-16.28 standard, 2001 V4:48
B-29 standard, 2001 V4:49
B-36.1 standard, 2001 V4:48
B-43 Standard Specification for Seamless Red Brass Standard Sizes, 2001 V4:27
b/m (bills of material), 2004 V1:14
back pressure tests, 2001 V4:5
back pressures in pipes, 2005 V2:2, 4, 2000 V3:251
back-siphonage, 2004 V1:18, 2000 V3:103. *See also* backflow
  defined, 2005 V2:67
back-spud water closets, 2001 V4:3
back-to-back water closets, 2001 V4:6–7
backfilling
  around septic tanks, 2005 V2:154
  backfill defined, 2004 V1:18
  building sewers and, 2005 V2:14
  fountain piping systems, 2000 V3:116
  labor productivity rates, 2004 V1:96
  in plumbing cost estimation, 2004 V1:93
  storage tanks, 2000 V3:155, 172
backflow. *See also* back-siphonage
  backflow connections, defined, 2004 V1:18

defined, 2004 V1:18, 2005 V2:67
backflow preventers
codes, 2004 V1:42
cold-water systems, 2005 V2:69–70
cross-connection control devices, 2005 V2:69–70
defined, 2004 V1:18
domestic cold water systems, 2005 V2:69–70
domestic water supply, 2000 V3:221–224
faucets, 2001 V4:13–14
fire-protection connections, 2000 V3:225, 226
fixtures in health-care facilities, 2000 V3:33
makeup water in fountains, 2000 V3:124
pressure loss, 2000 V3:224
reduced pressure zones, 2000 V3:223
thermal expansion compensation and, 2005 V2:116
vacuum breakers, 2000 V3:33, 45
background levels of radiation, 2005 V2:247
backing rings, 2004 V1:18
backup, defined, 2004 V1:18
backup demineralizers, 2000 V3:46
backup storm-drainage systems, 2005 V2:55–56
backwash from pool filtration, 2000 V3:112, 113, 137
backwash from water softeners, 2005 V2:168, 220
backwash pits, 2000 V3:137, 140, 143
backwashing
diatomaceous earth filters, 2000 V3:139
filters, 2005 V2:211
in regeneration cycle, 2005 V2:217
sand filters, 2000 V3:132
vacuum diatomaceous earth filtration, 2000 V3:135
backwater valves, 2004 V1:19, 43, 2005 V2:12
bacteria
biological fouling, 2005 V2:205, 228
chemical control, 2005 V2:223
demineralizer systems, 2000 V3:46
distilled water and, 2000 V3:46
in drinking water, 2005 V2:168
in feed water, 2005 V2:198–199
in filters, 2005 V2:211
in hot water, 2000 V3:45
killing in water systems, 2005 V2:120–122
in septic tanks, 2005 V2:153
in swimming pools, 2000 V3:148
in water-heating systems, 2005 V2:117–122
in wells, 2005 V2:166
baffle systems, 2000 V3:46
baffleplates, 2004 V1:18
bag-filter gross filtration, 2005 V2:211
Bahamas, gray-water systems in, 2005 V2:35
bailers, 2000 V3:162
balancing pumps, 2004 V1:197
balancing valves (BLV), 2004 V1:9, 2000 V3:115
ball-and-globe valves, 2000 V3:118
ball check valves, 2004 V1:18
ball joints, bracing and, 2004 V1:171
ball removal tests, 2001 V4:5
ball valves (BV), 2004 V1:9, 18, 2005 V2:240, 2000 V3:72
resistance coefficients, 2005 V2:100
Ballanco, Julius, 2005 V2:64
ballast pads, 2000 V3:172
ballcocks, 2001 V4:8
Baltimore Dept. of Public Works, 2005 V2:35
banned practices in asbestos concrete piping, 2001 V4:26
banquet halls, numbers of fixtures for, 2001 V4:19
bare pipe, 2004 V1:150, 2004 V1:150
barium, 2005 V2:199
baro, BARO (barometric), 2004 V1:14
baro pr, BARO PR (barometric pressure). *See* barometric pressure
barometers (baro, BARO)
symbols for, 2004 V1:14
vacuums and, 2005 V2:176
barometric (baro, BARO), defined, 2004 V1:14
barometric pressure (baro pr, BARO PR, BP), 2000 V3:200
altitude adjustments, 2005 V2:178
barometric, defined, 2004 V1:14
barometric pressure, defined, 2004 V1:15
in vacuums, 2005 V2:176, 194
barrels
converting to SI units, 2004 V1:39
dimensions, 2001 V4:29–31
barrier free, 2004 V1:18. *See also* people with disabilities
barriers
around tanks, 2000 V3:169
in sound insulation, 2004 V1:193
bars, converting to SI units, 2004 V1:39
bars, numbers of fixtures for, 2001 V4:19
base acquisition costs, 2004 V1:223
base materials
base defined, 2004 V1:18
compounds in water, 2005 V2:198
pH control, 2000 V3:91–92
base units, 2004 V1:33
basic functions in value engineering, 2004 V1:225, 227, 230
basic material standards, 2004 V1:66
Basic Plumbing Code (BOCA), 2000 V3:154
basket strainers
fountain pumps, 2000 V3:116
head loss and, 2000 V3:115
maintenance, 2000 V3:110
materials, 2000 V3:146
pre-manufactured skimmers, 2000 V3:137
pumps, 2000 V3:115
resistance coefficients, 2005 V2:100
swimming pool pumps, 2000 V3:140
bathhouses, 2005 V2:159, 2000 V3:129, 130
bathing rooms, 2004 V1:112–113
bathroom groups, 2000 V3:217
bathtub fill valves, 2001 V4:16
bathtubs
accessibility design, 2004 V1:117–119
acoustic ratings of, 2004 V1:194
bathtub enclosures, 2004 V1:118–119
estimated water flows from, 2005 V2:33
fixture pipe sizes and demand, 2005 V2:94
fixture-unit loads, 2005 V2:3
grab bars, 2004 V1:116, 117
gray-water systems and, 2004 V1:135, 2005 V2:26
health-care facilities, 2000 V3:32
hot water demand, 2005 V2:109
infant bathtubs, 2000 V3:34
minimum numbers of, 2001 V4:18–22
overflows, 2001 V4:16

patient rooms, 2000 V3:34
resilient-mounting design, 2004 V1:206
seats, 2004 V1:122
sound-damping materials, 2004 V1:196
standards, 2001 V4:2
temperatures, 2000 V3:45
types and requirements, 2001 V4:16
water fixture unit values, 2000 V3:217
batteries
corrosion cells in sacrificial anodes, 2004 V1:148
of fixtures, 2004 V1:18
batteries of fixtures
circuit and loop venting, 2005 V2:40–41
defined, 2005 V2:39
battery-controlled valves, 2004 V1:135
Baumeister, Theodore, 2004 V1:1, 2, 3, 5, 40
BCMC (Board for Coordination of Model Codes), 2004 V1:106
BCuP brazing, 2001 V4:45
beach components in pools, 2000 V3:128
bead-to-bead joints, 2001 V4:47
bead-to-cut-glass end joints, 2001 V4:47
beam clamps, 2004 V1:190
Beausoliel, R.W., 2005 V2:48
bed locator units, 2000 V3:57
bedding and settlement
building sewers and, 2005 V2:14–15
defined, 2000 V3:234
illustrated, 2000 V3:235
pipe supports and, 2005 V2:13
protecting against settlement, 2005 V2:16
settlement loads, 2004 V1:186
bedpan washers, 2000 V3:32, 34, 36, 38
bell-and-spigot joints and piping. *See also* hub-and-spigot piping and joints
defined, 2004 V1:18
earthquake protection and, 2004 V1:167
bell-hub depressions, 2005 V2:14
bell-mouth inlets or reducers, 2005 V2:101
bellows-style water hammer arresters, 2005 V2:81, 82
bells, defined, 2004 V1:18
bend-and-loop pipe configurations, 2004 V1:199
bending movements, conversion factors, 2004 V1:35
benefits in value engineering presentations, 2004 V1:258
Bennett, E.R., 2005 V2:161
bentonite clay, 2005 V2:215
bentonite grout, 2005 V2:167
Bernoulli's equation, 2004 V1:5–6
beta ray radiation, 2005 V2:246
BFP (backflow preventers). *See* backflow preventers
BFV (butterfly valves), 2004 V1:9, 20
bhp, BHP (brake horsepower), 2004 V1:6, 14
bicarbonates, 2005 V2:199, 206, 210
bid bonds, 2004 V1:62
bid by invitation, 2004 V1:62
bid shopping, 2004 V1:68
bidders
defined, 2004 V1:61
information in project manuals, 2004 V1:61
well construction, 2005 V2:172
bidding documents, 2004 V1:61
bidding requirements, 2004 V1:61
Biddison, 2004 V1:191
bidets, 2005 V2:94, 2000 V3:217, 2001 V4:2, 16–17
bills of material (b/m, BOM), 2004 V1:14
bimetallic traps, 2000 V3:182
binding, preventing in cleanouts, 2005 V2:9
biochemical measurements of microorganisms, 2005 V2:199
biocides, 2005 V2:223, 227, 228, 232–233
biodegradable foam extinguishers, 2000 V3:21
biofilm, 2005 V2:120
biofouling, 2005 V2:205, 227
biohazardous materials. *See* infectious and biological waste systems
biological and biomedical laboratories. *See* laboratories
biological characteristics of drinking water, 2005 V2:228
biological control in pure water systems. *See also* microbial growth and control
biological fouling, 2005 V2:205, 227
biological oxygen demand (BOD), 2000 V3:21, 93
biological treatment
in gray-water treatment, 2005 V2:32
of oil spills, 2005 V2:255
in pure water systems, 2005 V2:232–233
of sewage in septic tanks, 2005 V2:153
wastewater treatment plants, 2000 V3:93
biological waste systems. *See* infectious and biological waste systems
bio-pure water, 2000 V3:46
biosafety cabinets, 2005 V2:251
biosafety levels (BL1-BL4), 2005 V2:251
biostats, 2005 V2:223, 228
birthing rooms, 2000 V3:36, 52, 58
bitumastic-enamel-lined piping, 2005 V2:83
bituminized felt, 2004 V1:196
BL1-4 levels, 2005 V2:251
black iron coated pipe, 2001 V4:48
black pipes, 2004 V1:18
black steel piping, 2005 V2:50, 2000 V3:165, 254
black-water systems
amount of generated black water, 2005 V2:31
compared to gray water, 2005 V2:25, 31
estimating sewage quantities, 2005 V2:158–160
bladder bags, 2004 V1:116
bladder tanks, 2000 V3:21
blades in pumps, 2004 V1:197
Blake, Richard T., 2005 V2:234
blank flanges, 2004 V1:18
blast furnace gas, 2005 V2:126
blast gates, 2005 V2:189
bleachers, numbers of fixtures for, 2001 V4:19
bleaches, 2005 V2:156
bleed air, 2005 V2:181
bleed cocks, 2000 V3:4
block-like soils, 2005 V2:148
block-method irrigation, 2000 V3:100
blocking creativity, 2004 V1:231–232
blood analyzers, 2005 V2:13
blood or other objectionable materials, 2005 V2:15. *See also* infectious and biological waste systems
blood-type floor drains, 2000 V3:35
blow-off in air compressors, 2000 V3:205
blowdown

boiler blowdown, 2005 V2:226, 227
cooling towers, 2005 V2:227
removing sludge, 2005 V2:205
steam traps, 2000 V3:195
blowout fixtures, acoustic design and, 2004 V1:195
blowout urinals, 2001 V4:8–9, 9
blowout water closets, 2001 V4:3
blue dyes in gray water, 2005 V2:35
blue water in pools, 2000 V3:148
BLV (balancing valves), 2004 V1:9, 2000 V3:115
Board for Coordination of Model Codes (BCMC), 2004 V1:106
boarding houses, numbers of fixtures for, 2001 V4:20
bobbin-wound fiberglass filters, 2000 V3:131
BOCA. *See* Building Officials and Code Administrators International, Inc. (BOCA)
BOD (biological oxygen demand), 2000 V3:21, 93
body sprays, 2001 V4:16
Boegly, W.J., 2005 V2:161
Boiler and Pressure Vessel Code, 2000 V3:95
boiler blow-off tanks, 2004 V1:18
boiler blow-offs, 2004 V1:18
boiler feed lines, 2001 V4:34
boiler room earthquake protection, 2004 V1:166
Boiler Water Treatment, 2005 V2:234
boilers
cast-iron supports for, 2004 V1:162
codes and standards, 2004 V1:42
condensation, 2004 V1:267
earthquake protection, 2004 V1:163
feed lines, 2001 V4:34
feed pumps, 2000 V3:188–189
feed receivers, 2000 V3:188
feed water corrosion inhibitors, 2004 V1:151
feed water treatments, 2005 V2:226
gas train arrangements, 2000 V3:251
scaling, 2005 V2:205
sediment buckets in drains, 2005 V2:11
short cycling, 2000 V3:180
steam heating systems, 2000 V3:178
swimming pool heaters, 2000 V3:138
boiling points (bp, BP)
defined, 2005 V2:142
liquid fuels, 2000 V3:153
liquid oxygen, 2000 V3:61
symbols for, 2004 V1:14
bollards, 2000 V3:169, 172
bolting problems in seismic protection, 2004 V1:190
bolts for water closets, 2001 V4:6
BOM (bills of material), 2004 V1:14
bonded joints, 2004 V1:150
bonds and certificates, 2004 V1:62
bonnets, 2004 V1:18
booster-pump systems
cold-water supplies, 2005 V2:70–77
connections, 2000 V3:225
domestic water service, 2000 V3:216
fire-protection systems, 2000 V3:8
in health-care facilities, 2000 V3:44
low-pressure fire pumps, 2000 V3:25
noise control, 2004 V1:199
vacuum systems, 2005 V2:182
booster water heaters, 2004 V1:126, 129, 2005 V2:111
borate, 2005 V2:199
bored wells, 2005 V2:164–165, 172
borosilicate glass piping, 2005 V2:13, 14, 83, 2000 V3:40, 2001 V4:47
Bosich, Joseph F., 2004 V1:154
bottled water, 2001 V4:14
Bottom Loading and Vapor Recovery for MC-306 Tank Motor Vehicles (AOIRP 1004), 2000 V3:173
Bourdon gauges, 2005 V2:181
bowl depth of sinks, 2004 V1:117
Boyle's law, 2005 V2:73
BP (barometric pressure). *See* barometric pressure
bp, BP (boiling points). *See* boiling points (bp, BP)
braces (walking aids), 2004 V1:107
bracing
aircraft cable method, 2004 V1:171
alternate attachments for pipes, 2004 V1:174
avoiding potential earthquake problems, 2004 V1:189
defined, 2004 V1:191
hanger rod connections, 2004 V1:177
hanger rods, 2004 V1:166
hubless cast-iron pipe, 2004 V1:177
lateral sway bracing, 2004 V1:181–182
longitudinal and transverse bracing, 2004 V1:180
longitudinal-only bracing, 2004 V1:172, 180
open-web steel joists, 2004 V1:176
pipes on trapeze and, 2004 V1:175, 178
piping systems for seismic protection, 2004 V1:166–182
riser bracing for hubless pipes, 2004 V1:178
self bracing, 2004 V1:190
spacing of, 2004 V1:184
steel beam connections, 2004 V1:175
structural angle bracing, 2004 V1:171
structural channel bracing, 2004 V1:171
strut bracing, 2004 V1:173, 175
superstrut, 2004 V1:170
sway bracing, 2004 V1:179, 180, 181–182, 185–186, 187
Tension 360 bracing, 2004 V1:169
transverse bracing, 2004 V1:171, 179
truss-type actions, 2004 V1:190
typical earthquake bracing, 2004 V1:168
brainstorming in creativity, 2004 V1:232
brake horsepower (bhp, BHP)
fire pumps, 2000 V3:25
pumps, 2004 V1:6
symbols for, 2004 V1:14
branch-bottom connections, 2004 V1:11
branch intervals, 2004 V1:18, 2005 V2:38
branch length method, 2005 V2:67, 97, 98–99
branch lines, 2000 V3:85
branch sewers (submain sewers), 2004 V1:30
branch tees, 2004 V1:18
branch-top connections, 2004 V1:11
branch vents, 2004 V1:18
air admittance valves, 2005 V2:46
defined, 2005 V2:38
sizing, 2005 V2:38
branches, defined, 2004 V1:18
brand names in specifications, 2004 V1:66, 67
brass
dezincification, 2004 V1:141

in electromotive force series, 2004 V1:144
in galvanic series, 2004 V1:141
brass (copper alloy) pipe, 2005 V2:13, 2001 V4:27
brass floor drains, 2005 V2:15
brass pipes, 2005 V2:50, 83, 86, 2000 V3:116
brass pool lighting, 2000 V3:145
brazed joints
earthquake protection and, 2004 V1:167
inspection, 2000 V3:80
medical gas tubing, 2000 V3:77, 2001 V4:45
brazing ends, 2004 V1:18
Brazing Joints for Copper and Copper Alloy Pressure Fittings, 2001 V4:45
break points (chlorination), 2000 V3:149
break tanks, 2005 V2:73
breakdown chlorination, 2000 V3:149
breathing apparatus
chlorine gas, 2000 V3:148
diatomaceous earth and, 2000 V3:134
for emergencies, 2005 V2:239, 241
brines
hydrostatic monitoring systems, 2000 V3:160
refrigerants, 2004 V1:151
in water softening, 2005 V2:220
British thermal units (Btu, BTU)
British thermal units per hour (Btu/h), 2004 V1:18, 2000 V3:122
Btu (J) (fire loads), 2000 V3:3
calculating hot water savings, 2004 V1:127
converting to SI units, 2004 V1:39
defined, 2004 V1:18, 136
natural gas services, 2000 V3:249
symbols for, 2004 V1:14
bromine, 2005 V2:120, 2000 V3:123, 149
bromtrifluoro-methane CBrF3 (halon 1301), 2004 V1:25
bronze filtration tanks, 2000 V3:131
Bronze Fittings for Brazed Joints, 2001 V4:27, 34
bronze-mounted, defined, 2004 V1:18
bronze pumps, 2000 V3:115, 145
bronze sediment buckets, 2005 V2:13
bronze trim, 2004 V1:18
bronze valves, 2000 V3:145
bronze, in electromotive force series, 2004 V1:141
Brown & Sharpe wire gage (B&S), 2004 V1:14
Brown, F.R., 2004 V1:191
Brown, J., 2005 V2:234
brown water, 2000 V3:147
Brownstein, E., 2005 V2:47
brushes for swimming pool cleaning, 2000 V3:146
Bryan, John L., 2000 V3:29
B&S (Brown & Sharpe wire gage), 2004 V1:14
Btu, BTU (British Thermal units). *See* British Thermal units
Btu/h (British thermal units per hour), 2004 V1:18, 2000 V3:122
Btu (J) (fire loads), 2000 V3:3
bubble aerators, 2005 V2:208
bubbler irrigation heads, 2000 V3:103
bubbles, 2000 V3:21. *See also* detergents; soaps; suds
buffing finishes on grates, 2005 V2:11
building code list of agencies, 2004 V1:42
Building Code Requirements for Minimum Design Loads in Buildings and Other Structures, 2004 V1:191
building drains
combined, 2004 V1:19
cross-sections of, 2005 V2:2
defined, 2004 V1:19
flow in, 2005 V2:2
inspection checklist, 2004 V1:102–103
installation, 2005 V2:14–15
pneumatic pressure in, 2005 V2:2–3
sanitary. *See* sanitary drainage systems
storm. *See* storm-drainage systems
building inspectors, 2000 V3:2
Building Officials and Code Administrators International, Inc. (BOCA), 2005 V2:64, 2000 V3:154
BOCA Basic Plumbing Code, 2005 V2:64, 2000 V3:154
building sewers (house drains), 2004 V1:19, 2005 V2:14–15
building sites. *See* site utilities; sites
building storm-sewer pipe codes, 2004 V1:42
building subdrains, 2004 V1:19
Building Systems Design, 2005 V2:196
building traps, 2004 V1:19
defined, 2005 V2:38
vent sizing and, 2005 V2:43–44
buildings
acceptable plumbing noise levels, 2004 V1:193
building material acoustic insulation, 2004 V1:193
construction and fire hazards, 2000 V3:2
defined, 2004 V1:18
essential facilities, 2004 V1:191
expansion, 2000 V3:49
minimum numbers of fixtures, 2001 V4:18–22
standard fire tests, 2000 V3:3
storm-drainage systems. *See* storm-drainage systems
subdrains, 2004 V1:19
traps, 2004 V1:19
type of structure and earthquake protection, 2004 V1:167
utilities. *See* site utilities
built-in continuous pool gutters, 2000 V3:137
built-in showers, 2001 V4:15
bulk media tests, 2001 V4:6
bulk oxygen systems, 2000 V3:59, 61–62, 63
bulkhead fittings, 2000 V3:163
bull head tees, 2004 V1:20
bumpers, 2000 V3:228, 229
Buna-N (nitrile butadiene), 2000 V3:169
Bunsen burners, 2005 V2:128–129
buried piping. *See* underground piping
burners, defined, 2005 V2:142
burning methane, 2004 V1:130–131
burning rates of plastic pipe, 2001 V4:59–60
burst pressure, 2004 V1:20
Burton, Franklin L., 2000 V3:125
bushels, converting to SI units, 2004 V1:39
bushings, 2004 V1:20, 2005 V2:100
businesses, numbers of fixtures for, 2001 V4:19
butane, 2005 V2:126, 143. *See also* fuel-gas piping systems
butt caps on fire hydrants, 2000 V3:4
butt-welded standard weight pipe, 2001 V4:48
butt welding

butt-weld end connections, 2004 V1:23
butt weld joints, 2004 V1:20
butt weld pipes, 2004 V1:20
radioactive drainage systems, 2005 V2:249
butterfly valves (BFV), 2004 V1:9, 20, 2000 V3:118
resistance coefficients, 2005 V2:100
butylene, 2005 V2:126
BV (ball valves), 2004 V1:9, 18, 2005 V2:240
bypass systems for pools, 2000 V3:122, 144
bypass valves, 2004 V1:20, 2001 V4:18
bypasses, 2004 V1:20

C

C, °C (celsius), 2004 V1:14, 34
c (centi) prefix, 2004 V1:34
C (conductance), 2004 V1:14, 33
C (coulombs), 2004 V1:33, 139
c (curies), 2005 V2:247
C (specific heat). *See* specific heat
c to c, C TO C (center to center), 2004 V1:14
C-4 standard, 2001 V4:49
C-12 standard, 2001 V4:49
C-296 standard, 2001 V4:26
C-301 standard, 2001 V4:49
C-400 standard, 2001 V4:26
C-425 standard, 2001 V4:49
C-428 standard, 2001 V4:26
C-599-77 standard, 2001 V4:48
C-700 standard, 2001 V4:49
C-828 standard, 2001 V4:49
C-896 standard, 2001 V4:49
C/m^3 (coulombs per cubic meter), 2004 V1:33
CAAA (Clean Air Act Amendments), 2000 V3:154
cables, earthquake protection and, 2004 V1:166
CABO (Council of American Building Officials), 2004 V1:123
cadmium, 2004 V1:141
calcification in filters, 2000 V3:132, 150
calcium
defined, 2005 V2:200
scale formation and corrosion, 2005 V2:206
in water, 2005 V2:168, 199
calcium 45, 2005 V2:248
calcium bicarbonate, 2005 V2:199
calcium carbonate (lime), 2005 V2:199, 200, 201, 206, 2000 V3:147
calcium chloride, 2005 V2:200
calcium hydroxide, 2005 V2:200
calcium hypochlorite, 2005 V2:168, 2000 V3:148–149, 149, 150–151
calcium phosphate, 2005 V2:200
Calcium Saturation Index (CSI), 2000 V3:123
calcium silicates, 2005 V2:200
calcium sulfate, 2005 V2:199
calculations. *See* equations
calendars for irrigation controllers, 2000 V3:104
California Administrative Code of Regulations, 2004 V1:183
California Code of Regulations, 2004 V1:191
California Plumbing Code, 2005 V2:36
calories, converting to SI units, 2004 V1:39
calorific values in fire loads, 2000 V3:2–3
Cameron Hydraulic Data, 2005 V2:104
Cameron's Hydraulic Data, 2000 V3:221
camps, septic tank systems for, 2005 V2:156–157
CAN/CSA-B137.1 standard, 2001 V4:61
CAN/CSA-B137.2 standard, 2001 V4:62
CAN/CSA-B137.3 standard, 2001 V4:62
CAN/CSA-B137.9 standard, 2001 V4:62
CAN/CSA-B137.10 standard, 2001 V4:62
can pumps, 2004 V1:24
CAN3-B137.8 standard, 2001 V4:58
Canadian Standards Association (CSA)
address, 2004 V1:58, 2000 V3:86
consensus process, 2004 V1:41
list of standards, 2004 V1:53–54
medical compressed air standards, 2000 V3:67
publications
CAN/CSA-B137.1 standard, 2001 V4:61
CAN/CSA-B137.2 standard, 2001 V4:62
CAN/CSA-B137.3 standard, 2001 V4:62
CAN/CSA-B137.9 standard, 2001 V4:62
CAN/CSA-B137.10 standard, 2001 V4:62
CAN3-B137.8 standard, 2001 V4:58
CSA Z-305.1: Non-flammable Medical Gas Piping Systems, 2000 V3:86
water closet standards, 2001 V4:6
candelas (cd), 2004 V1:33
candelas per meter squared (cd/m^2), 2004 V1:33
cantilevered drinking fountains, 2004 V1:112
CAP (College of American Pathologists), 2005 V2:197, 229
capacitance
measurements, 2004 V1:33
tank gauging, 2000 V3:160
capacity (flow). *See* flow rates
capacity of swimming pools, 2000 V3:127–128
capillaries, 2004 V1:20
caps on ends of pipes, 2004 V1:11
capture-type vacuum pumps, 2005 V2:180
car traffic, 2005 V2:11
car washes
gray-water use, 2004 V1:267
heat recovery systems, 2004 V1:266
carbohydrazide, 2005 V2:226
carbon
adsorption of oil spills, 2005 V2:255
corrosion, 2004 V1:139, 145
total organic carbon, 2005 V2:204
in water, 2005 V2:199
carbon 14, 2005 V2:248
carbon dioxide (CO^2)
color coding, 2000 V3:56
decarbonation, 2005 V2:210
extinguishing systems, 2000 V3:20–21
medical gas system tests, 2000 V3:83
portable fire extinguishers, 2000 V3:27
in steam systems, 2000 V3:190
symbols for, 2004 V1:9
in water, 2005 V2:199, 200, 209
Carbon Dioxide Extinguishing Systems (NFPA 12), 2000 V3:20, 29
carbon filtration (absorphan). *See* activated carbon filtration (absorphan)
carbon monoxide, 2005 V2:126, 2000 V3:83

carbon steel, 2004 V1:144, 2000 V3:91, 92, 116, 210
carbonate films, 2004 V1:151
carbonates, 2005 V2:199, 200, 206, 2000 V3:147
carbonic acid, 2005 V2:199
carburetted water gas, 2005 V2:126
carpets, vacuum calculations for, 2005 V2:190
cartridge filtration, 2005 V2:211, 219, 224, 231, 2000 V3:112, 113
Cartwright, Peter, 2005 V2:234
cascade waterfall aerators, 2005 V2:208
casings
  driven wells, 2005 V2:165
  jetted wells, 2005 V2:165
  well casings, 2005 V2:164
Cassidy, Victor M., 2004 V1:137
cast bronze solder-joint fittings, 2001 V4:38
cast bronze threaded fittings, 2001 V4:27
Cast Bronze Threaded Fittings, 2001 V4:27, 34
Cast Copper Alloy Fittings for Flared Copper Tube, 2001 V4:37
Cast Copper Alloy Pipe Flanges and Flanged Fittings, 2001 V4:27, 34, 37
Cast Copper Alloy Solder-Joint Drainage Fittings, 2001 V4:45
cast-filled acrylic fixtures, 2001 V4:2
cast-filled fiberglass fixtures, 2001 V4:2
cast glands, 2000 V3:229
cast-in-place anchor bolts, 2004 V1:163
cast iron
  in electromotive series, 2004 V1:144
  fountain pumps, 2000 V3:115
  in galvanic series, 2004 V1:141
  graphitization, 2004 V1:141
  radiators, 2000 V3:179, 180
  swimming pool main drains, 2000 V3:143
cast-iron boiler supports, 2004 V1:162
cast-iron fixtures
  enameled, 2001 V4:1–2
  in health-care facilities, 2000 V3:33
  standards, 2001 V4:2
cast-iron floor drains, 2005 V2:15
cast-iron piping
  bracing, 2004 V1:177
  corrosion and, 2004 V1:150
  laboratories, 2000 V3:40
  Manning formula and, 2000 V3:245
  natural gas, 2000 V3:254
  radioactive materials systems and, 2005 V2:249
  roughness, 2005 V2:83, 86
  sanitary drainage systems, 2005 V2:13
  underground piping, 2005 V2:50
cast-iron soil pipe
  dimensions of hubs, spigots and barrels, 2001 V4:29–31
  telescoping and laying lengths, 2001 V4:28
  types, 2001 V4:27–31
Cast-iron Soil Pipe and Fittings Engineering Manual, 2005 V2:64
Cast Iron Soil Pipe Institute (CISPI), 2004 V1:20, 53, 58, 2005 V2:64
  CISPI 301 standard, 2001 V4:28
  CISPI 310 standard, 2001 V4:28
cast-iron tank legs, 2004 V1:163
catch basins, 2000 V3:157
Category II, III, or IV vent systems, 2004 V1:43
cathodes
  defined, 2004 V1:139, 152
  galvanic series of metals, 2004 V1:141
cathodic corrosion, 2004 V1:152
cathodic inhibitors, 2004 V1:151
cathodic potential (electropositive potential), 2004 V1:153
cathodic protection
  criteria, 2004 V1:150–151
  defined, 2004 V1:20, 152
  introduction, 2004 V1:139
  liquid fuel tanks, 2000 V3:155
  methods, 2004 V1:147–151
  sand filtration tanks, 2000 V3:131
  wells, 2005 V2:172
cathodic, defined, 2004 V1:152
cations
  cation resins, 2005 V2:201, 217
  defined, 2004 V1:152, 2005 V2:197
  in ion exchange, 2005 V2:215, 216
  in pH values, 2005 V2:239
caulking
  caulked joints on floor drains, 2005 V2:15
  defined, 2004 V1:20
  drains, 2005 V2:13
causes and effects
  in creativity checklist, 2004 V1:234
  of earthquakes, 2004 V1:156–158
caustic embrittlement, 2004 V1:152
caustic soda, 2005 V2:245, 2000 V3:93
caustic waste from regeneration cycle, 2005 V2:217
cavitation
  anti-vortex drains, 2000 V3:117
  cavitation corrosion, 2004 V1:152
  defined, 2004 V1:20, 152
  flexible pipe connectors and, 2004 V1:200
  fountain pumps, 2000 V3:108
  modifications to pump plants, 2004 V1:197
  pressure levels and, 2004 V1:200
  reducing noise source strength, 2004 V1:199
  water level in pools and, 2000 V3:112
cavitation corrosion, 2004 V1:152
CCS (Certified Construction Specifier), 2004 V1:72
ccw, CCW (counterclockwise), 2004 V1:14
CD. *See* construction contract documents (CD)
cd (candelas), 2004 V1:33
CD (condensate drains), 2004 V1:8
cd/m^2, 2004 V1:33
CDA (Copper Development Association), 2004 V1:20
CDC (Centers for Disease Control and Prevention), 2005 V2:118
CDI (continuous deionization), 2005 V2:219–220
ceiling-mounted medical gas systems, 2000 V3:57–59, 58–59
ceiling-with-gas-stacks systems, 2000 V3:58
ceilings, piping in, 2004 V1:195, 201
cell pairs, 2005 V2:219
cells, defined, 2004 V1:152
cellulose acetate membranes, 2005 V2:223
cellulose gas filters, 2000 V3:250
cellulose tricetate membranes, 2005 V2:223

celsius (°C), 2004 V1:14
cement grout, 2005 V2:167
cement joints, 2004 V1:20
cement-lined piping
  Manning formula and, 2000 V3:245
  roughness, 2005 V2:83
  in sprinkler hydraulic calculations, 2000 V3:17
  water pipes, 2001 V4:32
Cement Mortar Lining, 2001 V4:32
cement plaster joints, 2001 V4:32
center to center (c to c, C TO C), 2004 V1:14
centerline spacing of gas outlets, 2000 V3:56
Centers for Disease Control and Prevention, 2005 V2:118
centersets for faucets, 2001 V4:10
"centi" prefix, 2004 V1:34
Centigrade conversion factors, 2004 V1:38
centipoise, 2004 V1:39, 2000 V3:154
central chilled drinking water systems, 2004 V1:265
central heating boilers, 2000 V3:138
central-supply rooms, 2000 V3:46
central-water purification equipment, 2005 V2:233–234
centrally-located vacuum cleaning systems. *See* vacuum cleaning systems
centrifugal air compressors, 2000 V3:65, 202, 205
centrifugal drum traps, 2000 V3:42
centrifugal pumps
  acid wastes and, 2005 V2:241
  defined, 2004 V1:24
  fountains, 2000 V3:115
  pump pressure and, 2005 V2:72
  shallow well discharge, 2005 V2:170
  vacuum pumps, 2005 V2:180
centrifugal separators
  centrifugal-type vacuum separators, 2005 V2:188
  for oil spills, 2005 V2:256
centrifugal vacuum cleaning systems, 2005 V2:194
centrifugation of oil, 2005 V2:255
ceramic fixtures
  standards, 2001 V4:2
  types of, 2001 V4:1–2
ceramic wool, 2004 V1:193
CERCLA (Comprehensive Environmental Response Compensation and Liability Act), 2000 V3:88, 2000 V3:89–90
certificates of insurance, 2004 V1:62
certification
  certification of performance, 2005 V2:103
  LEED program, 2004 V1:263–264
  medical gas systems, 2000 V3:77–83
  medical gas zones, 2000 V3:72
  storage tanks, 2000 V3:171
Certified Construction Specifier (CCS), 2004 V1:72
Certified Plumbing Designer (CPD), 2004 V1:72
cesspools
  defined, 2004 V1:20
  irrigation systems and, 2005 V2:30
CF (contact factors), 2004 V1:14
CFAC, CFACT (correction factors), 2004 V1:14
CFCs (chlorofluorocarbons), 2000 V3:22
cfh (cubic feet per hour), 2000 V3:200, 248
cfm (cubic feet per minute). *See* cubic feet per minute
CFR (Code of Federal Regulations), 2000 V3:88
CFT (cubic feet), 2004 V1:14
cfus (colony forming units), 2005 V2:199
CGA. *See* Compressed Gas Association, Inc.
cGMP (current good manufacturing practices), 2005 V2:234, 237
CGPM (General Conference of Weights and Measures), 2004 V1:32
chainwheel-operated valves, 2004 V1:20
chambers (air chambers). *See* air chambers (AC)
Chan, Wen-Yung W., 2004 V1:40
change orders, 2004 V1:63
changed standpipes, 2004 V1:13
channels, 2004 V1:20
character in creativity checklist, 2004 V1:234
Characteristics and Safe Handling of Medical Gases (CGA P-2), 2000 V3:86
Characteristics of Rural Household Waste Water, 2005 V2:36
chart recorders, 2000 V3:142
chases, 2004 V1:20
check valves (CV)
  defined, 2004 V1:20
  dry-pipe systems, 2000 V3:11
  flow data, 2005 V2:102
  fountains, 2000 V3:118–119
  irrigation systems, 2000 V3:103
  multilevel pools, 2000 V3:108
  swimming pool pumps, 2000 V3:142
  symbols for, 2004 V1:9
  thermal expansion compensation and, 2005 V2:116
  vacuum systems, 2005 V2:189
checklists and forms
  creativity worksheets, 2004 V1:233–234, 236
  designs and drawings, 2004 V1:100–102
  detail/product/material specification checklist, 2004 V1:220
  evaluation checklists, 2004 V1:237–238
  field checklists, 2004 V1:102–103
  final checklist, 2004 V1:103
  forms of agreement, 2004 V1:62
  fuel systems, 2000 V3:171
  function definitions, 2004 V1:225–227
  functional evaluation worksheets, 2004 V1:243–251
  general checklists for jobs, 2004 V1:99
  health-care facility medical gas and vacuum systems, 2000 V3:49–50
  idea development and estimated cost forms, 2004 V1:241–242
  idea evaluation worksheet, 2004 V1:243, 253
  project information checklists, 2004 V1:215–220
  project information sources checklists, 2004 V1:221
  recommendations worksheets, 2004 V1:258, 259
  storage tanks, 2000 V3:173
  using in presentations, 2004 V1:257
  value engineering checklists, 2004 V1:214
chemical cleaning connections, 2000 V3:47
chemical feed pumps for pools, 2000 V3:148, 150–151
chemical filtration, 2000 V3:112
Chemical Plant and Petroleum Refinery Piping (ANSI B3.13), 2000 V3:95
chemical plants, 2000 V3:87
chemical pretreatment of oils, 2000 V3:93

chemical regeneration in demineralizers, 2000 V3:46
chemical-resistance testing, 2001 V4:2
chemical spill emergency fixtures, 2001 V4:17
chemical-waste drains
  glass pipe, 2001 V4:47
  plastic pipes, 2001 V4:58
chemical-waste systems
  codes and standards, 2005 V2:252–253
  defined, 2004 V1:20
  design considerations, 2005 V2:253
  pipe and joint selection, 2005 V2:253
chemically-stabilized emulsions, 2005 V2:255
chemicals
  analysis of swimming pool water, 2000 V3:131
  chemical characteristics of drinking water, 2005 V2:227–228, 228
  chemical control of microbes in water, 2005 V2:223
  chemical treatment of oil spills, 2005 V2:255–256
  emulsions, 2000 V3:93
  feed pumps for pools, 2000 V3:148, 150–151
  filtration, 2000 V3:112
  laboratory vacuum systems, 2005 V2:182
  material safety data sheets, 2000 V3:90
  in septic tanks, 2005 V2:155–156
  in special-waste effluent, 2005 V2:238
chemistry of water. *See* water chemistry
Chicago, city building code, 2005 V2:118
children, fixtures and
  fixture heights, 2004 V1:107
  in hot water demand classifications, 2005 V2:109
  water closets, 2001 V4:4–5
  water coolers, 2001 V4:14
chilled drinking water recirculating (DWR), 2004 V1:8
chilled drinking water supply (DWS), 2004 V1:8, 265, 2000 V3:34
chilled water returns (CWR), 2004 V1:8
chilled water supply (CWS), 2004 V1:8
chimneys
  codes, 2004 V1:43
  defined, 2005 V2:143
china fixtures, 2001 V4:1–2
chips in acid-neutralization tanks, 2000 V3:40, 41
chloramines, 2000 V3:149
chlorides, 2004 V1:147, 2005 V2:199, 200, 216
chlorimine, 2005 V2:211
chlorinated polyethylene sheet shower pans, 2001 V4:15
chlorinated polyvinyl-chloride (CPVC)
  defined, 2004 V1:21, 2005 V2:67
  industrial waste usage, 2000 V3:93
  pipe characteristics, 2000 V3:48, 2001 V4:59–60
  pipes, 2005 V2:201, 2001 V4:62
  velocity and, 2005 V2:92
  VOCs and, 2005 V2:201
chlorination
  domestic water systems, 2005 V2:103
  drinking water, 2005 V2:168
  gray water, 2005 V2:28, 35
  wells, 2005 V2:166
chlorine
  as biocides, 2005 V2:120
  as disinfectant in pools, 2000 V3:123
  bleaches, 2005 V2:156
  breakdown chlorination, 2000 V3:149
  chlorine-resistant grates, 2005 V2:13
  cyanide and, 2000 V3:93
  gas, 2000 V3:146, 148
  hyperchlorination, 2005 V2:122
  microbial control, 2005 V2:223
  pure water systems, 2005 V2:232
  reflecting pools and fountains, 2000 V3:108
  removing, 2005 V2:211
  residuals, 2000 V3:146, 147, 148
  reverse osmosis and, 2000 V3:47
  small drinking water systems, 2005 V2:228
  superchlorination, 2000 V3:149
  swimming pool heaters and, 2000 V3:138
  swimming pool water chemistry, 2000 V3:146
  in water chemistry, 2005 V2:199, 201
chlorine dioxide gas injection, 2005 V2:120
chlorine dioxide treatment, 2005 V2:122
chlorofluorocarbons (CFCs), 2000 V3:22
chloroform, 2000 V3:70
chrome-plated brass, 2000 V3:145
chromium III, 2000 V3:93
chromium-iron, 2004 V1:141
chromium VI, 2000 V3:93
Church, James, 2005 V2:64
churches, numbers of fixtures for, 2001 V4:19, 22
Ciba-Geigy Pipe Systems, Inc., 2000 V3:97
cigarette burn testing, 2001 V4:2
CIN (cubic inches), 2004 V1:14
circles, calculating area, 2004 V1:5
circuit venting, 2004 V1:20, 2005 V2:39, 44–45
circuits (ckt, CKT), 2004 V1:14, 20
circular lavatories, 2001 V4:11
circulating pumps in pools, 2000 V3:139
circulating water systems
  in geothermal energy systems, 2004 V1:131
  hot water systems, 2005 V2:115
  standby losses in, 2004 V1:127
circulation loops, 2000 V3:47
CISMA Standard 177, 2005 V2:17
CISPI (Cast Iron Soil Pipe Institute)
  abbreviation, 2004 V1:20
  address, 2004 V1:58
  Cast Iron Soil Pipe and Fittings Engineering Manual, 2005 V2:64
  CISPI 301 standard, 2001 V4:28
  CISPI 310 standard, 2001 V4:28
  publications, 2004 V1:53
cisterns, 2005 V2:170
citing codes and standards, 2004 V1:67
citric acid, 2004 V1:146
City of Chicago Building Code, 2005 V2:118
city water. *See* municipal water supply
ckt, CKT (circuits), 2004 V1:14, 20
CL, C/L (critical level), 2004 V1:21
clad steel tanks, 2000 V3:155, 165, 172
Claes, 2004 V1:154
clamp gate valves, 2004 V1:20
clamp joints
  cast iron pipes, 2001 V4:28
clams, 2005 V2:199
clappers

deluge valves, 2000 V3:14
dry-pipe systems, 2000 V3:11
clarification treatments for water, 2005 V2:208–209, 225
clarifying tanks, 2000 V3:40
classes of service, standpipe systems, 2004 V1:30, 2000 V3:18, 19
classifications
bedding, 2000 V3:234, 235
disabilities, 2004 V1:107
fires, 2000 V3:3, 19, 27
liquid fuel, 2000 V3:153–154
steam and condensate systems, 2000 V3:175–189
claw-type pumps, 2005 V2:180
clay loams, 2000 V3:100, 243
clay piping
industrial discharge piping, 2005 V2:253
noise insulation, 2005 V2:14
surface roughness, 2005 V2:83
underground piping, 2005 V2:50
vitrified clay pipe, 2001 V4:49, 56–57
clay soils, 2005 V2:29, 30
clays
in feed water, 2005 V2:205
in soil texture, 2005 V2:148
Clean Agent Extinguishing Systems (NFPA 2001), 2000 V3:22, 23, 25, 29
Clean Air Act Amendments (CAAA), 2000 V3:154
clean extinguishing agents, 2000 V3:22
Clean Water Act, 2005 V2:49, 252, 2000 V3:87, 88–89, 96
cleaning
cold-water systems, 2005 V2:103–104
filters, 2000 V3:150
fixtures, 2001 V4:1
medical gas pipes, 2000 V3:74, 80
pipes and piping, 2001 V4:25
pool filters, 2000 V3:137
pools and fountains, 2000 V3:107, 112
pure-water systems, 2000 V3:47
radioactive waste piping, 2005 V2:249
section in specifications, 2004 V1:71, 92
septic tanks, 2005 V2:154
swimming pools, 2000 V3:146
cleanout plugs (CO), 2004 V1:11
cleanouts
chemical-waste systems, 2005 V2:253
cleaning drains, 2005 V2:15
defined, 2004 V1:20
manholes, 2000 V3:240, 241
radioactive waste systems, 2005 V2:250
sanitary drainage systems, 2005 V2:9
vacuum cleaning systems, 2005 V2:195
cleanouts to grade (CO), 2004 V1:11
cleanup/utility rooms, 2000 V3:32
clear floor space
bathtub accessibility, 2004 V1:117
bathtubs, 2004 V1:117
drinking fountains and water coolers, 2004 V1:112
laundry equipment, 2004 V1:123
lavatories and sinks, 2004 V1:117
urinal design, 2004 V1:116
water closet and toilet accessibility, 2004 V1:113–116
for wheelchairs, 2004 V1:109, 110
clear space in septic tanks, 2005 V2:154
clear-water wastes
defined, 2004 V1:20
clearance
clean agent gas fire containers, 2000 V3:23
fixtures in health-care facilities, 2000 V3:33
piping and, 2001 V4:25
clg load, CLG LOAD (cooling loads), 2004 V1:14
climate, storm-drainage systems and, 2005 V2:49
clinic sinks, 2000 V3:32
clinics, 2000 V3:83
clo, converting to SI units, 2004 V1:39
CLOAD (cooling loads), 2004 V1:14
clockwise (cw, CW), 2004 V1:14
close-coupled centrifugal pumps, 2000 V3:115
close-coupled water closets, 2001 V4:3
close nipples, 2004 V1:20
closed-circuit cooling systems, 2004 V1:151
closed proprietary specifications, 2004 V1:67
closed-type sprinklers, 2000 V3:9
clothes washers. *See* laundry systems and washers
cloudy water in pools, 2000 V3:147
clubs, hot water demand, 2005 V2:109
CMPR (compressors). *See* compressors
cndct, CNDCT (conductivity), 2004 V1:14, 33
CO (cleanout plugs), 2004 V1:11
CO (yard cleanouts or cleanouts to grade). *See* cleanouts; cleanouts to grade
CO_2 (carbon dioxide). *See* carbon dioxide
coagulants in clarification, 2005 V2:209
coagulation in gray-water treatment, 2005 V2:30
coal tar epoxy, 2000 V3:156
coalescence and filtration of oil spills, 2005 V2:255
coalescing filters in vacuum systems, 2005 V2:181
coalescing media, 2000 V3:93
coarse sands, 2005 V2:29, 30, 2000 V3:100
coat hooks
accessibility in toilet and bathing rooms, 2004 V1:113
ambulatory accessible toilet compartments, 2004 V1:115–116
coated metal
cathodic protection, 2004 V1:150
coated steel filters, 2000 V3:131
corrosion protection, 2004 V1:147
passivation, 2004 V1:146–147
sprinkler head ratings, 2000 V3:17
storage tanks, 2000 V3:172
storm piping, 2005 V2:50
coaxial truck delivery hoses, 2000 V3:157
coaxial vapor recovery, 2000 V3:163, 167
cocks, 2004 V1:20
Code of Federal Regulations (CFR), 2005 V2:229, 2000 V3:88, 2000 V3:96, 154
codes and standards
chemical-waste systems, 2005 V2:252–253
citing, 2004 V1:67
codes, defined, 2004 V1:20
cold water systems, 2005 V2:68
concrete pipe, 2001 V4:32
domestic water supply, 2000 V3:216
ductile iron pipe, 2001 V4:32
fire protection, 2000 V3:1, 225

fixtures, 2001 V4:2
gasoline and diesel-oil systems, 2000 V3:154
gray-water systems, 2005 V2:25–26
health-care facilities, 2000 V3:31–34
hot-water systems, 2005 V2:124
industrial wastewater treatment, 2000 V3:87–90
infectious and biological waste systems, 2005 V2:251
medical gas systems, 2000 V3:83
natural gas services, 2000 V3:248
natural gas systems, 2005 V2:127
NFPA standards, 2000 V3:1
plumbing materials and equipment, 2004 V1:41–57
plumbing standards for people with disabilities, 2004 V1:105–106
preventing Legionella growth, 2005 V2:118
private water systems, 2005 V2:163
reference-based standards, 2004 V1:66
sanitary drainage systems, 2005 V2:1
searching, 2000 V3:215
seismic protection, 2004 V1:171–184
special-waste drainage systems, 2005 V2:237
storm-drainage systems, 2005 V2:50
storm sewers, 2000 V3:240
swimming pools, 2000 V3:127
vacuum-cleaning systems, 2005 V2:188
vacuum systems, 2005 V2:182
water analysis, treatment and purification, 2005 V2:197, 229
water heaters, 2004 V1:129
coefficients (coeff., COEF), 2004 V1:14
coefficients of expansion, 2004 V1:20
coefficients of hydrant discharge, 2000 V3:4, 5
coefficients of permeability (K factor), 2005 V2:166
coefficients of valve flow (C_v, C_v, CV), 2004 V1:14
coffee sinks. *See also* sinks and wash basins
cogeneration systems, waste heat usage, 2004 V1:134
coherent unit systems, 2004 V1:32
coils (COIL), 2004 V1:14
coke oven gas, 2005 V2:126
cold water (CW), 2004 V1:8
cold-water systems
backflow prevention, 2005 V2:69–70
booster pump systems, 2005 V2:70–77
codes and standards, 2005 V2:68
constant pressure in, 2005 V2:72
cross connection controls, 2005 V2:69–70
domestic water meters, 2005 V2:68–69
examples for pipe sizing, 2005 V2:97–99
excess water pressure, 2005 V2:77–79
glossaries, 2005 V2:67
introduction, 2005 V2:67
pipe codes, 2004 V1:45
pipe sizing, 2005 V2:86–96, 87–90
potable water systems, 2000 V3:45
references, 2005 V2:104
sizing, 2005 V2:97
testing, cleaning, and disinfection, 2005 V2:103–104
water flow tests, 2005 V2:95
water hammer, 2005 V2:79–82
water line sizing, 2005 V2:82–103
Colebrook formula, 2005 V2:84–86
coliform group of bacteria, 2004 V1:21
coliform organism tests, 2005 V2:104
coliseums, numbers of fixtures for, 2001 V4:19
collection legs in condensate drainage, 2000 V3:191, 195
collective bargaining agreements, cost estimates and, 2004 V1:98
collectors (dug wells), 2005 V2:164
College of American Pathologists (CAP), 2005 V2:197, 229
Collentro, W.V., 2005 V2:234
colloidal particles, removing, 2005 V2:209, 2000 V3:93
colloidal silica, 2005 V2:200
colony forming units (cfus), 2005 V2:199
color
of drinking water, 2005 V2:227
of feed water, 2005 V2:198, 203
of gray water, 2005 V2:35
medical gas codes, 2000 V3:54, 56
of pool lights, 2000 V3:121
of soils, 2005 V2:148
of swimming pool water, 2000 V3:147
color codes
copper drainage tube, 2001 V4:45
copper pipes, 2001 V4:35–36
medical gas tube, 2001 V4:45
seamless copper water tube, 2001 V4:37
column radiators, 2000 V3:181
columns in ion exchange systems, 2005 V2:216
combination building water supplies, 2000 V3:225–226
combination dry-pipe and pre-action systems, 2004 V1:29, 2000 V3:15
combination fixtures, defined, 2004 V1:21
combination storm-drainage and sanitary sewers, 2005 V2:12, 32, 2000 V3:247
combination temperature and pressure relief valves, 2005 V2:115
combination thermostatic and pressure balancing valves, 2001 V4:15, 16
combination vacuum-cleaning systems, 2005 V2:188
combination waste and vent systems, 2004 V1:21
combined building drains, 2004 V1:20
combined residuals, 2000 V3:146
combustibles
defined, 2000 V3:83, 153
fire loads, 2000 V3:2–3
metal fires, 2000 V3:20
combustion efficiency, 2004 V1:21
combustion products, 2000 V3:83
combustion properties of gases, 2005 V2:126
Commercial Energy Conservation Manual, 2004 V1:137
commercial facilities
commercial/industrial gas service, 2000 V3:249
estimating sewage quantities, 2005 V2:158
firefighting demand flow rates, 2000 V3:232
gray-water systems, 2005 V2:28–29
grease interceptors, 2005 V2:12
oil interceptors in drains, 2005 V2:12
radioactive waste drainage and vents, 2005 V2:245
commercial kitchen sinks, 2001 V4:12, 13
commercial laundries. *See* laundry systems and washers
commercial service gas, 2005 V2:126
Commercial Standards (CS), 2004 V1:21
Commercial Water Use Research Project, 2005 V2:35
commissioning section in specifications, 2004 V1:71, 92

Commodity Specification for Air (CGA G-7.1/ANSI ZE 86.1), 2000 V3:65, 83, 86
Commodity Specification for Nitrogen (CGA G-10.1), 2000 V3:86
commodity tube, 2001 V4:35
common vents (dual vents), 2004 V1:21, 2005 V2:38
  air admittance valves, 2005 V2:46
  defined, 2005 V2:38
  sizing, 2005 V2:38
community bathhouses, 2005 V2:159
Compact Fittings, 2001 V4:32
compacted fill, building sewers and, 2005 V2:14
companion flanges, 2004 V1:21
comparative cost analysis, 2004 V1:254
comparing functions in value engineering, 2004 V1:243
compartments in septic tanks, 2005 V2:154–155
competition swimming pools, 2000 V3:128, 129, 139
components section in specifications, 2004 V1:91
composite tanks, 2000 V3:156
composting toilets, 2004 V1:136, 265
compound gauges, 2000 V3:144
compound magnetic drive meters, 2005 V2:95, 96
compound water meters, 2005 V2:68, 69
compounds in water, 2005 V2:199
Comprehensive Environmental Response Compensation and Liability Act (CERCLA), 2000 V3:88, 2000 V3:89–90, 96
compressed air (A, X#, X#A). *See also* compressed air systems
  compared to free air, 2000 V3:199
  defined, 2004 V1:18
  laboratory or medical compressed air, 2004 V1:8, 2000 V3:37–39, 65–68, 75, 82–83
  overview, 2000 V3:199
  supplies to water tanks, 2005 V2:170
  symbols for, 2004 V1:8
  tools and equipment, 2000 V3:208
  uses, 2000 V3:199
  water vapor in air, 2000 V3:200–201
Compressed Air and Gas Data, 2005 V2:144
Compressed Air and Gas Handbook, 2000 V3:214
"Compressed Air Data," 2000 V3:214
"Compressed Air Design for Industrial Plants," 2000 V3:214
Compressed Air for Human Respiration (CGA G-7.0), 2000 V3:86
Compressed Air Fundamentals, 2000 V3:214
Compressed Air Handbook, 2000 V3:214
Compressed Air Magazine, 2000 V3:214
compressed air systems
  accessories, 2000 V3:202–203
  air dryers, 2000 V3:203–204, 207
  air receivers, 2000 V3:205–206
  compressors, 2000 V3:201–202, 210–213
  condensate removal, 2000 V3:213
  conditioning, 2000 V3:207
  contaminants, 2000 V3:201
  definitions, 2000 V3:199–200
  earthquake bracing for piping, 2004 V1:167
  measurement units, 2000 V3:200
  overview, 2000 V3:199
  piping system design, 2000 V3:206–213
  air-consuming devices, 2000 V3:206–207
  air dryers, 2000 V3:207
  design sequence, 2000 V3:206
  duty cycles, 2000 V3:207
  filters, 2000 V3:207
  future expansion, 2000 V3:210
  leakage, 2000 V3:209
  materials, 2000 V3:210
  sizing piping, 2000 V3:74, 78, 210
  use factors, 2000 V3:209
  pressure drops, 2000 V3:212
  references, 2000 V3:214
  regulation methods, 2000 V3:205
  starting unloaders, 2000 V3:205
  tools and equipment, 2000 V3:208
  water vapor in air, 2000 V3:200–201
compressed gas. *See* natural gas systems
Compressed Gas Association, Inc. (CGA), 2000 V3:56
  address, 2004 V1:58, 2000 V3:86
  list of standards, 2004 V1:53
  publications
    CGA C-9: Standard for Color-marking of Compressed Gas Cylinders Intended for Medical Use, 2000 V3:86
    CGA G-7.0: Compressed Air for Human Respiration, 2000 V3:86
    CGA G-7.1/ANSI ZE 86.1: Commodity Specification for Air, 2000 V3:83, 86
    CGA G-8.1: Standard for the Installation of Nitrous Oxide Systems at Consumer Sites, 2000 V3:86
    CGA G-10.1: Commodity Specification for Nitrogen, 2000 V3:86
    CGA P-2: Characteristics and Safe Handling of Medical Gases, 2000 V3:86
    CGA P-9: Inert Gases: Argon, Nitrogen and Helium, 2000 V3:81, 82, 86
    CGA V-5: Diameter-Index Safety System, 2000 V3:83, 86
    Compressed Air and Gas Handbook, 2000 V3:214
  standard air definition, 2000 V3:200
compression couplings
  clay pipe, 2001 V4:49
  glass pipe, 2001 V4:48
compression fittings
  cast iron, 2001 V4:27, 28
  defined, 2004 V1:24
compression joints, 2004 V1:21
compressive strength of plastic pipe, 2001 V4:59–60
compressors (cprsr, CMPR)
  defined, 2004 V1:21
  earthquake protection, 2004 V1:164
  symbols for, 2004 V1:14
computer processing of specifications, 2004 V1:71–72
computer programs
  abbreviations in, 2004 V1:14–16
  computer analysis of piping systems, 2004 V1:186
  ETI (Economic Thickness of Insulation), 2004 V1:127
  plumbing cost estimation, 2004 V1:93, 98
  specifications programs, 2004 V1:71–72
computer room waste heat usage, 2004 V1:134
concealed piping, 2000 V3:73

concealed sprinklers, 2004 V1:29
concentration cells
attack corrosion, 2004 V1:141
defined, 2004 V1:152
concentration gradients, 2005 V2:221
concentration polarization, 2004 V1:152
concentration tests, 2000 V3:82
concentric reducers, 2004 V1:10, 2000 V3:115
concrete, 2000 V3:147
concrete anchors
floor-mounted equipment, 2004 V1:163
problems in seismic protection, 2004 V1:188
concrete ballast pads, 2000 V3:172
concrete barriers around tanks, 2000 V3:169
concrete base devices, 2004 V1:204–205
concrete embedments, 2004 V1:190
concrete floors, leveling around, 2005 V2:16
concrete inertia bases, 2004 V1:203
Concrete Pipe Handbook, 2005 V2:64
concrete piping
flow rate, 2000 V3:245
noise insulation, 2005 V2:14
roughness, 2005 V2:86
standards, 2001 V4:32
surface roughness, 2005 V2:83
underground piping, 2005 V2:50, 2001 V4:32
concrete restraints, 2000 V3:229
concrete roofing drains, 2005 V2:63
concrete shielding from radiation, 2005 V2:247
concrete-tank saddles, 2004 V1:164
concrete tanks, 2000 V3:91, 165
cond, COND (condensers, condensation). *See* condensation; condensers
condensate drains (CD), 2004 V1:8
condensate grooving, 2000 V3:190
condensate receivers, 2000 V3:188–189
condensate return methods, 2000 V3:186–189
gravity return, 2000 V3:186–187
mechanical return, 2000 V3:186–189
boiler feed pumps, 2000 V3:188–189
condensate transfer pumps, 2000 V3:187
vacuum pumps, 2000 V3:189
condensate transfer pumps, 2000 V3:188, 189
condensates, 2000 V3:138. *See also* steam and condensate systems
corrosion inhibitors, 2004 V1:151
defined, 2004 V1:21, 2005 V2:143
condensation (cond, COND)
air drying, 2000 V3:204
compressed air systems, 2000 V3:213
corrosion and, 2004 V1:146
dew points, 2000 V3:201
earthquakes and, 2004 V1:170
gray water systems, 2004 V1:267
non-circulating hot water systems, 2004 V1:127
protecting against, 2005 V2:16
swimming pools, 2000 V3:129
symbols for, 2004 V1:14
vacuum piping, 2005 V2:184
condensation loads
equations, 2000 V3:194, 195
safety factors, 2000 V3:194
steam piping, 2000 V3:193
condensers
condenser system water treatments, 2005 V2:227
distilled water systems, 2000 V3:46
scale deposits, 2005 V2:205
symbols for, 2004 V1:14
waste heat reclamation, 2004 V1:132, 133
water measurement in, 2000 V3:124
condensing gas water heaters, 2004 V1:130
conditioning compressed air, 2000 V3:207, 211
conditioning water. *See* water treatment
conditions in creativity checklist, 2004 V1:234
conductance (C), 2004 V1:14, 33
conductivity (cndct, CNDCT, K)
evaporation and, 2000 V3:121
measurements, 2004 V1:33
mho (specific conductivity), 2005 V2:203
symbols for, 2004 V1:14
conductors
defined, 2004 V1:21
number of, 2004 V1:14
conduits
defined, 2004 V1:21
seismic protection, 2004 V1:155
cones
calculating volume, 2004 V1:4
of depression, 2005 V2:165
"Conference Generale de Poids et Measures," 2004 V1:32
confluent vents, 2004 V1:21
connected loads, defined, 2005 V2:144
connected standbys, 2000 V3:23
connections section in specifications, 2004 V1:91
conserving energy
alternate energy sources, 2004 V1:130–131
Bernoulli's equation, 2004 V1:5–6
domestic water temperatures, 2004 V1:124–125
glossary, 2004 V1:136–137
hot water system improvements, 2004 V1:127
introduction, 2004 V1:124
nondepletable and alternate energy sources, 2004 V1:130–131
off-peak power, 2004 V1:128–129
reduced water flow rates, 2004 V1:126–127
references, 2004 V1:137
saving utility costs, 2004 V1:128–130
standby losses in circulating systems, 2004 V1:127
thermal insulation thickness, 2004 V1:127
waste heat usage, 2004 V1:131–134
conserving water
design techniques, 2004 V1:134–135
domestic water supply, 2000 V3:43
green design, 2004 V1:263–267
institutional wastewater systems, 2005 V2:157
introduction, 2004 V1:124
urinals, 2001 V4:8–9
water closet fixtures, 2001 V4:3
constant-pressure pumps, 2005 V2:72
constant velocity method, 2005 V2:67, 97
Constructed Science Research Foundation Spectext, 2004 V1:71
construction change directives, 2004 V1:63
construction contract documents (CD)

contract documents defined, 2004 V1:61
defined, 2004 V1:61
overview, 2004 V1:61
project manuals, 2004 V1:62–63
value engineering clauses in, 2004 V1:258, 260
construction costs in value engineering, 2004 V1:212
Construction Specifications Canada (CSC) Uniformat, 2004 V1:64
Construction Specifications Institute (CSI)
classes, 2004 V1:72
Constructed Science Research Foundation, 2004 V1:71
general conditions documents, 2004 V1:62
Manual of Practice, 2004 V1:61
MasterFormat, 2004 V1:64
MasterFormat 2004, 2004 V1:64–65, 77–88
MasterFormat Level Four (1995), 2004 V1:76
MasterFormat Level One (1995), 2004 V1:73
MasterFormat Level Three (1995), 2004 V1:76
MasterFormat Level Two (1995), 2004 V1:73–75
section shell outline, 2004 V1:88–92
Sectionformat, 2004 V1:65
Uniformat, 2004 V1:64, 73
web site, 2004 V1:65
Consultation phase in value engineering, 2004 V1:243, 254
consumption. *See* demand
contact corrosion, defined, 2004 V1:152
contact factors (CF), 2004 V1:14
contact sheets, 2000 V3:215
contact time for microbial control, 2005 V2:223
Containment Control in Biotechnology Environments, 2005 V2:256
containment floors or dikes, 2000 V3:90
containment of biological wastes, 2005 V2:250–251
containment sumps, 2000 V3:156, 163, 167
contamination issues
backflow prevention, 2005 V2:69
bored wells, 2005 V2:165
compressed air, 2000 V3:201
contaminant classification, 2000 V3:222
contaminators, defined, 2004 V1:21
dug wells, 2005 V2:164
gray-water irrigation systems and, 2005 V2:35
well protection, 2005 V2:166
contingency
plans for industrial wastes, 2000 V3:89
in plumbing cost estimation, 2004 V1:94
continuing education, 2004 V1:72
continuous acid-waste treatment systems, 2005 V2:246
continuous deionization (CDI), 2005 V2:219–220
continuous duty pumps, 2000 V3:26
continuous flow. *See* steady flow
continuous flow pool gutters, 2000 V3:142
continuous vents, defined, 2004 V1:21, 2005 V2:39
continuous waste, 2004 V1:21
continuous wastewater treatment, 2000 V3:95
continuous welding technique, 2001 V4:48
contract documents. *See* construction contract documents
contraction of pipes
calculating, 2004 V1:3
pool temperature and, 2000 V3:145
protecting against, 2005 V2:16
Control of Pipeline Corrosion, 2004 V1:154
control panels
clean gas systems, 2000 V3:24
fire alarm, 2004 V1:12
fountains, 2000 V3:120–121
vacuum systems, 2005 V2:181
control systems in geothermal energy systems, 2004 V1:131
control valves
medical gas systems, 2000 V3:71–72
swimming pools, 2000 V3:139
controlled-flow storm-drainage systems, 2005 V2:52–53
controlled-substance spills, 2005 V2:195–196
controllers
defined, 2004 V1:21
for irrigation systems, 2000 V3:104
controls
in accessible shower compartments, 2004 V1:120
in bathtubs, 2004 V1:118
defined, 2004 V1:21
on gas boosters, 2005 V2:133
on water heaters, 2005 V2:114
for vacuum systems, 2005 V2:181, 189, 2000 V3:70
convection, 2000 V3:121
convention halls, numbers of fixtures for, 2001 V4:21
convergent thinking in evaluation, 2004 V1:235
converging seismic plates, 2004 V1:158
conversion factors and converting
Fahrenheit and Centigrade, 2004 V1:38
feet of head to pounds per square inch, 2004 V1:2
gas pressure to destinations, 2005 V2:138, 141
IP and metric units, 2000 V3:29
IP and SI, 2004 V1:39–40, 2005 V2:176
measurements, 2004 V1:32
meters of head to pressure in kilopascals, 2004 V1:2
vacuum acfm and scfm, 2005 V2:176–178, 178
vacuum pressures, 2005 V2:176–178
water impurity measurements, 2005 V2:202
cooling compressors, 2000 V3:201
cooling equipment, green building and, 2004 V1:264
cooling fire areas, 2000 V3:20
cooling loads (clg load, CLG LOAD, CLOAD), 2004 V1:14
cooling-tower water
corrosion inhibitors, 2004 V1:151
exclusion from gray-water systems, 2005 V2:25
Legionella pneumophila, 2005 V2:117
reducing makeup water, 2004 V1:264
use of gray water in, 2005 V2:25
waste heat usage, 2004 V1:131
water treatments, 2005 V2:227
cooling vacuum pumps, 2005 V2:181
coordination disabilities, 2004 V1:107
coordination with other designers, 2005 V2:52, 64
COP (coefficient of performance), 2004 V1:136
copper
corrosion, 2004 V1:139
in electromotive series, 2004 V1:144
in galvanic series, 2004 V1:141
pool lighting, 2000 V3:145
swimming pool main drains, 2000 V3:143
copper alloy piping, 2005 V2:13, 2001 V4:27
copper-copper sulfite half-cells, 2004 V1:144

Copper Development Association (CDA), 2004 V1:20, 2005 V2:47
Copper Development Institute, 2005 V2:104
copper drainage tube, 2001 V4:45, 46
copper-nickel alloys, 2004 V1:141
copper-phosphorous-silver brazing (BCuP), 2001 V4:45
copper-phosphorus brazing, 2001 V4:45
copper piping
  aboveground piping, 2005 V2:13, 50
  commodity tube, 2001 V4:35
  compressed air systems, 2000 V3:210
  conserving energy, 2004 V1:128
  copper K piping, 2005 V2:183
  copper L piping, 2005 V2:183
  fountains, 2000 V3:116
  Legionella control and, 2005 V2:122
  pure-water system, 2000 V3:47
  radioactive waste systems, 2005 V2:249
  roughness, 2005 V2:83
  sprinkler systems, 2000 V3:12, 17
  swimming pools, 2000 V3:145
  types, 2001 V4:34–36
  velocity and, 2005 V2:92
copper salts, 2000 V3:145, 148
copper-silver ionization, 2005 V2:120, 122
Copper Sovent Single-stack Plumbing System Handbook Supplement, 2005 V2:47
copper-sulfate electrodes, 2004 V1:150
copper tube size (CTS), 2001 V4:59, 61
copper water tube, 2001 V4:34–44
Copson, H.R., 2004 V1:154
corona-discharge generators, 2005 V2:224
corporation cocks, 2004 V1:21
correction factors, 2004 V1:14
correctional centers, numbers of fixtures for, 2001 V4:20
corroded end of galvanic series, 2004 V1:141
corrosion
  boilers, 2005 V2:226
  calcium carbonate and, 2005 V2:206
  cathodic protection, 2004 V1:147–151
  causes, 2005 V2:205–206
  coatings, 2004 V1:147
  control of, 2004 V1:145–151, 2005 V2:16, 168
  cooling towers, 2005 V2:227
  corrosion cells, 2004 V1:139, 140, 148
  corrosion mitigation, 2004 V1:152
  corrosion potential, 2004 V1:152
  corrosion-resistant materials, 2004 V1:146, 2005 V2:14
  corrosion-resistant sprinklers, 2004 V1:29
  corrosive wastes, 2005 V2:13
  deaeration and, 2005 V2:209
  defined, 2004 V1:139, 152
  electromotive force series, 2004 V1:144
  factors in rate of, 2004 V1:144–145
  fatigue and fatigue limits, 2004 V1:152
  glossary, 2004 V1:151–154
  hot-water relief valves, 2005 V2:115
  inhibitors, 2004 V1:151
  introduction, 2004 V1:139
  passivation, 2004 V1:146–147
  plastic water pipes, 2005 V2:172
  predicting water deposits and corrosion, 2005 V2:206–208
  prevention, 2004 V1:152
  protection, 2000 V3:165
  references, 2004 V1:154
  sacrificial anodes, 2004 V1:148
  steam systems, 2000 V3:190
  storage tanks, 2000 V3:91, 155, 165
  swimming pool heaters, 2000 V3:146
  total organic carbon and, 2005 V2:204
  types of, 2004 V1:141
  water mains, 2000 V3:8
Corrosion, 2004 V1:154
Corrosion and Resistance of Metals and Alloys, 2004 V1:154
Corrosion Causes and Prevention, 2004 V1:154
Corrosion Control, 2004 V1:154
Corrosion Engineering, 2004 V1:154
corrosion fatigue, 2004 V1:152
Corrosion Handbook, 2004 V1:154
Corrosion in Swimming Pools and General Guide to Materials Selection (NSPI 18), 2000 V3:145
corrosion mitigation, 2004 V1:152
corrosion potential, 2004 V1:152
corrosion prevention, 2004 V1:152
Corrosion Prevention for Practicing Engineers, 2004 V1:154
corrosion-resistant materials, 2004 V1:146, 2005 V2:14
Corrosion Resistant Materials Handbook, 2000 V3:97
corrosion-resistant sprinklers, 2004 V1:29
corrosive wastes, 2005 V2:13, 2000 V3:40, 2001 V4:27
corrugated steel piping, 2005 V2:83, 2000 V3:245
cosmic radiation, 2005 V2:247
Cost Analysis phase in value engineering, 2004 V1:235, 241–243, 254
costs and economic concerns
  administrative and operation costs, 2004 V1:212
  collecting data on, 2004 V1:222–225
  construction costs, 2004 V1:212
  cost fitting, defined, 2004 V1:258
  cost information in value engineering, 2004 V1:222–225
  cost of goods, 2004 V1:222
  cost-to-function relationship, 2004 V1:225
  defined, 2004 V1:213, 222–225
  development costs, 2004 V1:212
  economic values, 2004 V1:213–214
  engineering and design costs, 2004 V1:212
  estimating costs, 2004 V1:93–98
  idea development and estimated cost forms, 2004 V1:241–242
  labor costs, 2004 V1:212
  life-cycle costs, 2004 V1:137
  material costs, 2004 V1:212
  overhead, 2004 V1:212
  Pareto principle, 2004 V1:224
  relationships, 2004 V1:223
  specific applications
    air dryers, 2000 V3:207
    cathodic protection costs, 2004 V1:150, 2004 V1:151
    corrosion resistant materials, 2004 V1:146

fuel product dispensing systems, 2000 V3:164
galvanic cathodic protection costs, 2004 V1:150
gas booster location, 2005 V2:133
gray-water system costs, 32–34
hot-water systems, 2005 V2:107
ion-exchange cartridges, 2005 V2:219, 233
ion-exchange resins, 2005 V2:216, 217
laboratory acid-waste drainage, 2005 V2:242
pool filtration systems, 2000 V3:135
sanitary drainage systems, 2005 V2:1
seismic protection costs, 2004 V1:156, 183
special-waste drainage systems, 2005 V2:238
swimming pool heaters, 2000 V3:138, 139
utility costs, 2004 V1:128–130
vacuum system piping, 2005 V2:183
water distillers, 2005 V2:210
well construction, 2005 V2:165, 172
in specifications, 2004 V1:69
supporting details for, 2004 V1:257–258
types of, 2004 V1:222–225
value engineering process and, 2004 V1:211
vs. prices, 2004 V1:222
cotton gin, creativity and, 2004 V1:231
coulombs (C)
corrosion, 2004 V1:139
SI units, 2004 V1:33
coulombs per cubic meter (C/m^3), 2004 V1:33
Council for National Cooperation in Aquatics, 2000 V3:151
Council of American Building Officials (CABO), 2004 V1:123
countdown timer delays, 2000 V3:24
counter-e.m.f.s, 2004 V1:153
counter-mounted kitchen sinks, 2001 V4:12
counter-mounted lavatories, 2001 V4:11
counter sinks, 2000 V3:32
counterclockwise (ccw, CCW), 2004 V1:14
counterflow piping designs, 2000 V3:178, 183
counterzoning, 2000 V3:24
couple action. *See* galvanic corrosion
couples, defined, 2004 V1:152
couplings
asbestos concrete piping, 2001 V4:26
cast iron hubless pipes, 2001 V4:28
defined, 2004 V1:21
glass pipe, 2001 V4:47
nonrigid couplings, 2004 V1:186
resistance coefficients, 2005 V2:100
course vacuum, 2005 V2:175
c_p, c_p, CP (sp ht at constant pressure), 2004 V1:16
CPD (Certified Plumbing Designer), 2004 V1:72
cprsr (compressors). *See* compressors
CPVC (chlorinated polyvinyl chloride). *See* chlorinated polyvinyl-chloride (CPVC)
cracking, defined, 2004 V1:152
Craytor, J., 2005 V2:35
creativity
assisted and unassisted, 2004 V1:232
creativity worksheets, 2004 V1:233–234, 236
first phase in value engineering, 2004 V1:213, 231–235
questions for, 2004 V1:234
second phase in value engineering, 2004 V1:254
creep, pipe supports and, 2005 V2:13
crevice-attack corrosion
crud traps in radioactive-waste piping, 2005 V2:249, 250
defined, 2004 V1:141, 152, 2005 V2:206
reducing, 2004 V1:146
crimping tools, 2001 V4:37
CRIP (critical pressure), 2004 V1:15
critical care areas, 2000 V3:32, 57
critical flows, defined, 2004 V1:2
critical level, defined, 2004 V1:21
critical path functions, 2004 V1:230
critical pressure, 2004 V1:15
cross connections
backflow prevention, 2005 V2:69
backwash pits, 2000 V3:137
cold-water systems, 2005 V2:69–70
defined, 2004 V1:21
health-care facilities, 2000 V3:45
medical gas pipe tests, 2000 V3:80
taking precautions against, 2005 V2:31
types of prevention devices, 2005 V2:69–70
cross-country pipe lines, 2004 V1:150
cross-flow filter media, 2005 V2:201, 211
cross-linked polyethylene/aluminum/cross-linked polyethylene (PEX-AL-PEX), 2001 V4:61–62
cross-linked polyethylene (PEX), 2001 V4:61
cross-sections of ditches, 2000 V3:247–248
cross-sections of drains, 2005 V2:2, 3
cross valves, 2004 V1:21
crosses, defined, 2004 V1:21
crossovers, 2004 V1:21
crown vents, 2004 V1:21
crowns, 2004 V1:21
crud traps, 2005 V2:206, 249, 250
crutches, 2004 V1:107
cryogenic tanks, 2000 V3:61, 62
CS (Commercial Standards), 2004 V1:21
CSA. *See* Canadian Standards Association (CSA)
CSC (Construction Specifications Canada) Uniformat, 2004 V1:64
CSI and CSI format. *See* Construction Specifications Institute (CSI)
CSI (Calcium Saturation Index), 2000 V3:123
CTS (copper tube size), 2001 V4:59, 61
CU IN (cubic inches), 2004 V1:14
CU FT (cubic feet), 2004 V1:14, 2000 V3:29
cubes, calculating volume, 2004 V1:4
cubic feet (ft^3, CU FT, CUFT, CFT), 2004 V1:14, 2000 V3:29
cubic feet per hour (cfh), 2000 V3:200, 248
cubic feet per minute (cfm, CFM), 2000 V3:200. *See also* scfm, SCFM (standard cubic feet per minute)
compressed air systems, 2000 V3:211
converting to metric units, 2000 V3:29
defined, 2005 V2:143
medical vacuum systems, 2000 V3:69
symbols for, 2004 V1:14
vacuum exhausters and, 2005 V2:193–194
vacuum measurements, 2005 V2:176
cubic feet per second, standard (scfs, SCFS), 2004 V1:14
cubic foot meters (cfms)

defined, 2005 V2:143
vacuum exhausters and, 2005 V2:193–194
vacuum measurements, 2005 V2:176
cubic inches (in^3, CU IN, CUIN, CIN), 2004 V1:14
cubic meters, 2004 V1:33
cubic meters per kilogram, 2004 V1:33
cubic meters per minute, 2000 V3:200
cubic meters per second, 2004 V1:33
CUFT (cubic feet), 2004 V1:14, 2000 V3:29
cultured marble acrylic fixtures, 2001 V4:2
cultured marble fixtures, 2001 V4:2
Culvert Pipe, 2001 V4:32
cup sinks, 2000 V3:32, 37, 38
curb boxes, 2004 V1:21
curies (c), 2005 V2:247
current
cathodic protection, 2004 V1:147
in corrosion, 2004 V1:139, 144
electromotive force series, 2004 V1:144
large anode current requirements, 2004 V1:150
measurements, 2004 V1:33
current good manufacturing practices (cGMP), 2005 V2:234, 237
cuspidors, dental, 2000 V3:38
Cutting and Welding Processes, 2005 V2:144
cutting oils, 2005 V2:12
CV (check valves). *See* check valves
c_v, c_v, CV (sp ht at constant volume), 2004 V1:16
C_v, C_v, CV (valve flow coefficients), 2004 V1:14
CVOL (specific volume). *See* specific volume
CW (clockwise), 2004 V1:14
cw, CW (clockwise), 2004 V1:14
CWA. *See* Clean Water Act
CWR (chilled water return), 2004 V1:8
CWS (chilled water supply), 2004 V1:8
cyanide, 2000 V3:93
cyanurates, 2000 V3:149
cyanuric acid, 2000 V3:123, 149
cycle of concentration in cooling towers, 2005 V2:227
cyclopropane, 2000 V3:56
cycolac skimmers, 2000 V3:146
cylinder-manifold-supply systems, 2000 V3:59, 60, 62–63, 64, 65, 68
cylinder snubbers, 2004 V1:164
cylinders
calculating volume, 2004 V1:4
carbon dioxide extinguishing systems, 2000 V3:20, 21
clean agent gas fire suppression, 2000 V3:23
cystoscopic rooms
fixtures, 2000 V3:35
health-care facilities, 2000 V3:32
medical gas stations, 2000 V3:51, 58

D

d (deci) prefix, 2004 V1:34
D (difference or delta), 2004 V1:14
D (drains). *See* drains
D (indirect drains), 2004 V1:8
D-1148 standard, 2001 V4:61
D-1784 standard, 2001 V4:62
D-1785 standard, 2001 V4:62
D-2239 standard, 2001 V4:61
D-2241 standard, 2001 V4:62
D-2464 standard, 2001 V4:62
D-2466 standard, 2001 V4:62
D-2467 standard, 2001 V4:62
D-2609 standard, 2001 V4:61
D-2662 standard, 2001 V4:58
D-2665 standard, 2001 V4:62
D-2666 standard, 2001 V4:58
D-2672 standard, 2001 V4:62
D-2737 standard, 2001 V4:61
D-3139 standard, 2001 V4:62
da (deka) prefix, 2004 V1:34
Dalton's law, 2005 V2:81
damage. *See* bedding and settlement; corrosion; creep; hazards; scale and scale formation; seismic protection; water damage
damped, single-leaf barriers, 2004 V1:193
dampen, defined, 2004 V1:21
damping
in earthquakes, 2004 V1:160–161, 183, 186
sound damping, 2004 V1:195
dance halls, numbers of fixtures for, 2001 V4:19
dancing fountains, 2000 V3:111
Darcy's law, 2004 V1:2, 3, 2005 V2:6, 84, 165–166
data storage for specifications programs, 2004 V1:71
databases of plumbing costs, 2004 V1:93, 98
Daugherty, Robert L., 2005 V2:19
Dawson, F.M., 2005 V2:4, 19, 80
dB, DB (decibels), 2004 V1:14, 206
DB (dry-bulb temperature), 2004 V1:14, 23
dB(A) (decibel (A) scale), 2004 V1:206
dbt, DBT (dry-bulb temperature), 2004 V1:23
dbt, DBT (effective temperature), 2004 V1:14
DC current, 2004 V1:14, 147, 2005 V2:219
dc, DC (direct current), 2004 V1:14, 147, 2005 V2:219
DCBP (double-check backflow preventers), 2004 V1:10
DCV (double-check valves), 2000 V3:223, 224, 226
DD (design development phase), 2004 V1:64
DE (deionized water), 2004 V1:8
DE (diatomaceous earth). *See* diatomaceous earth
deactivation, defined, 2004 V1:152
dead-end service in pressure-regulated valves, 2005 V2:67
dead ends, defined, 2004 V1:21
dead legs in pure water systems, 2005 V2:233
dead loads on roof, 2005 V2:53
"dead-man" abort stations, 2000 V3:24
deaerators
boiler feed water, 2005 V2:226
deaeration water treatment, 2005 V2:209
sovent deaerators
in sovent systems, 2005 V2:17
dealkalizing treatment, 2005 V2:209–210
dealloying, defined, 2004 V1:152
debris in pools and fountains, 2000 V3:108, 110, 138
decarbonation, 2005 V2:210
dechlorination, 2000 V3:123
"deci" prefix, 2004 V1:34
decibel (A) scale (dB(A)), 2004 V1:206
decibels (dB, DB)
defined, 2004 V1:206
symbols for, 2004 V1:14
decomposition potential, 2004 V1:152

decontaminating radioactive waste piping, 2005 V2:249
decorative pools, gray water and, 2005 V2:25
deep-bed sand filtration, 2005 V2:211
deep (dp, DP, DPTH). *See* depth
deep ends of swimming pools, 2000 V3:128
deep fill, building sewers and, 2005 V2:14
deep-seated fires, 2000 V3:23
deep wells, 2005 V2:163, 164, 169
definitions. *See* glossaries
definitions section in specifications, 2004 V1:69, 88
deg., °, DEG (degrees), 2004 V1:14
degasification, 2005 V2:209
degradation of pure water, 2005 V2:233
degrees (deg., °, DEG), 2004 V1:14
degrees celsius, 2004 V1:34
DEHA (diethylhydroxylamine), 2005 V2:226
deionization, 2005 V2:215. *See also* demineralizer systems
deionized water (DE), 2004 V1:8
"deka" prefix, 2004 V1:34
delay relays, 2000 V3:24
delays in clean gas extinguishing systems, 2000 V3:24
deliquescent dryers, 2000 V3:207
delivery rooms. *See* birthing rooms
delivery section in specifications, 2004 V1:70, 89–90
Delphia method of evaluation, 2004 V1:254
delta (diff., Δ, DIFF, D, DELTA), 2004 V1:14
delta t (temperature differential), 2004 V1:136
DELTP (pressure drops or differences). *See* pressure drops or differences
Deluge Foam-water Sprinkler Systems and Foam-water Spray Systems (NFPA 16), 2000 V3:21, 29
deluge systems, 2004 V1:29, 2000 V3:13–15
deluge valves, 2004 V1:13, 2000 V3:13, 14
demand
  cold-water systems, 2005 V2:83
  defined, 2005 V2:143
  drinking water, 2005 V2:167
  estimating, 2005 V2:91
  fire demand, 2000 V3:3
  fire hydrant water demand, 2000 V3:5–8
  flow rates, 2000 V3:230–232
  gas appliances, 2005 V2:128
  hot water, 2004 V1:136, 2005 V2:107
  hydropneumatic-tank systems, 2005 V2:72, 73–74
  medical air systems, 2000 V3:66
  medical gas systems, 2000 V3:49, 50, 53, 59
  medical school-laboratory water demand, 2000 V3:45
  natural gas, 2005 V2:136, 2000 V3:253–254
  natural gas systems, 2005 V2:135
  pipe sizing and, 2005 V2:86, 92
  sizing water heaters, 2005 V2:108–109
  sprinkler systems, 2000 V3:3–8, 17
  vacuum systems, 2000 V3:55, 70
  water conservation and paybacks, 2004 V1:126
  water heater types and, 2005 V2:111
  water treatment methods and, 2005 V2:221
demineralizer systems, 2005 V2:209, 215, 2000 V3:46–47
demographics in hot water demand classifications, 2005 V2:109
demolition work, in plumbing cost estimation, 2004 V1:93
Denoncourt, 2005 V2:234
dens, DENS (density). *See* density
density (dens, DENS, RHO)
  measurements, 2004 V1:33
  of natural gas, 2005 V2:131–133
  purified water, 2005 V2:82
  symbols for, 2004 V1:14
dental equipment, 2000 V3:39, 51
department connections, 2004 V1:12
departments having jurisdiction, 2004 V1:22
dependent functionality
  defined, 2004 V1:225
  in FAST approach, 2004 V1:230
depolarization, defined, 2004 V1:152
depolarizing cathodes, 2004 V1:145
deposition corrosion, defined, 2004 V1:152
deposits from feed water, 2005 V2:205–206. *See also* scale and scale formation; sediment; slime; sludge
depth (dp, DP, DPTH)
  of liquids in septic tanks, 2005 V2:155
  of media beds in sand filters, 2000 V3:132
  of reflecting pools, 2000 V3:107
  of septic tanks, 2005 V2:154
  of soils, 2005 V2:148
  symbols for, 2004 V1:14
  of wells, 2005 V2:164
depth filters, 2005 V2:221
derived units of measurement, 2004 V1:33
description in value engineering phases, 2004 V1:214
descriptive specifications, 2004 V1:66
desiccant air dryers, 2000 V3:204, 207
design
  for people with disabilities, 2004 V1:107
  reducing corrosion, 2004 V1:146
  seismic, 2004 V1:160–161, 186–188
  value engineering and, 2004 V1:212
design areas for sprinkler systems, 2000 V3:16
design density, 2000 V3:15
design development phase (DD), 2004 V1:64
Design Information for Large Turf Irrigation Systems, 2000 V3:105
Design of Hoffman Industrial Vacuum Cleaning Systems, 2005 V2:196
design standards, 2004 V1:66
design storms, 2000 V3:242–244
desolver tanks, 2005 V2:220
destruction phase in ozonation, 2005 V2:225
destructive forces in pipes. *See* water hammer
details in projects, checklists, 2004 V1:220
detector-check water meters, 2005 V2:68–69
detectors, smoke, 2004 V1:22
detention centers, numbers of fixtures for, 2001 V4:20
detention times for treated water, 2005 V2:208
detergents
  factors in trap seal loss, 2005 V2:45
  high-expansion foam, 2000 V3:21
  in septic tanks, 2005 V2:156
  venting for, 2005 V2:46
developed length, 2004 V1:22
developers
  perception of engineering, 2004 V1:260
  value engineering and, 2004 V1:212
development costs
  defined, 2004 V1:222

in value engineering, 2004 V1:212
Development phase in value engineering
activities, 2004 V1:235, 243, 254
idea development and estimated cost forms, 2004 V1:241–242
in process, 2004 V1:213
sketches, 2004 V1:254, 255
Development Presentation phase in value engineering, 2004 V1:213
deviations in measurements, 2004 V1:32
dew-point temperature (dpt, DPT), 2004 V1:14
dew points
defined, 2004 V1:22, 2000 V3:201
lowering, 2000 V3:204
medical gas system tests, 2000 V3:83
monitors, 2000 V3:66
refrigerated air dryers, 2000 V3:207
dezincification of brass, 2004 V1:141
DFRAD (diffuse radiation), 2004 V1:14
dfu (drainage fixture units), 2004 V1:24, 2005 V2:39
vent sizing and, 2005 V2:39
DHEC (Department of Health and Environmental Control), 2005 V2:124
DI (deionization), 2005 V2:215
dia., DIA (diameters). *See* diameters
diagnostic facilities, 2005 V2:248
dialogue in FAST approach, 2004 V1:231
dialysis machines, 2000 V3:39
Diameter-Index Safety System (CGA V-5), 2000 V3:83, 86
diameters (dia., DIA)
defined, 2004 V1:22
inside (ID), 2004 V1:14
outside (OD), 2004 V1:14
symbols for, 2004 V1:14
diaper changing stations, 2001 V4:23
diaphragm gauges, 2005 V2:181
diaphragm pumps, 2005 V2:180
diaphragm reciprocating compressors, 2000 V3:201
diaphragm tanks, 2000 V3:21
diaphragm valves, 2004 V1:22, 2005 V2:240
diaphragms
defined, 2004 V1:22
in deluge valves, 2000 V3:14
diatomaceous earth filtration
advantages and disadvantages, 2005 V2:228
compared to sand filtration, 2000 V3:135–137
maintenance, 2000 V3:112
materials for filter tanks, 2000 V3:131
overview, 2000 V3:134–135
pressure and vacuum filters, 2000 V3:132, 141
swimming pool usage, 2000 V3:130, 131
types of, 2000 V3:139
die-cast metals, 2000 V3:33
dielectric fittings, 2004 V1:22
dielectric insulation, 2004 V1:146, 2004 V1:151
dielectric isolation, 2000 V3:116
dielectric unions, 2000 V3:156
diesel drivers, 2000 V3:25
diesel engines, 2000 V3:26
diesel fuel, 2005 V2:12
diesel-oil systems
aboveground tank systems, 2000 V3:165–169
connections and access, 2000 V3:166
construction, 2000 V3:165
corrosion protection, 2000 V3:165
filling and spills, 2000 V3:166–167
leak prevention and monitoring, 2000 V3:167–168
materials, 2000 V3:165
overfill prevention, 2000 V3:167
product dispensing systems, 2000 V3:168
tank protection, 2000 V3:169
vapor recovery, 2000 V3:168
venting, 2000 V3:167
codes and standards, 2000 V3:154
components, 2000 V3:155
definitions and classifications, 2000 V3:153–154
designing
installation considerations, 2000 V3:172–173
piping materials, 2000 V3:169
piping sizing, 2000 V3:169–170
submersible pump sizing, 2000 V3:170
testing, 2000 V3:170–172
overview, 2000 V3:153
references, 2000 V3:173
resources, 2000 V3:173
underground tank systems, 2000 V3:155–165
leak detection and system monitoring, 2000 V3:158–163
product dispensing systems, 2000 V3:163–165
storage tanks, 2000 V3:155–158
vapor recovery systems, 2000 V3:163
dietary services in health-care facilities, 2000 V3:32
diethylhydroxylamine, 2005 V2:226
diff., DIFF (difference or delta), 2004 V1:14
difference (diff., (, DIFF, D, DELTA), 2004 V1:14
differential aeration cells, 2004 V1:152
differential environmental conditions, corrosion by, 2004 V1:141
differential movement in earthquakes, 2004 V1:161
differential pressure
in sand filtration, 2000 V3:113
in sizing steam traps, 2000 V3:193
differential regulators, 2000 V3:251
differentials, defined, 2004 V1:22
difficulties in value engineering presentations, 2004 V1:258
diffuse radiation (DFRAD), 2004 V1:14
diffuser plates, 2000 V3:120
diffusion aerators, 2005 V2:208, 228
digester gas, 2005 V2:126
digestion, 2004 V1:22
digits, 2004 V1:32
dikes
for aboveground storage tanks, 2000 V3:165, 167
for hazardous waste areas, 2000 V3:90
dilution air, defined, 2005 V2:143
dilution, pollution and, 2000 V3:87
dimensions
in creativity checklist, 2004 V1:234
defined, 2004 V1:32
wheelchairs, 2004 V1:108
DIN 52218, 2004 V1:194
dir radn, DIR RADN (direct radiation), 2004 V1:14
DIRAD (direct radiation), 2004 V1:14

direct-acting gas regulators, 2000 V3:250
direct-count epifluorescent microscopy, 2005 V2:199
direct current (dc, DC)
  cathodic protection, 2004 V1:147
  in deionization, 2005 V2:219
  symbols for, 2004 V1:14
direct-fill ports, 2000 V3:156
direct-filtration package plants, 2005 V2:228
direct-fired gas water heaters, 2004 V1:130, 2000 V3:138, 146
direct-operated pressure-regulated valves, 2005 V2:78
direct pump water supplies, 2000 V3:8
direct radiation (dir radn, DIR RADN, DIRAD), 2004 V1:14
directly-heated, automatic storage water heaters, 2005 V2:111
dirt cans for vacuum systems, 2005 V2:188
dirt in feed water, 2005 V2:205
dirty filters, 2000 V3:115
dirty gas, 2000 V3:250
disabled individuals. *See* people with disabilities
disc-type positive displacement meters, 2005 V2:95, 96
disc water meters, 2005 V2:68
discharge characteristic fixture curves, 2005 V2:3
discharge coefficients, 2004 V1:5
discharge curves, 2000 V3:220
discharge permits, 2000 V3:88
discharge piping for vacuum cleaning systems, 2005 V2:193–194
discharge times in fire suppression, 2000 V3:23
disconnect switches for pumps, 2000 V3:120
discontinuous regulation in air compressors, 2000 V3:205
discs, defined, 2004 V1:22
discussions in FAST approach, 2004 V1:231
dished ends on tanks, 2000 V3:156
dishwashers
  acoustic ratings of, 2004 V1:195
  defined, 2004 V1:22
  fixture pipe sizes and demand, 2005 V2:94
  fixture-unit loads, 2005 V2:3
  health-care facilities, 2000 V3:36
  heat recovery systems, 2004 V1:266
  hot water demand, 2005 V2:109
  water fixture unit values, 2000 V3:217
  water temperatures, 2000 V3:45
disinfecting
  codes for, 2004 V1:43
  cold-water systems, 2005 V2:103–104
  decontaminating infectious wastes, 2005 V2:252
  disinfectant residuals, 2000 V3:122
  drinking water, 2005 V2:168
  feed water, 2005 V2:205, 223–225
  gray water, 2005 V2:28, 35
  reflecting pools and fountains, 2000 V3:123
  septic tanks, 2005 V2:155
  small drinking water systems, 2005 V2:228
  swimming pools, 2000 V3:149–151
  water systems, 2005 V2:172
Disinfecting, 2001 V4:32
Disinfection of Escherichia Coli by Using Water Dissociation Effect on Ion Exchange Membranes, 2005 V2:234
disintegrations per second (dps), 2005 V2:247
disk filters, 2005 V2:221
dispenser pans, 2000 V3:165
dispensers
  aboveground tanks, 2000 V3:168
  fuel product dispensers, 2000 V3:164–165
  high-rate dispensers, 2000 V3:169
  multiple dispenser flow rates, 2000 V3:170
dispersed oil, 2005 V2:255
displacement
  defined, 2004 V1:22
  in earthquakes, 2004 V1:159
  swimming pools, 2000 V3:143
  water meters, 2005 V2:69
displays in fountains
  display piping, 2000 V3:111–112
  filtration turnover, 2000 V3:110
  height of, 2000 V3:120
  piping for, 2000 V3:119
  pumps, 2000 V3:113–115
  remote controls, 2000 V3:120
  selecting, 2000 V3:108–110
  types of, 2000 V3:111
  weirs and waterfalls, 2000 V3:109
disposal fields (sewage). *See* leaching trenches (leach fields)
disposal wells in geothermal energy, 2004 V1:131
disposers. *See* food waste grinders
DISS connectors, 2000 V3:83
dissolved elements and materials in water
  dissolved gases, 2005 V2:200, 209, 226
  dissolved inorganics, 2005 V2:204
  dissolved metals, 2000 V3:93
  dissolved minerals, 2005 V2:226
  dissolved oil, 2005 V2:255
  dissolved organics, 2005 V2:211
  dissolved oxygen, 2000 V3:93
  dissolved solids, 2005 V2:204
distances in standpipe systems, 2000 V3:18
distilled water (DL)
  distillation treatment, 2005 V2:210–211, 214
  health-care facility stills, 2000 V3:39
  producing, 2000 V3:46
  symbols for, 2004 V1:8
distribution gray-water pumps, 2004 V1:267
distribution of wealth, 2004 V1:224
ditches, 2000 V3:247–248
divergent thinking
  in creativity, 2004 V1:231–235
  in evaluation, 2004 V1:235
diversity factor
  compressed air tools, 2000 V3:208
  defined, 2005 V2:143
  health-care facility systems, 2000 V3:45
  liquid fuel piping, 2000 V3:170
  medical gas, 2000 V3:50, 75
  medical vacuum, 2000 V3:54, 55, 75
  natural gas systems, 2000 V3:249, 253
  nitrogen systems, 2000 V3:74, 75
  nitrous oxide, 2000 V3:75
  oxygen, 2000 V3:75
  vacuum systems, 2005 V2:184–185
diverter plates, 2000 V3:119–120

diverters, spray accessories on sinks, 2001 V4:14
diving pools, 2000 V3:128, 143
divinyl benzene, 2005 V2:216
division in SI units, 2004 V1:34
Divisions in MasterFormat 2004, 2004 V1:65, 77–88
DL. *See* distilled water (DL)
DN (nominal diameter), 2005 V2:175
DNA materials, 2005 V2:251
dolomite limestone chips, 2005 V2:245
dome grates in shower rooms, 2005 V2:11
dome roof drains, 2005 V2:54
dome strainers, 2005 V2:63
domestic sewage, 2004 V1:22
domestic spaces, acoustic plumbing design for, 2004 V1:196
domestic systems. *See* domestic water supply; residential systems
Domestic Water Heating Design Manual, 2005 V2:104, 109, 2000 V3:45
domestic water meters, 2005 V2:68–69
domestic water supply
  codes and standards, 2000 V3:216
  combined with fire-protection supply, 2000 V3:225–226
  health-care facilities, 2000 V3:43–48
  overview, 2000 V3:216
  preliminary information, 2000 V3:215–216
  service components and design, 2000 V3:217–224
    backflow prevention, 2000 V3:221–224
    elevation differences, 2000 V3:224
    piping runs, 2000 V3:221
    strainer losses, 2000 V3:224
    taps, 2000 V3:221
    valves and fittings, 2000 V3:221
    water meters, 2000 V3:224
    water pressure, 2000 V3:217–221
  service connection, 2000 V3:221
  system requirements, 2000 V3:216–217
  water fixture unit values, 2000 V3:217
  water mains, 2000 V3:216
  water utility letters, 2000 V3:216, 256
doors, accessibility and, 2004 V1:113, 114, 115
dope, pipe, 2005 V2:201
dormitories
  acoustic plumbing design for, 2004 V1:196
  numbers of fixtures for, 2001 V4:20, 21
doses of radiation, 2005 V2:247
dosimeters, 2005 V2:247
dosing tanks, 2004 V1:22
dot products, defined, 2004 V1:93
DOTn. *See* U.S. Department of Transportation (DOTn)
double. *See also entries beginning with dual-, multiple-, or two-*
double-acting altitude valves, 2005 V2:172
double-acting cylinders in compressors, 2000 V3:201
double-check backflow preventers (DCBP), 2004 V1:10
double-check valves (DCV), 2000 V3:223, 224, 226
double-compartment sinks, 2001 V4:11, 12
double-contained piping systems, 2005 V2:252, 253, 2000 V3:40, 162–163
double-contained tanks, 2000 V3:156
double discs, 2004 V1:22
double extra-strong steel pipe, 2001 V4:48
double-leaf barriers, 2004 V1:193
double offsets, 2004 V1:22
double-ported valves, 2004 V1:22
double-seated pressure-regulated valves, 2005 V2:78
double-sweep tees, 2004 V1:22
double tees, 2000 V3:119–120, 2001 V4:6–7
double-wall piping, 2005 V2:237
double-wall tanks, 2000 V3:156
double wedges, 2004 V1:22
Dow Chemical Corp., 2005 V2:234
down, defined, 2004 V1:22
downfeed risers, 2000 V3:185
downspouts and leaders. *See also* vertical stacks
  defined, 2004 V1:22, 26
  roof drainage systems, 2005 V2:51–52, 64
  roof expansion and, 2005 V2:51
  roof leaders, 2005 V2:51
downstream, defined, 2004 V1:22
downward-tapered weirs, 2000 V3:109
dp, DP (depth). *See* depth
dps (disintegrations per second), 2005 V2:247
dpt, DPT (dew-point temperature), 2004 V1:14
DPTH (depth). *See* depth
draft hoods, 2005 V2:143
drain bodies. *See* sumps and sump pumps
drain cleaners in septic tanks, 2005 V2:156
drain fields. *See* leaching trenches (leach fields)
drain line carry tests, 2001 V4:6
drain tiles, 2005 V2:151
drain valves, 2000 V3:103, 191
drain, waste, and vent pipes (DWV)
  copper drainage tube, 2001 V4:45
  copper pipe, 2001 V4:36
  defined, 2004 V1:23
  DWV pattern schedule 40 plastic piping, 2005 V2:13
  DWV piping, 2005 V2:50
  glass pipe, 2001 V4:47
  plastic pipes, 2001 V4:58
  PVC pipes, 2001 V4:62
  Sovent systems, 2005 V2:17
drain, waste, and vent stacks (DWV)
  copper, 2001 V4:34
  Sovent systems, 2005 V2:17
drainage channels, irrigation systems and, 2005 V2:29
drainage (corrosion), defined, 2004 V1:152
drainage fittings, 2004 V1:22
drainage fixture units (dfu), 2004 V1:24, 2005 V2:39. *See also* fixture units and unit values
drainage piping
  acoustic ratings of fixtures, 2004 V1:194
  copper pipe, 2001 V4:34
  glass pipe, 2001 V4:45
  nonreinforced concrete pipe, 2001 V4:32
drainage structures
  defined, 2000 V3:234–236
  manholes, 2000 V3:234–236
drainage systems. *See also specific types of drainage systems*
  air compressor systems, 2000 V3:213
  condensate drainage, 2000 V3:189–197
  defined, 2004 V1:22, 2005 V2:1
  health-care facilities, 2000 V3:39–42

laboratories
acid-waste drainage, 2000 V3:39–40
acid-waste metering, 2000 V3:41–42
acid-waste solids interceptors, 2000 V3:41, 43
acidic-waste neutralization, 2000 V3:40–41
corrosive-waste piping materials, 2000 V3:40
discharge to sewers, 2000 V3:40
sink traps, 2000 V3:42
waste and vent piping, 2000 V3:42
reflecting pools and fountains, 2000 V3:112, 125
storm water, 2000 V3:245–247
swimming pools, 2000 V3:131, 143
drainage, waste, and vents (DWV). *See* drain, waste, and vent
drainline heat reclamation, 2004 V1:134
drains (D). *See also* building drains; horizontal drains; *specific types of drains*
defined, 2004 V1:22
multilevel pools, 2000 V3:108
pools and fountains, 2000 V3:110
secondary containment areas, 2000 V3:90
symbols for, 2004 V1:11
drawdowns (wells), 2005 V2:166, 169, 172
drawings, plumbing. *See* plumbing drawings
drawn temper (hard), 2001 V4:37, 45
drawoff installations. *See specific kinds of interceptors*
drench equipment for emergencies, 2005 V2:239
drench showers, 2000 V3:32, 37
dressing facilities, 2000 V3:130
drift
defined, 2004 V1:22
problems in seismic protection, 2004 V1:190
drilled anchor bolts, 2004 V1:163, 190
drilling wells, 2005 V2:172
drinking fountains
access to, 2004 V1:109–112
energy use, 2004 V1:266
fixture pipe sizes and demand, 2005 V2:94
gray-water systems, 2004 V1:135
health-care facilities, 2000 V3:32, 33, 38
minimum numbers of, 2001 V4:18–22
standards, 2001 V4:2
swimming pool bathhouses, 2000 V3:130
types, 2001 V4:14
water fixture unit values, 2000 V3:217
wheelchair approaches, 2004 V1:112
drinking water
amount of, 2004 V1:263
chilled systems, 2004 V1:265
drinking water supply (DWS), 2004 V1:8
drinking water supply recirculating (DWR), 2004 V1:8
drinking water systems. *See* private water systems
health-care facilities, 2000 V3:43, 45
material codes, 2004 V1:43
potable water, 2004 V1:27, 263
treatments for, 2005 V2:228
drip irrigation, 2004 V1:266
drip lips on weirs, 2000 V3:109
drip pots, 2000 V3:252
drive points, 2005 V2:165
driven wells, 2005 V2:165
droop, 2004 V1:22
drop elbows, 2004 V1:22
drop manholes, 2000 V3:234, 238
drop nipples on pendant sprinklers, 2004 V1:13
drop tees, 2004 V1:23
drop tubes, 2000 V3:157, 163
drops, 2004 V1:11, 22, 2000 V3:156
dross, 2004 V1:23
drug rooms, 2000 V3:35
drum traps, 2000 V3:42
dry (DRY), 2004 V1:14
dry acid (sulfuric acid), 2000 V3:150
dry-bulb temperature (dbt, DBT, DB), 2004 V1:14, 23
dry cast pipe, 2001 V4:32
dry-chemical extinguishing systems, 2000 V3:19–20, 27
Dry Chemical Extinguishing Systems (NFPA 17), 2000 V3:20, 29
dry chlorine, 2000 V3:123
dry gas, 2000 V3:254
dry hose stations, 2004 V1:13
dry ice, 2000 V3:20
dry nitrogen, 2000 V3:20, 252
dry pendent sprinklers, 2004 V1:29
dry-pipe systems
accelerators, 2000 V3:12–13
air compressors, 2000 V3:12
combined dry-pipe and pre-action systems, 2000 V3:15
defined, 2004 V1:29
normal conditions, 2000 V3:11–12
riser diagram, 2000 V3:11
sprinklers, 2000 V3:9–13
dry-pipe valves, 2004 V1:13, 23
dry-powder extinguishing systems, 2000 V3:20
dry pumps, 2005 V2:183, 2000 V3:113, 115
dry returns, 2000 V3:178–179, 183
dry standpipes, 2004 V1:13, 30
dry-storage water softeners, 2005 V2:220
dry surfaces, 2004 V1:16
dry upright sprinklers, 2004 V1:29
dry-vacuum cleaning systems (DVC), 2004 V1:9, 2005 V2:188, 194, 2000 V3:69
dry-weather flows, 2004 V1:23
dry wells (leaching wells), 2004 V1:26, 2000 V3:247
dryers in laundry facilities, 2000 V3:36
du Moulin, G.C., 2005 V2:234
dual. *See also entries beginning with* double-, multiple-, *or* two-
dual-bed deionization (two-step), 2005 V2:216, 217
dual-flush water closets, 2004 V1:136, 265
dual-gas booster systems, 2005 V2:132
dual sensors, 2000 V3:125
dual vents (common vents), 2004 V1:21. *See also* common vents
dual water-supply systems, 2000 V3:43
ductile action of building systems, 2004 V1:183
ductile iron fittings, 2000 V3:116
ductile iron grates, 2005 V2:13
ductile iron piping
characteristics and standards, 2001 V4:32–33
radioactive waste and, 2005 V2:249
sizing, 2000 V3:245
underground piping, 2005 V2:50
ducts. *See* vents and venting systems

dug wells, 2005 V2:164
Dumfries Triangle and Occoquan-Woodbridge Sanitary District, 2005 V2:35
dump loads, 2000 V3:45
Dunleavy, M., 2005 V2:234
duplex. *See also entries beginning with* double-, dual-, *or* two-
duplex air compressors, 2000 V3:66, 213
duplex bed pressure swing dryers, 2000 V3:204
duplex manifolds, 2000 V3:63, 65
duplex sump pump systems, 2005 V2:8
duplex vacuum pump arrangements, 2005 V2:182–183, 186
duration of rainfall, 2005 V2:53–57, 2000 V3:244
Durham systems, 2004 V1:23
durion, 2004 V1:23
duty cycles, 2000 V3:206, 207, 211
duty-cycling controls, 2000 V3:67, 70
DVC (dry vacuum cleaning), 2004 V1:9, 2005 V2:188, 194
dwellings. *See* buildings
DWR (drinking water supply recirculating), 2004 V1:8
DWS (drinking water supply), 2004 V1:8
DWV. *See* drain, waste, and vent stacks (DWV)
DWV piping, 2001 V4:36, 45
dye tests, 2001 V4:5, 9
dyes in gray water, 2005 V2:35
dynamic air compressors, 2000 V3:65, 66, 201
dynamic fountain displays, 2000 V3:111, 119
dynamic head, 2005 V2:169
dynamic pressure, 2004 V1:15
dynamic pressure drop, 2005 V2:67
dynamic properties of piping, defined, 2004 V1:191
dynamic response (K) to ground shaking, 2004 V1:159, 161
dynamic viscosity
  converting to SI units, 2004 V1:39
  measurements, 2004 V1:33
dyne, converting to SI units, 2004 V1:39

E

E (exa) prefix, 2004 V1:34
E (roughness), 2004 V1:16. *See also* roughness
E (volts). *See* volts
E-33.08B (Plumbing Noise), 2004 V1:194
early flame knockdown, 2000 V3:20
early-suppression fast-response systems (ESFR), 2000 V3:2
earth loads
  in pipe selection, 2001 V4:26
  protecting against, 2005 V2:16
earthquake protection of plumbing equipment. *See* seismic protection
Earthquake Resistance of Buildings, 2004 V1:191
Earthquake Resistant Design Requirements Handbook, 2004 V1:191
Eaton, Herbert N., 2005 V2:4, 19
eccentric fittings, 2004 V1:23
eccentric reducers, 2004 V1:10, 2000 V3:115
eccentricity in connections, 2004 V1:189
economic concerns. *See* costs and economic concerns
Economic Thickness of Insulation, 2004 V1:127
economic values, 2004 V1:213–214
Eddy, 2005 V2:161
edge distances, problems in seismic protection, 2004 V1:190
edr, EDR (equivalent direct radiation), 2004 V1:14, 39, 2000 V3:178, 180
educating public on gray-water systems, 2005 V2:35
educational facilities. *See* schools
eff, EFF (efficiency). *See* efficiency
effect water in fountains, 2000 V3:124
effective openings, 2004 V1:23
effective pressure, 2005 V2:67
effective temperature (ET*, ET), 2004 V1:14
effectiveness (EFT), 2004 V1:14
effects in multi-effect distillation, 2005 V2:210–211
effects of earthquakes, 2004 V1:156–158
efficiency (eff, EFF)
  fin (FEFF), 2004 V1:14
  surface (SEFF), 2004 V1:14
  symbols for, 2004 V1:14
  thermal, 2004 V1:136
effluent. *See also* private onsite wastewater treatment systems (POWTS)
  asbestos concrete piping, 2001 V4:26
  chemicals in special-waste effluent, 2005 V2:238
  defined, 2004 V1:23
  estimating sewage quantities, 2005 V2:158–160
  layers of in septic tanks, 2005 V2:153
  samples of radioactive waste effluent, 2005 V2:250
  special-waste drainage systems, 2005 V2:237
  temperature of special-waste effluent, 2005 V2:238
  treatment of sewage effluent, 2005 V2:153
Effluent Guideline program, 2000 V3:88–89
EFT (effectiveness), 2004 V1:14
Egozy, 2005 V2:234
EJ (expansion joints). *See* expansion joints
EJCDC (Engineers Joint Contract Documents Committee), 2004 V1:63
ejector pumps and pits, 2000 V3:236
ejectors
  defined, 2005 V2:8
  in sanitary drainage systems, 2005 V2:8
EL (elevation). *See* elevation
elastic limits, 2004 V1:23
elastic rebound theory, 2004 V1:158
elastic vibration in pipes, 2004 V1:6
elasticity of plastic pipes, 2001 V4:60
elastomeric seals or gaskets
  reinforced concrete pipe, 2001 V4:32
  swimming pools, 2000 V3:144
  water closets, 2001 V4:6
elbows
  ells, 2004 V1:23
  risers up or down, 2004 V1:10
elderly
  aging disabilities, 2004 V1:107
  fixtures and, 2004 V1:107
  in hot water demand classifications, 2005 V2:109
electric capacitance measurements, 2004 V1:33
electric charge density measurements, 2004 V1:33
electric fire pumps, 2000 V3:26
electric hot-water heaters, 2004 V1:129–130
electric inductance, 2004 V1:33

electric instantaneous water heaters, 2004 V1:265
electric irrigation valves, 2000 V3:103
electric permeability measurements, 2004 V1:33
electric permitivity measurements, 2004 V1:33
electric resistance, 2004 V1:33
electric-resistance welding (ERW), 2001 V4:48
electric resistivity measurements, 2004 V1:33
electric vaporizers, 2000 V3:61
electric water heaters, 2005 V2:110, 2000 V3:121
electrical components in gas boosters, 2005 V2:130
electrical connections for pool heaters, 2000 V3:138
electrical engineers, 2000 V3:27–28
electrical equipment
  fires, 2000 V3:21
  installation of pipe and, 2001 V4:25
electrical makeup water method, 2000 V3:124
electrical phases, 2004 V1:15
electricity
  conversion factors, 2004 V1:35
  measurements, 2004 V1:33
  off-peak power savings, 2004 V1:128–129
electrochemical equivalents in corrosion, 2004 V1:139
Electrochemical Society, 2004 V1:153
electrodeionization, 2005 V2:219–220
electrodes, defined, 2004 V1:152
electrolysis, 2004 V1:23. *See also* galvanic action
electrolytes
  defined, 2004 V1:139, 152, 2005 V2:197
  specific resistance, 2005 V2:203
electromagnetic radiation, 2005 V2:247
electrometric compression liners, 2001 V4:48
electromotive force (emf, EMF)
  counter-e.m.f.s, 2004 V1:153
  electromotive force series, 2004 V1:144
  measurements, 2004 V1:33
  symbols for, 2004 V1:14
electromotive force series, 2004 V1:144, 152
electron microscopes, 2000 V3:38, 39, 45, 51
electronegative potential, 2004 V1:153
electronic grade water, 2001 V4:58
electronic product level gauges, 2000 V3:168
electronic tank gauging, 2000 V3:160
electronics-grade water, 2005 V2:229, 230
electroplating wastewater treatment, 2000 V3:94
electropositive potential, 2004 V1:153
electroregeneration, 2005 V2:220
elements in water, 2005 V2:199
elev., ELEV (elevation). *See* elevation
elevated water storage tanks, 2005 V2:170
elevated water supplies, 2005 V2:74–76, 2000 V3:8
elevation (elev., EL, ELEV)
  adjustments for vacuum, 2005 V2:178, 194
  air compressors and, 2000 V3:66
  altitude (alt, ALT), 2004 V1:14
  altitude valves, 2005 V2:172
  compressed air and, 2000 V3:199, 211
  medical vacuum systems and, 2000 V3:69
  natural gas and, 2005 V2:129
  pressure drops and, 2005 V2:95
  pressure losses and, 2000 V3:224
  in sprinkler hydraulic calculations, 2000 V3:17
  symbols for, 2004 V1:14
elevation pressure, 2005 V2:67
elevator shafts
  medical gas piping and, 2000 V3:73
  protection systems, 2000 V3:25
ellipses, calculating area, 2004 V1:4
ells (elbows), 2004 V1:23
elongated bowls on water closets, 2001 V4:4
elutriation, 2004 V1:23
embedments, problems in seismic protection, 2004 V1:190
emergency drains for pools and fountains, 2000 V3:125
emergency equipment for acid spills, 2005 V2:239, 241
emergency fixtures
  emergency eyewashes, 2001 V4:17–18
  emergency showers, 2001 V4:17–18
  floor drains (copy all HERE), 2001 V4:17
  standards, 2001 V4:2
Emergency Planning and Community Right-To-Know Act (EPCRA) (SARA Title III), 2000 V3:154
emergency power for fire pumps, 2000 V3:26
emergency rooms, 2000 V3:32
  fixtures, 2000 V3:35
  medical gas stations, 2000 V3:51, 58
  medical vacuum, 2000 V3:54
  water demand, 2000 V3:45
emergency showers, 2000 V3:32, 37
emergency shutoffs for fuel dispensers, 2000 V3:165
emergency tank vents, 2000 V3:166, 167
e.m.f. series, 2004 V1:144, 152
emitters in irrigation systems, 2005 V2:30
employee facilities, numbers of fixtures for, 2001 V4:20, 21
emptying noises, acoustic design and, 2004 V1:195
emulsions, 2005 V2:255
enameled cast iron fixtures
  defined, 2001 V4:1–2
  health care facilities, 2000 V3:33
  standards, 2001 V4:2
enameled floor drains, 2005 V2:15
enameled sediment buckets, 2005 V2:13
enclosures for showers, 2004 V1:120
The Encyclopedia of Chemical Technology, 2000 V3:97
end connections, 2004 V1:23
end-head flows, 2000 V3:17, 18
end-of-main vents, 2000 V3:180
end-suction pumps, 2004 V1:24, 2000 V3:115, 142
end-use restrictions
  conserving energy, 2004 V1:126
  reduced water usage, 2004 V1:126
end venting, 2005 V2:39
endotoxins, 2005 V2:199, 204
energy
  conversion factors, 2004 V1:35
  defined, 2004 V1:137
  measurements, 2004 V1:33
  non-SI units, 2004 V1:34
  nondepletable, 2004 V1:130–131, 137
  recovered, 2004 V1:137
Energy & Atmosphere design (LEED), 2004 V1:263
energy code list of agencies, 2004 V1:42
energy conservation. *See* conserving energy
energy efficiency. *See* conserving energy
Energy Policy Act (EPACT), 2004 V1:124, 136, 264
Energy Policy and Conservation Act (EPCA), 2004 V1:124

Energy Saving and the Plumbing System, 2004 V1:137
enflurane, 2000 V3:70
engineered dry-chemical systems, 2000 V3:19
Engineered Plumbing Design, 2004 V1:40, 2005 V2:64
Engineered Plumbing Design II, 2005 V2:104
engineered plumbing systems, 2004 V1:23
engineering and design costs, 2004 V1:212
Engineering Fluid Mechanics, 2005 V2:104
Engineering Manual of the War Department, 2005 V2:64
Engineers Joint Contract Documents Committee (EJCDC), 2004 V1:63
engines, earthquake protection for, 2004 V1:164
entering (entr, ENT), 2004 V1:14
enthalpy (H), 2004 V1:14
entr (entering), 2004 V1:14
entropy (S)
  measurements, 2004 V1:33
  symbols for, 2004 V1:14
environmental conditions, corrosion by, 2004 V1:141
environmental design, 2004 V1:263–267
Environmental Protection Agency. *See* U.S. Environmental Protection Agency
Environmental Quality design (LEED), 2004 V1:263
environs (facilities with radiation), 2005 V2:247
EPA. *See* U.S. Environmental Protection Agency
The EPA Effluent Guidelines Series (EPA 440), 2000 V3:96
EPACT (Energy Policy Act), 2004 V1:124, 136, 264
EPCA (Energy Policy and Conservation Act), 2004 V1:124
EPCRA (Emergency Planning and Community Right-To-Know Act) (SARA Title III), 2000 V3:154
EPDM (ethylene-propylene diene monomer), 2001 V4:37
epicenters of earthquakes, 2004 V1:156
epicyclic gears, 2004 V1:196
epm (equivalents per million), 2005 V2:201
epoxy
  as thermoset, 2001 V4:58
  coatings, 2004 V1:147, 2000 V3:169
  linings for pipes, 2001 V4:26
EQFT (equivalent feet), 2004 V1:14
EQIN (equivalent inches), 2004 V1:14
eqiv ft, EQIV FT (equivalent feet), 2004 V1:14
eqiv in, EQIV IN (equivalent inches), 2004 V1:14
equalization fittings, 2000 V3:137
equalizer lines, 2000 V3:108
equations
  acfm to scfm, 2000 V3:65–66
  air receiver sizing, 2000 V3:206
  anode expected life, 2004 V1:148
  areas and volumes, 2004 V1:3–5
  Bernoulli's equation, 2004 V1:5–6
  Boyle's law, 2005 V2:73
  calculating seismic forces, 2004 V1:183–186
  Colebrook formula, 2005 V2:84–86
  collection legs in condensate drainage, 2000 V3:195
  condensate loads, 2000 V3:194
  corrosion rates, 2004 V1:144
  Darcy's Law, 2004 V1:2, 3, 2005 V2:6, 84
  Faraday's Law, 2004 V1:144
  flow at outlets, 2004 V1:3, 5
  flow capacity in vertical stacks, 2005 V2:3
  flow from outlets, velocity of, 2004 V1:6
  flow rates, 2004 V1:1
  fountain head formulas, 2000 V3:118
  friction head, 2004 V1:6, 2005 V2:71
  friction head loss, 2004 V1:2
  gas laws, 2005 V2:131
  gravity circulation, 2004 V1:5
  Hazen-Williams formula, 2004 V1:2, 2005 V2:6, 83, 2000 V3:118
  hot-water systems, 2005 V2:109–110
  hydrant flow tests, 2000 V3:5
  hydraulic shock, 2004 V1:6
  International System of Units (SI), 2004 V1:1
  Joukowsky's formula, 2005 V2:79–80
  kinetic energy, 2004 V1:2
  Manning formula, 2000 V3:244–245, 246
    alternative sewage-disposal systems, 2005 V2:152
    open-channel flow, 2004 V1:1, 2005 V2:6
    sloping drains, 2005 V2:7
  medical gas pipe sizing, 2000 V3:74
  mixing flows of water, 2004 V1:126
  natural gas pipe sizing, 2005 V2:136–137
  Ohm's Law, 2004 V1:144
  pipe expansion and contraction, 2004 V1:3
  plumbing cost estimation, 2004 V1:93–98
  potential energy, 2004 V1:2
  pump affinity laws, 2004 V1:6
  pump efficiency, 2004 V1:6–7
  pump head, 2005 V2:71
  pump noise levels, 2004 V1:198
  Rational Method formulas, 2004 V1:7, 2000 V3:242
  references, 2004 V1:40
  Reynold's number, 2004 V1:2
  soil resistivity, 2004 V1:150
  Spitzglass formula, 2004 V1:7, 2005 V2:137
  sprinkler demand, 2000 V3:17
  sprinkler design density, 2000 V3:16
  sprinkler end-head pressures, 2000 V3:18
  square feet EDR, 2000 V3:178
  stack terminal velocity and length, 2004 V1:3
  steady-state heat balance equations, 2005 V2:109–110
  steam system traps, 2000 V3:194–195
  steam warm-up loads, 2000 V3:195
  storm drainage, 2004 V1:7
  terminal velocity and terminal length, 2005 V2:2
  vacuum system demand, 2000 V3:70
  value, worth and cost, 2004 V1:213
  velocity head, 2004 V1:5
  vent piping length, 2004 V1:3
  water flow in pipes, 2004 V1:2
  water hammer, 2004 V1:198
  water mass and volume, 2005 V2:77
  well equilibrium equations, 2005 V2:165–166
  Weymouth formula, 2004 V1:7, 2005 V2:137
equilibrium equations for wells, 2005 V2:165–166
equipment
  acoustic concerns in selection, 2004 V1:200
  defined, 2004 V1:191
  section in specifications, 2004 V1:91
  seismic protection, 2004 V1:163–171
  steam and condensate systems, 2000 V3:178
equivalent direct radiation (edr, EDR)
  cast iron radiators, 2000 V3:180
  EDR hot water, 2004 V1:39

EDR steam, 2004 V1:39
operating pressure steam classification, 2000 V3:178
steam heating, 2000 V3:178
symbols for, 2004 V1:14
equivalent feet (eqiv ft, EQIV FT, EQFT), 2004 V1:14
equivalent inches (eqiv in, EQIV IN, EQIN), 2004 V1:14
equivalent length
compressed air piping, 2000 V3:211
defined, 2005 V2:144
medical gas piping, 2000 V3:73
natural gas piping, 2005 V2:136
equivalent static force, calculating, 2004 V1:183
equivalent weight, 2005 V2:198, 199
equivalents per million, 2005 V2:201
erosion, 2004 V1:23, 2000 V3:47, 99
erosion corrosion, 2005 V2:205
ERW (electric-resistance welding), 2001 V4:48
ESFR (early-suppression fast-response systems), 2000 V3:2
essential facilities, defined, 2004 V1:191
estates, septic tank systems for, 2005 V2:156–157
estimating costs. *See also* costs and economic concerns
factors in estimates, 2004 V1:98
idea development and estimated cost forms, 2004 V1:241–242
overestimating, 2004 V1:224
per-area costs, 2004 V1:97–98
per-fixture or per-appurtenance estimates, 2004 V1:97
plumbing cost estimation, 2004 V1:93–98
software for cost estimation, 2004 V1:98
in value engineering, 2004 V1:243
estimating medical gas and vacuum stations, 2000 V3:50, 51–52
ET*, ET (effective temperature), 2004 V1:14
ethane, 2005 V2:126
ethylene-propylene diene monomer (EPDM), 2001 V4:37
ETI (Economic Thickness of Insulation), 2004 V1:127
EVAC stations, 2000 V3:51–52
Evaluation phase in value engineering
activities, 2004 V1:235–243
checklists, 2004 V1:237–238
comparing functions, 2004 V1:243
functional evaluation worksheets, 2004 V1:243–251
idea evaluation checklist, 2004 V1:243, 253
in process, 2004 V1:213
second creativity, cost, and evaluation analysis, 2004 V1:254
evap, EVAP. *See* evaporation; evaporators
evaporation (evap, EVAP)
staged, 2005 V2:210
storage tanks, 2000 V3:172
swimming pools, 2000 V3:131
symbols for, 2004 V1:14
evaporative coolers. *See* cooling-tower water
evaporators (evap, EVAP), 2004 V1:14, 2000 V3:46
evapotranspiration
defined, 2004 V1:23
in irrigation, 2000 V3:105
sewage treatment, 2005 V2:153
"exa" prefix, 2004 V1:34
exact conversions, 2004 V1:32
exam/treatment rooms
fixtures, 2000 V3:35
health-care facilities, 2000 V3:32
medical gas stations, 2000 V3:51
medical vacuum, 2000 V3:54
examination section in specifications, 2004 V1:71, 91
excavation
labor productivity rates, 2004 V1:95–97
plumbing cost estimation, 2004 V1:93
excess air, defined, 2005 V2:143
excess flow gas valves, 2005 V2:127
excess pressure pumps, 2004 V1:24
excess water pressure, 2005 V2:77–79
excessive costs, value engineering and, 2004 V1:212
exchange capacity of resins, 2005 V2:216
exchangers in distillers, 2005 V2:210
Execution section in specifications, 2004 V1:69, 91–92
exhaust
filters on vacuum systems, 2005 V2:182
from vacuum, 2005 V2:184
pressure loss in vacuum systems, 2005 V2:194
vacuum exhaust pipe sizing, 2005 V2:186
vacuum system piping, 2005 V2:180, 194, 2000 V3:70
vacuum system stacks, 2000 V3:70
exhausted cartridges in ion exchange, 2005 V2:219
exhausters (dry-pipe systems), 2000 V3:11
exhausters (vacuum)
air-bleed controls, 2005 V2:189
defined, 2005 V2:188
locating, 2005 V2:190
sizing, 2005 V2:193–194
exhibition halls, numbers of fixtures for, 2001 V4:19
existing work, 2004 V1:23
exp, EXP (expansion). *See* expansion
expanded air in vacuums, 2005 V2:178
expansion (exp, EXP, XPAN)
backflow prevention and, 2005 V2:70
buildings, 2000 V3:49
calculating pipe expansion, 2004 V1:3
foam extinguishing agents, 2000 V3:21
future expansion of compressed air systems, 2000 V3:210
glass pipe, 2001 V4:48
HDPE pipe, 2001 V4:61
hot-water systems and, 2005 V2:116
linear expansion in PVC pipe, 2001 V4:62
plastic pipe, 2001 V4:60
protecting against pipe expansion, 2005 V2:16
sanitary drainage systems, 2005 V2:16
storage tanks and piping, 2000 V3:172
swimming pool piping, 2000 V3:145
symbols for, 2004 V1:14
thermal expansion tanks, 2005 V2:116
expansion bends, 2005 V2:16
expansion joints (EJ)
defined, 2004 V1:23
roofs, 2005 V2:54
symbols for, 2004 V1:10
thermal expansion and, 2005 V2:16
expansion loops
bracing and, 2004 V1:171
defined, 2004 V1:23
protecting against thermal expansion, 2005 V2:16

expansion tanks, 2005 V2:76–77
expert costs, 2004 V1:223
explosions
  explosion-proof (XP) construction, 2005 V2:130
  explosion-relief devices for vacuums, 2005 V2:188
  fire-protection systems, 2000 V3:22
  hot-water heaters, 2005 V2:107
  nitric acid, 2005 V2:242
exposed ends of piping, 2001 V4:25
exposures, fire hazards and, 2000 V3:2
extended-coverage sidewall sprinklers, 2004 V1:29
extinguishing systems, 2004 V1:12
extra-hazard occupancies
  defined, 2004 V1:29
  deluge systems, 2000 V3:13
  firefighting hose streams, 2000 V3:230
  portable fire extinguishers, 2000 V3:27, 28
extra-heavy cast-iron soil pipe (XH), 2001 V4:27, 29–30
extra-heavy piping, 2004 V1:23
extra materials section in specifications, 2004 V1:70, 90
extra-strength vitrified clay piping, 2005 V2:50
extra-strong steel pipe, 2001 V4:48
extra-strong weight brass pipe (Schedule 40), 2001 V4:27
extractors in laundry facilities, 2000 V3:36
extruded steel piping, 2001 V4:48
eyeball inlet fittings, 2000 V3:137
eyewashes for emergencies, 2005 V2:239–240, 2000 V3:37, 2001 V4:17–18

F

°F, F (Fahrenheit), 2004 V1:14, 38
F (farads), 2004 V1:33
f (femto) prefix, 2004 V1:34
F (fire-protection water supply). *See* fire-protection systems
f to f, F TO F (face to face), 2004 V1:14, 23
f & t (flow and thermostatic traps), 2000 V3:182, 194
F-477 standard, 2001 V4:62
F-876 standard, 2001 V4:61
F-877 standard, 2001 V4:61
F-1281 standard, 2001 V4:62
F-1282 standard, 2001 V4:62
F/m (farads per meter), 2004 V1:33
fa, FA (face area), 2004 V1:14
fabrication section in specifications, 2004 V1:91
face area (fa, FA), 2004 V1:14
face piping, 2000 V3:115
face to face (f to f, F TO F)
  face-to-face dimensions, defined, 2004 V1:23
  symbols for, 2004 V1:14
face velocity (fvel, FVEL, FV), 2004 V1:14
face washes, 2000 V3:37
faceplates for pool lighting fixtures, 2000 V3:145
Facility Piping System Handbook, 2005 V2:104, 196, 234, 256, 2000 V3:173, 214
factories, numbers of fixtures for, 2001 V4:19
factors
  correction factors (CFAC, CFACT), 2004 V1:14
  friction factors (FFACT, FF), 2004 V1:14
Factory Mutual Research Corporation (FM)
  air compressors in dry-pipe systems, 2000 V3:12
  design density requirements, 2000 V3:16
  Factory Mutual (FM) Loss Prevention Data Sheets, 2005 V2:129, 2000 V3:225
  FM Global, 2005 V2:127
  seismic protection recommendations, 2004 V1:184
Fahrenheit (°F, F)
  conversion factors, 2004 V1:38
  symbols for, 2004 V1:14
fail-safe mixing valves, 2001 V4:18
Failsafe Neutralization of Wastewater Effluent, 2005 V2:256
failure values of anchors, 2004 V1:190
Fair Housing Accessibility Guidelines, 2004 V1:106
fairly-rough piping, 2005 V2:89
fairly-smooth piping, 2005 V2:88
fall-off pressure, 2005 V2:67
false alarms for sprinkler systems, 2000 V3:9
families, in hot water demand classifications, 2005 V2:109
fan-coil units, 2004 V1:267
fan-cooled electric motors, 2004 V1:196
fan pressurization tests, 2000 V3:24–25
fans (FAN)
  pulsation from, 2004 V1:196
  silencers, 2004 V1:197
  symbols for, 2004 V1:14
Faraday's Law, 2004 V1:139, 144
farads, 2004 V1:33
farads per meter, 2004 V1:33
FAST approach to function analysis, 2004 V1:227–231
fasteners, sound damping, 2004 V1:195
fats in kitchens. *See* grease
faucets
  accessible shower compartments, 2004 V1:120
  acoustic design and pressure, 2004 V1:200
  backflow preventions, 2001 V4:13–14
  centersets, 2001 V4:10
  Energy Policy Act requirements, 2004 V1:264
  flow rates, 2001 V4:10, 13
  health-care facilities, 2000 V3:33
  leakage, 2004 V1:134
  low flow, 2004 V1:136
  patient rooms, 2000 V3:34
  reduced water usage, 2004 V1:126–127
  reducing flow rates, 2004 V1:135
  residential kitchen sinks, 2001 V4:11
  self-metering, 2001 V4:13
  sinks, 2004 V1:117
  standards, 2001 V4:2
  types of, 2001 V4:13–14
  wasted water, 2004 V1:136
faults and fault zones, 2004 V1:156–158
FC (flexible connectors). *See* flexible connectors
FCO (floor cleanouts), 2004 V1:11
FD (floor drains with p-traps), 2004 V1:11
FDA (Food and Drug Administration), 2005 V2:197, 231, 234, 237
features, defined, 2004 V1:32
fecal matter. *See* black-water systems; effluent
federal agencies. *See specific agencies under "US"*
Federal Energy Management Improvement Act (FEMIA), 2004 V1:124
Federal Food, Drug and Cosmetic Act, 2005 V2:229
Federal Register (FR), 2000 V3:88

federal specifications (FS), 2004 V1:25, 54, 58
Federation Internationale de Natation Amateur (FINA), 2000 V3:127, 151
feed-gas treatment units in ozone generators, 2005 V2:224
feed water
  defined, 2005 V2:197
  pure-water systems, 2005 V2:230–231
feet (ft, FT)
  converting to metric units, 2000 V3:29
  converting to SI units, 2004 V1:39
  feet per minute (fpm, FPM), 2004 V1:14, 2000 V3:29
  feet per second (fps, FPS), 2004 V1:14
  foot-pounds (ft-lb, FT LB), 2004 V1:14
  of head, converting, 2004 V1:2
  symbols for, 2004 V1:14
FEFF (efficiency, fin), 2004 V1:14
felt, 2004 V1:195
female threads, 2004 V1:23
female urinals, 2001 V4:9
FEMIA (Federal Energy Management Improvement Act), 2004 V1:124
"femto" prefix, 2004 V1:34
ferric hydroxide, 2005 V2:199
ferric iron, 2005 V2:199, 200
ferrous bicarbonate, 2005 V2:200
ferrous iron, 2005 V2:199, 200
ferrous pipes, 2004 V1:51–52, 2000 V3:12
FF (friction factors), 2004 V1:14
FF (full-flow conditions), 2004 V1:1
FFACT (friction factors), 2004 V1:14
FI (film coefficients), 2004 V1:14
fiber piping, 2005 V2:83
fiberglass fixtures, 2001 V4:2
fiberglass-reinforced plastic (FRP)
  cold water systems, 2005 V2:68
  exposed piping on storage tanks, 2000 V3:165
  fixtures, 2001 V4:2
  fuel product dispensing, 2000 V3:169
  liquid fuel tanks, 2000 V3:155
  storage tanks, 2000 V3:165, 172
  sulfuric acid and, 2000 V3:93
  velocity, 2000 V3:170
  VOCs and, 2005 V2:201
fiberglass-reinforced storage tanks
  aboveground storage tanks, 2000 V3:165
  high-purity water, 2005 V2:233
  liquid fuel tanks, 2000 V3:155
  storage tanks, 2000 V3:172
  storage tanks and hazardous wastes, 2000 V3:91
fiberglass sealants, 2004 V1:193
field checklists, 2004 V1:102–103
field orders, 2004 V1:63
field quality control section in specifications, 2004 V1:71, 91–92
fill
  sewers, 2005 V2:14–15
  types of, around building sewers, 2005 V2:14–15
fill hoses, 2000 V3:157
fill lines for pools, 2000 V3:116
fill ports, 2000 V3:166
fill spouts in pools, 2000 V3:145
filling
  aboveground tank systems, 2000 V3:166–167
  swimming pools, 2000 V3:144
  underground liquid fuel tanks, 2000 V3:156–157
film coefficients
  inside (FI, HI), 2004 V1:14
  outside (FO, HO), 2004 V1:14
film-processing areas, 2000 V3:39, 45
films
  carbonate, 2004 V1:151
  film formation in rate of corrosion, 2004 V1:145
  sodium hexametaphosphate, 2004 V1:151
  sodium silicate, 2004 V1:151
filter alum, 2005 V2:209
filter cakes, 2000 V3:134
filter coats, 2000 V3:134
filter intakes, 2000 V3:66
filter pumps, 2000 V3:115–116, 120
filter tanks, 2000 V3:131
filters and filtration
  air compressors, 2000 V3:203
  cleaning filters, 2000 V3:150
  compressed air systems, 2000 V3:207
  defined, 2004 V1:23
  filter bags on vacuum systems, 2005 V2:188–189
  filter elements or media, 2004 V1:23, 2000 V3:134–135
  filtration water systems, 2000 V3:47
  fountains
    design criteria, 2000 V3:112–113
    filter pumps, 2000 V3:115–116
    piping, 2000 V3:111–112, 119
    turnover time, 2000 V3:110
  fuel dispensers, 2000 V3:165
  gas line filters, 2000 V3:250
  granular filters, 2000 V3:132–134
  gray water, 2004 V1:267, 2005 V2:30–32, 35
  infectious waste systems, 2005 V2:252
  iron-removal filters, 2000 V3:147
  Legionella control, 2005 V2:122
  membrane filtration and separation, 2005 V2:221–223
  microorganisms, 2005 V2:224
  oil spills, 2005 V2:255, 256
  pure water systems, 2005 V2:231–232
  sand filters, 2000 V3:149–150
  slurry feeding, 2000 V3:134–135
  small drinking water systems, 2005 V2:228
  swimming pools, 2000 V3:110–111, 131–140
  utility water, 2005 V2:225
  vacuum systems, 2005 V2:188–189
  water quality and, 2005 V2:167–168
  water treatment, 2005 V2:211–215, 214
fin efficiency (FEFF), 2004 V1:14
FINA (Federation Internationale de Natation Amateur), 2000 V3:127, 151
final checklists, 2004 V1:103
fine sands
  gray-water irrigation systems and, 2005 V2:29
  irrigating, 2000 V3:100
fine vacuum, 2005 V2:175
finish coats, 2004 V1:147
finish inspection, 2004 V1:103
Finnemore, E. John, 2005 V2:19
fire areas, 2000 V3:16

fire departments, 2000 V3:2, 216
fire hydrants. *See* hydrants
fire loads, 2000 V3:2–3
fire marshals, 2000 V3:2, 216
Fire Protection Handbook, 2000 V3:8, 29
fire-protection systems. *See also* sprinkler systems (fire protection)
alarms
electric gongs, 2000 V3:11
fire alarm control panels, 2004 V1:12, 2000 V3:24
fire alarm systems, 2004 V1:23–24
automatic systems, 2000 V3:1–18
codes and standards, 2004 V1:42–43
detection, 2000 V3:13, 19
extinguishers, 2004 V1:12, 13, 2000 V3:27
fire department connections, 2004 V1:24, 2000 V3:11
fire-department connections, 2004 V1:12
fire extinguishers, 2000 V3:27
fire hazards
defined, 2004 V1:24
evaluation, 2000 V3:2–3
fire loads and resistance ratings, 2000 V3:2–3
flammable or volatile liquids, 2005 V2:12, 254–256
oxygen storage areas, 2000 V3:63
fire lines
defined, 2004 V1:24
fire-line water meters, 2005 V2:68–69
fire mains, 2000 V3:8
fire-protection engineers, 2000 V3:28
fire pumps, 2004 V1:12, 24, 2000 V3:25–26, 225
firefighting equipment, 2004 V1:13
firefighting water drainage, 2005 V2:253–254
flow tests, 2000 V3:3–4
hydrants
public hydrants, 2004 V1:12
valves, 2004 V1:24
other trades and, 2000 V3:27–28
overview, 2000 V3:1
references, 2000 V3:29
sanitary systems and, 2005 V2:16
seismic protection, 2004 V1:183–184
special extinguishing systems, 2000 V3:19–25
carbon-dioxide systems, 2000 V3:20–21
dry-chemical extinguishing systems, 2000 V3:19–20
dry-powder extinguishing systems, 2000 V3:20
elevator shaft protection systems, 2000 V3:25
foam extinguishing systems, 2000 V3:21–22
gaseous fire-suppression systems, 2000 V3:22–25
sprinkler systems. *See* sprinkler systems (fire protection)
standpipe systems, 2000 V3:18–19
symbols, 2004 V1:12–13
terminology, 2004 V1:17–31
water lines, 2001 V4:35
water supply for
building water supply, 2000 V3:225–226
codes and standards, 2000 V3:225
fire risers, 2000 V3:16
flow rates, 2000 V3:230–232
graphs, 2000 V3:5, 6
guard posts, 2000 V3:228, 229
hydrants, 2000 V3:226–228
hydraulic calculations, 2000 V3:17
joint restrainers, 2000 V3:228–229
overview, 2000 V3:224–225
piping system layout, 2000 V3:8
post indicator valves, 2000 V3:228
preliminary information, 2000 V3:215–216
quantity and availability, 2000 V3:3–8
reliability, 2000 V3:8
sizing system, 2000 V3:229–232
standpipe systems, 2000 V3:19
symbols for water supply (F), 2004 V1:8
tank capacity, 2000 V3:232
water demands, 2005 V2:167, 170
fire-rated sealants, 2004 V1:193
Fire Resistance (UL 2085), 2000 V3:154
fires
classes of, 2000 V3:3
growth rate, 2000 V3:2
firm gas services, 2000 V3:249
first-degree burns, 2005 V2:122
Fitting, 2001 V4:32
fittings. *See also specific types of fittings*
acoustic ratings, 2004 V1:194–195
cast bronze threaded fittings, 2001 V4:27
cast iron radiators, 2000 V3:179
codes and standards, 2004 V1:44
compressed air, 2000 V3:210, 211
compression, 2004 V1:24
copper and bronze, 2001 V4:37–38
copper drainage tubes, 2001 V4:45, 46
copper pipe, 2001 V4:34
cross-linked polyethylene, 2001 V4:61
defined, 2004 V1:24
domestic pressure drops and, 2000 V3:221
ductile iron water and sewer pipe, 2001 V4:32–33
earthquake damage, 2004 V1:162
earthquake protection, 2004 V1:166
equivalent lengths for natural gas, 2005 V2:135
flanged, 2004 V1:24
fountains, 2000 V3:119
friction loss and, 2005 V2:99–102
glass pipe, 2001 V4:48, 49–50
grab bars, 2004 V1:121–122
hub and spigot, 2001 V4:27
hubless pipe and fittings, 2001 V4:28
lead pipe, 2001 V4:49
medical gas tube, 2001 V4:45
natural gas pipes, 2000 V3:252
plastic pipes, 2001 V4:58
PVC piping, 2001 V4:62
radioactive waste systems, 2005 V2:250
red brass pipe, 2001 V4:27
screwed fittings, 2004 V1:162
seamless copper water tube, 2001 V4:37
standards, 2001 V4:2
steel or galvanized piping, 2001 V4:48
steel pipe, 2001 V4:48
swimming pools, 2000 V3:137, 144, 145
tank manways, 2000 V3:156
types of, 2001 V4:1
vacuum cleaning systems, 2005 V2:189

welded, 2004 V1:24
Fitzgerald, 2004 V1:154
fixed costs, in plumbing cost estimation, 2004 V1:93
fixed floor-mounted equipment, 2004 V1:163
fixed shower heads, 2004 V1:120
fixed suspended equipment, 2004 V1:164
fixture batteries
circuit and loop venting, 2005 V2:44–45
defined, 2005 V2:39
fixture branches, 2004 V1:24
fixture carrier fittings, 2004 V1:24
fixture carriers, 2004 V1:24
fixture drains
defined, 2004 V1:24
discharge characteristics, 2005 V2:3
flow in, 2005 V2:2
flow rate in, 2004 V1:3
simultaneous use of fixtures, 2005 V2:3, 4
fixture supplies, 2004 V1:24
fixture units and unit values
cold-water system demand, 2005 V2:92
conversion to gpm, 2005 V2:93, 2000 V3:218, 234
drainage fixture units (dfu), 2004 V1:24, 2005 V2:39
fixture units (fu) defined, 2005 V2:39
forms for charting, 2005 V2:94
governing fixtures, 2005 V2:95–97
maximum for vertical stacks, 2005 V2:4
minimum sizes of pipes for fixtures, 2005 V2:94
pipe sizing and, 2005 V2:91
sanitary drainage system loads, 2005 V2:3
slope of drains, 2005 V2:6, 7–8
steady flow in horizontal drains, 2005 V2:8
supply fixture units (sfu), 2004 V1:24
water hammer and, 2005 V2:82
fixtures and fixture outlets. *See also specific types of fixtures (water closets, showers, etc.)*
accessibility standards, 2001 V4:2
batteries of fixtures, 2004 V1:18
building requirement tables, 2001 V4:18–23
codes and standards, 2004 V1:43–44
cold-water system demand, 2005 V2:92
defined, 2004 V1:27, 2001 V4:1
domestic water supply and, 2000 V3:216
fittings, 2001 V4:1
health-care facilities, 2000 V3:31–39
inspection, 2004 V1:103
installation productivity rates, 2004 V1:97
laboratory acid-waste drainage systems, 2005 V2:244
materials, 2001 V4:1–2
minimum numbers of, 2001 V4:18–22
per-fixture cost estimation, 2004 V1:97
plumbing cost estimation, 2004 V1:93
plumbing fixtures, defined, 2004 V1:24
reduced water usage, 2004 V1:126–127
reducing flow rates, 2004 V1:134–135
resilient-mounting design, 2004 V1:206, 207
resiliently mounted plumbing fixtures, 2004 V1:207
sizing vents, 2005 V2:43–44
standards, 2001 V4:2
types of, 2001 V4:1
vibration of, 2004 V1:205
water fixture unit values, 2000 V3:217
water-saving fixtures, 2004 V1:126
flame arresters, 2000 V3:158
Flammable and Combustible Liquids Code (NFPA 30), 2005 V2:127, 2000 V3:29, 95, 173
automatic fire-protection systems, 2000 V3:2
dike construction, 2000 V3:167
foam systems, 2000 V3:21
liquid fuel system codes, 2000 V3:154
liquid fuel system definitions, 2000 V3:153
tank construction, 2000 V3:165
flammable gases, 2000 V3:83
flammable or volatile liquids, 2005 V2:12, 254–256, 2000 V3:153
flanged ells, 2005 V2:101
flanged end connections, 2004 V1:23
Flanged Pipe, 2001 V4:32
flanged tees, 2005 V2:101
flanges
bonnets, 2004 V1:25
defined, 2004 V1:25
fittings, 2004 V1:25
flange ends, 2004 V1:25
flange faces, 2004 V1:25
flanged fittings, 2001 V4:38
problems in seismic protection, 2004 V1:190
flap valves, 2004 V1:25
flared fittings, 2001 V4:34
flash attacks, 2004 V1:146, 153
flash fires, 2000 V3:16
flash points
defined, 2004 V1:25, 2000 V3:83, 153
foam extinguishing systems and, 2000 V3:21
liquid fuels, 2000 V3:153
flash tanks, 2000 V3:195, 196
flashing condensate, 2000 V3:197
flashing flanges, 2005 V2:16
flashing flow, 2000 V3:196–197
flashing L flanges, 2005 V2:16
flashing rings, 2005 V2:11, 16, 55
flat roof drains, 2005 V2:54
flat-spray irrigation sprinklers, 2000 V3:103
flexible connectors (FC)
acoustics and, 2004 V1:200
illustrated, 2004 V1:204, 210
symbols for, 2004 V1:10
vibration control devices, 2004 V1:203, 205
flexible hose connections, 2001 V4:14
flexible plastic piping, 2000 V3:169
flexural strength of plastic pipe, 2001 V4:60
float switches, 2000 V3:188
float-type level controls, 2005 V2:171
float valves, 2004 V1:25, 2000 V3:124, 144
booster pump systems, 2005 V2:73
floatation devices for oil spills, 2005 V2:256
floatation of oil in spills, 2005 V2:255
floatation vibration isolation, 2004 V1:164
floating ball devices in tanks, 2000 V3:158
floating floors, soundproofing, 2004 V1:196
floc, 2005 V2:209
flocculation, 2005 V2:209, 2000 V3:150
flood level rims, 2004 V1:25
flood levels

vents and, 2005 V2:37
flooded, defined, 2004 V1:25
flooding factors
clean agent gas fire suppression, 2000 V3:23
combined sewers and, 2005 V2:49
rainfall, 2000 V3:244
underground storage tanks and, 2000 V3:155
floor cleanouts (FCO), 2004 V1:11
floor drains (FD)
acid-resistant floor drains, 2005 V2:15
blood-type, 2000 V3:35
chemical-waste systems, 2005 V2:253
components, 2005 V2:10
fire-suppression drainage and, 2005 V2:254
fixture-unit loads, 2005 V2:3
floor leveling around, 2005 V2:16
food-preparation areas, 2000 V3:36
grate open areas, 2005 V2:10
gravity drains, 2000 V3:140
health-care facilities, 2000 V3:32, 38
infectious and biological waste systems, 2005 V2:252
kitchen areas, 2005 V2:15
mechanical spaces and vaults, 2000 V3:111
with p-traps (FD), 2004 V1:11
public areas in health-care facilities, 2000 V3:34
radioactive waste systems, 2005 V2:250
sanitary drainage systems, 2005 V2:10
standards, 2001 V4:2
swimming pool bathhouses, 2000 V3:130
types, 2001 V4:17
waterproofing, 2005 V2:15–16
floor inlets in pools, 2000 V3:137, 143
floor-mounted back-outlet water closets, 2001 V4:4
floor-mounted bidets, 2001 V4:17
floor-mounted pumps, 2004 V1:205
floor mounted urinals, 2001 V4:10
floor-mounted vibration-isolated equipment, 2004 V1:164–166
floor-mounted water closets, 2001 V4:4, 6–7
floor sinks, 2005 V2:10, 15
floors
bathhouses, 2000 V3:130
design considerations in seismic protection, 2004 V1:186
floor penetrations of pipes, 2004 V1:201
leveling, 2005 V2:16
motions in earthquakes, 2004 V1:160
shaking in earthquakes, 2004 V1:161
flow. *See also* flow rates
at outlet, 2004 V1:3
building drains, 2005 V2:2
critical flows, defined, 2004 V1:2
equalization in gray-water treatment, 2005 V2:30
fixture drains, 2004 V1:3, 2005 V2:2
flow pressure, 2004 V1:25, 2005 V2:67
flow pressure drop, 2005 V2:67
hydraulic jumps in, 2005 V2:2, 6
open-channel flow, 2004 V1:1, 2005 V2:6
outlet velocity, 2004 V1:6
rate of flow, calculating, 2004 V1:1
stacks, 2005 V2:1–2
steady flow, 2005 V2:6
surging flows, 2005 V2:5
symbols for, 2004 V1:11
velocity and water hammer, 2004 V1:198
velocity of uniform flow, 2004 V1:1
water flow in pipes, calculating, 2004 V1:2
flow and thermostatic traps (f & t), 2000 V3:182, 194
flow hydrants, 2000 V3:4
flow indicators, 2000 V3:142
flow meters, 2000 V3:140
flow rate totalizers, 2000 V3:142
flow rates
acoustic ratings and, 2004 V1:194, 200
air flow in vacuum pressure, 2005 V2:175
air flow rates (QAR, QAIR), 2004 V1:14
altitude and, 2005 V2:178
at outlets, 2004 V1:5
capacity, 2004 V1:20, 33
cold-water systems, 2005 V2:78, 83
compressed air systems, 2000 V3:212
air compressors, 2000 V3:205
air-consuming devices, 2000 V3:206–207
measurements, 2000 V3:200
tools and equipment, 2000 V3:208
conserving energy, 2004 V1:126–127
conversion factors, 2004 V1:37
diatomaceous earth filters, 2000 V3:134, 139
domestic water supply, 2000 V3:216
emergency showers and eyewashes, 2001 V4:18
Energy Policy Act requirements, 2004 V1:264
faucets, 2001 V4:13
fire-protection demand, 2000 V3:230–232
fixture drains, 2004 V1:3
flash steam, 2000 V3:197
fluctuating flows in horizontal drains, 2005 V2:5
fluid (QFL), 2004 V1:14
fountain systems, 2000 V3:108–110, 112, 115
fuel product dispensers, 2000 V3:164–165
gas boosters, 2005 V2:131, 133
gas flow rates (QGA, QGAS), 2004 V1:14
high-rate dispensers, 2000 V3:169
hydrants, 2000 V3:217
kitchen sinks, 2001 V4:11
lavatories, 2001 V4:10
liquid fuel piping, 2000 V3:169–170
measurements, 2004 V1:33, 2005 V2:175–177
medical air, 2000 V3:74
medical gas, 2000 V3:50–54
medical oxygen, 2000 V3:74
medical vacuum, 2000 V3:74, 79
natural gas systems, 2005 V2:134, 2000 V3:253
nitrogen, 2000 V3:68, 74
nitrous oxide, 2000 V3:74
pump capacity, 2004 V1:6
rate of flow, calculating, 2004 V1:1
reducing for fixtures, 2004 V1:134–135
resin bead regeneration, 2005 V2:217
RPZ discharge, 2005 V2:70
sand filters, 2000 V3:113, 132
showers, 2001 V4:15
special-waste drainage systems, 2005 V2:238
sprinkler hydraulic calculations, 2000 V3:16
steam piping, 2000 V3:182

submersible fuel pumps, 2000 V3:170
swimming pool filtration, 2000 V3:131, 139
urinals, 2001 V4:10
vacuum cleaning systems, 2005 V2:190, 191
vacuum exhauster sizing, 2005 V2:193–194
vacuum systems, 2005 V2:176–178, 184
valves and fittings, 2005 V2:102
water closets, 2001 V4:8
water fountains, 2004 V1:109
water heater types and, 2005 V2:111
weirs and waterfalls, 2000 V3:108, 109
wells, 2005 V2:172
flow restrictors, 2004 V1:126
flow switches (FS), 2004 V1:10, 2000 V3:121
flow tests
equations, 2000 V3:5
fire-protection systems, 2000 V3:3–4
hydrants, 2000 V3:217, 219
medical gas systems, 2000 V3:81
flowing pressure. *See* residual pressure
fluctuating flows in horizontal drains, 2005 V2:5
flue gases, 2005 V2:143
flues, 2004 V1:25
fluid flow rates, 2004 V1:14
Fluid Mechanics with Engineering Applications, 2005 V2:19
fluoride, 2005 V2:168, 200
fluorine, 2005 V2:199
fluoroprotein-mixed chemical concentrates, 2000 V3:21
flush controls
urinals, 2004 V1:116
water closet and toilet accessibility, 2004 V1:114
water closet requirements, 2004 V1:116
flush sprinklers, 2004 V1:29
flush tanks
acoustic design, 2004 V1:195
fixtures units and, 2005 V2:92
flush valves. *See also* flushometer valves
fixture units and, 2005 V2:92
wasted water and, 2004 V1:136
water closet acoustic design, 2004 V1:200
flushing
acoustic ratings of toilets, 2004 V1:194
acoustic ratings of urinals, 2004 V1:194
cold-water systems, 2005 V2:103
Energy Policy Act requirements, 2004 V1:264
gray water use, 2004 V1:267
performance testing, 2001 V4:5–6
resin beds, 2005 V2:218
urinal tests, 2001 V4:9
water closet system types, 2001 V4:6–8
water conservation and toilets, 2001 V4:3
water systems, 2005 V2:172
flushing rim sinks, 2005 V2:94
flushing rims, 2005 V2:15
flushing-type floor drains, 2004 V1:25
flushometer tanks, 2001 V4:3, 8
flushometer valves
defined, 2004 V1:25, 2001 V4:3, 8
sanitation and, 2005 V2:15
urinals, 2001 V4:10
flushometer water closets, 2001 V4:3, 8
flux
in joints, 2004 V1:266
membrane productivity, 2005 V2:231
natural osmosis, 2005 V2:221
standards, 2001 V4:37
FM. *See* Factory Mutual Research Corporation (FM)
FMRC (Factory Mutual). *See* Factory Mutual Research Corporation (FM)
FO (film coefficients), 2004 V1:14
foam extinguishing systems, 2000 V3:21–22, 27
foam-water sprinkler heads, 2000 V3:21
foaming in gray water, 2005 V2:31
fog nozzles, 2005 V2:240
fogging in swimming pools, 2000 V3:129
Follow-up phase in value engineering, 2004 V1:213
Fontana, Mars G., 2004 V1:154
Food and Drug Administration (FDA), 2005 V2:197, 231, 234, 237
food courts, numbers of fixtures for, 2001 V4:19
food dyes in gray water, 2005 V2:35
food-processing areas and kitchens
drains, 2005 V2:15
fixture pipe sizes and demand, 2005 V2:94
gas demands for appliances, 2005 V2:128
gas efficiency, 2005 V2:127
health-care facility fixtures, 2000 V3:36
medical gas piping and, 2000 V3:73
numbers of fixtures for, 2001 V4:19
rates of sewage flows, 2005 V2:159
sanitation, 2005 V2:15
sewage estimates, 2005 V2:159
typical gray-water demand, 2005 V2:29
water fixture-unit values, 2000 V3:217
water temperatures, 2000 V3:45
food-processing plants, 2005 V2:228
food waste grinders
acoustic ratings of, 2004 V1:195
defined, 2004 V1:22
fixture-unit loads, 2005 V2:3
sink outlets and, 2001 V4:11
foot basins, 2005 V2:109
foot controls on faucets, 2000 V3:33
foot or feet. *See* feet
foot pedals for nitrogen systems, 2000 V3:68
foot-pounds (ft-lb, FT LB), 2004 V1:14
foot valves, 2004 V1:25, 2005 V2:100, 2000 V3:119
footing drains (subsoil drains, SSD), 2004 V1:8, 30
footings of buildings
defined, 2004 V1:25
FOR (fuel oil return), 2004 V1:8
force
conversion factors, 2004 V1:35
factors in seismic force calculations, 2004 V1:183
measurements, 2004 V1:33
in seismic design, 2004 V1:188
force mains, 2000 V3:234, 236–240, 241
forced-air vaporizers, 2000 V3:61
forced distortions of piping, 2004 V1:161
forced drainage (corrosion), defined, 2004 V1:153
forcing functions in earthquakes, 2004 V1:160
forcing pipes, 2001 V4:25
formazin turbidity unit, 2005 V2:203–204

forms. *See* checklists and forms
formula rooms, 2000 V3:32
formulas. *See* equations
forward approaches and reaches
  approaches for wheelchairs, 2004 V1:110
  drinking fountains and water coolers, 2004 V1:109
  reach for wheelchairs, 2004 V1:109, 111
FOS (fuel oil supply), 2004 V1:8
fouling of water, 2005 V2:205, 227
Foundation for Cross-Connection Control and Hydraulic Research, 2000 V3:224
foundations of pumps, 2005 V2:166, 169
fountains
  controls, 2000 V3:120–121
  discharge devices, 2000 V3:119–120
  filtration systems, 2000 V3:112–113
  gray water in, 2005 V2:25
  lighting, 2000 V3:121
  makeup-water systems, 2000 V3:124–125
  overflow and drainage, 2000 V3:125
  overview, 2000 V3:107
  piping and valves, 2000 V3:116–119
  pool design, 2000 V3:107–111
  pumps, 2000 V3:113–116
  references, 2000 V3:125–126
  systems and components, 2000 V3:111–112, 114
  valves, 2000 V3:118–119
  water-heating equipment, 2000 V3:121–122
  water-treatment systems, 2000 V3:122–124
FOV (fuel oil vents), 2004 V1:8
fp, FP (freezing points), 2004 V1:14
fpm, FPM (feet per minute), 2004 V1:14, 2000 V3:29
fps, FPS (feet per second), 2004 V1:14
FR (Federal Register), 2000 V3:88
fracture rooms, 2000 V3:32, 36
framing drawings for facilities, 2000 V3:31
Frankel, Michael, 2005 V2:64, 104, 196, 234, 256, 2000 V3:173, 214
Franzini, Joseph B., 2005 V2:19
fraternities and sororities, numbers of fixtures for, 2001 V4:20
Frederick, Ralph H., 2005 V2:64
free air
  defined, 2004 V1:18, 2000 V3:200
  properties, 2000 V3:199
  water vapor in, 2000 V3:200–201
free chlorine, 2000 V3:149
free-floating oils, 2000 V3:93
free oil, 2005 V2:254
free residuals, 2000 V3:146
free vibration, 2004 V1:160
freeboard in ditches, 2000 V3:248
freestanding lights for fountains, 2000 V3:121
freestanding siamese fire-department connections, 2004 V1:12
freestanding sprinkler heads in irrigation, 2000 V3:102
freezing points (fp, FP), 2004 V1:14, 2001 V4:61
"freezing," preventing in cleanouts, 2005 V2:9
freezing temperatures
  dry-pipe sprinkler systems and, 2000 V3:9, 11
  fountains and, 2000 V3:121–122
  frost lines, 2000 V3:226
  ice and oxygen storage, 2000 V3:61
  ice inside water storage tanks, 2005 V2:170
  irrigation system valves and, 2000 V3:103
  swimming pool maintenance and, 2000 V3:131
  testing of cold-water systems, 2005 V2:103
  water meters and, 2005 V2:68
  well heads and, 2005 V2:166–167
Freije, M., 2005 V2:118
french drains, 2004 V1:25
frequencies (Hz, HZ)
  measurements, 2004 V1:33
  symbols for, 2004 V1:15
frequency of ion regeneration cycles, 2005 V2:218–219
fresh-air inlets, 2004 V1:25
friction clamps, 2000 V3:229
friction connectors, 2004 V1:189
friction factors, 2004 V1:14
friction head, calculating, 2004 V1:6
friction losses in flow
  calculating friction head loss, 2004 V1:2
  compressed air, 2000 V3:78, 210, 211
  counterflow piping designs, 2000 V3:178
  examples for pipe sizing, 2005 V2:97–99
  fountain display pumps, 2000 V3:115
  fuel dispensers, 2000 V3:170
  Hazen-Williams formula, 2004 V1:2, 2005 V2:83
  liquid fuel piping, 2000 V3:170
  medical air, 2000 V3:68, 74, 78
  medical gas piping, 2000 V3:73
  medical vacuum systems, 2000 V3:74, 79
  natural gas systems, 2005 V2:134, 2000 V3:253
  nitrogen systems, 2000 V3:74, 77
  nitrous oxide, 2000 V3:74, 76
  oxygen, 2000 V3:74, 76
  pipe pressure and, 2005 V2:86, 92
  pressure and, 2005 V2:98
  reduced pressure zones, 2005 V2:71
  sizing pipes and, 2005 V2:92–96
  standpipe systems, 2000 V3:19
  steam pipes, 2000 V3:187
  submersible fuel pumps, 2000 V3:170
  swimming pool gutters and, 2000 V3:142
  vacuum cleaning systems, 2005 V2:191–193, 194
  vacuum exhauster sizing, 2005 V2:193–194
  valves and threaded fittings, 2005 V2:99–102
  vent systems, 2005 V2:37
  water mains, 2000 V3:8
  well pumps, 2005 V2:170
front-end documents, 2004 V1:63, 65
front-loading skimmers, 2000 V3:110
frost. *See* freezing temperatures
frost lines, 2000 V3:226
frostproof closets, 2004 V1:25
FRP. *See* fiberglass-reinforced plastic
FS (federal specifications), 2004 V1:25, 58
FS (flow switches), 2004 V1:10
ft, FT (feet). *See* feet
ft-lb, FT LB (foot-pounds), 2004 V1:14
ft^2 EDR, 2000 V3:178, 180
ft^3 (cubic feet), 2004 V1:14
FTUs (formazin turbidity units), 2005 V2:203–204
fu values. *See* fixture units and unit values

fuel double containment systems, 2001 V4:58
fuel gas codes, list of agencies, 2004 V1:42
Fuel Gas Piping, 2005 V2:144
fuel-gas piping systems. *See also* diesel-oil systems; gasoline systems
  fuel gas, defined, 2005 V2:143
  glossary, 2005 V2:142–144
  liquefied petroleum gas, 2005 V2:137, 142
  methane, 2004 V1:130
  natural gas systems, 2005 V2:125–137, 2001 V4:35, 36
fuel loads (fire hazards), 2000 V3:2
fuel oil
  copper pipe, 2001 V4:35
  fuel oil return (FOR), 2004 V1:8
  fuel oil supply (FOS), 2004 V1:8
  fuel oil vents (FOV), 2004 V1:8
  pipe bracing, 2004 V1:166, 167
full-flow conditions (FF), 2004 V1:1
full-port ball valves, 2000 V3:72
fully-sprinklered spaces, 2004 V1:12
fume hoods, 2005 V2:250
fumes, hazardous. *See also* gases
  acid-waste drainage systems, 2000 V3:39
  acids, 2005 V2:239, 241
  filter cleaners, 2000 V3:150
  in soil profiles, 2000 V3:162
  vent piping, 2000 V3:42
  VOCs, 2005 V2:201
fuming grade sulfuric acid, 2005 V2:240
Function Analysis phase in value engineering
  defined, 2004 V1:224
  FAST approach, 2004 V1:227–231
  function definitions forms, 2004 V1:225–227, 228
  in process, 2004 V1:213
  rules, 2004 V1:225
Function phase in value engineering, 2004 V1:213
Functional Analysis System Technique (FAST), 2004 V1:227–231
functions
  basic or secondary, 2004 V1:225
  comparing in evaluation phase, 2004 V1:243
  cost-to-function relationship, 2004 V1:225
  defined, 2004 V1:224
  evaluation checklists, 2004 V1:237–241
  in evaluation phase, 2004 V1:235
  in FAST approach, 2004 V1:230
  interrelationships, 2004 V1:227
  levels of importance, 2004 V1:225
  ranking and comparing, 2004 V1:243
  sketches of, 2004 V1:237, 239–240
  specific and dependent, 2004 V1:225
  two-word expressions, 2004 V1:225
fundamental corrosion cells, defined, 2004 V1:139
Fundamentals Handbook, 2000 V3:197
Fundamentals of Underground Corrosion Control, 2004 V1:154
fungi, 2005 V2:199, 205
funnel-type drains, 2005 V2:253, 2000 V3:39
furring-out requirements for roofs, 2005 V2:52
fusible link sprinklers, 2000 V3:9
Fusion-Bonded Epoxy Coating, 2001 V4:32
fusion-joint plastic piping systems, 2000 V3:42
future expansion of compressed air systems, 2000 V3:210
FV (face velocity), 2004 V1:14
fvel, FVEL (face velocity), 2004 V1:14

G

G (giga) prefix, 2004 V1:34
G (low-pressure gas), 2004 V1:8
g, G (gravitational constants), 2004 V1:15
G pipes, 2001 V4:36
ga, GA (gauges). *See* gauges
Gabrielson, M. Alexander, 2000 V3:151
GACs (granulated carbon filters), 2005 V2:228, 231–232. *See also* activated carbon filtration
GAGE (gages). *See* gages
gages (ga, GA, GAGE). *See also* gauges
  cast iron radiators, 2000 V3:180
  defined, 2004 V1:15
  pressure, 2000 V3:200
gal, GAL (gallons). *See* gallons (gal, GAL)
galleries, numbers of fixtures for, 2001 V4:19
gallons (gal, GAL)
  converting to metric units, 2000 V3:29
  converting to SI units, 2004 V1:39
  gallons per day (gpd, GPD), 2004 V1:15
  gallons per hour (gph, GPH), 2004 V1:15, 39, 2005 V2:108–109
  gallons per minute (gpm), 2005 V2:93, 164
    converting to fixture units, 2000 V3:218, 234
    converting to metric units, 2000 V3:29
    estimating demand, 2005 V2:92
    fountains, 2000 V3:115
    pressure and, 2005 V2:83, 84
  grains per gallon (gpg), 2005 V2:201
  standard gallons per hour (std gph, SGPH), 2004 V1:15
  symbols for, 2004 V1:15
galvanic action, 2004 V1:25. *See also* electrolysis
galvanic anodes, 2004 V1:147–150
galvanic cells, defined, 2004 V1:153
galvanic corrosion, 2004 V1:141, 153, 2005 V2:205
galvanic series of metals
  defined, 2004 V1:153
  dielectric insulation and, 2004 V1:146
  listing, 2004 V1:141
galvanized coatings for corrosion prevention, 2004 V1:147
galvanized-iron piping, 2005 V2:13, 86
galvanized pipe fittings, 2001 V4:48
galvanized-steel filters, 2000 V3:131
galvanized-steel piping
  aboveground piping, 2005 V2:13, 50
  fountains and, 2000 V3:116
  fuel product dispensing and, 2000 V3:169
  vacuum systems, 2005 V2:183
galvanizing, defined, 2004 V1:25
galvomag alloy, 2004 V1:144
gamma ray radiation, 2005 V2:246, 247
garbage disposers. *See* food waste grinders
garnet in filters, 2005 V2:211
gas. *See* gases; medical-gas systems; natural gas systems; *specific types of gases*
Gas and Vacuum Systems, 2001 V4:45
gas boosters, 2005 V2:130–134
gas chlorinators

disinfecting swimming pools, 2000 V3:148
iron removal, 2000 V3:147
gas-fired water heaters
conserving energy, 2004 V1:129
defined, 2004 V1:129–130
efficiency, 2005 V2:107
fountains, 2000 V3:121
instantaneous heaters, 2004 V1:265
net efficiency of, 2004 V1:130
swimming pools, 2000 V3:138
gas flow rates, 2004 V1:14
gas laws, 2005 V2:131
gas logs, defined, 2005 V2:143
gas meters, 2005 V2:127
gas piping codes, 2004 V1:42
gas piping systems. *See also* fuel-gas piping systems; gasoline systems; liquefied petroleum gas; natural gas systems
bracing, 2004 V1:167
defined, 2004 V1:191
gas cocks, 2004 V1:9
gas line earthquake-sensitive valves, 2004 V1:162
gas main inspection checklist, 2004 V1:103
gas pressure regulators, 2005 V2:144, 2000 V3:250–252
gas stops (gas cocks), 2004 V1:9
gas trains, 2005 V2:143, 2000 V3:251
gas vents (GV), 2004 V1:8
high-pressure (HG), 2004 V1:8
line filters, 2000 V3:250
low-pressure (G), 2004 V1:8
medium-pressure (MG), 2004 V1:8
plastic pipes, 2001 V4:58
services at laboratory outlets, 2000 V3:37–39
Spitzglass formula, 2004 V1:7, 2005 V2:137
Weymouth formula, 2005 V2:137
gas stations, 2000 V3:166, 2001 V4:20
gas stripping, 2005 V2:204
gas-transfer vacuum pumps, 2005 V2:180
Gas Utilization Equipment for Large Boilers, 2005 V2:127
gaseous chlorine, 2000 V3:123
gaseous fire-suppression systems, 2000 V3:22–25
gases. *See also* fuel-gas piping systems; liquefied petroleum gas; natural gas systems
as fluids, 2000 V3:199
combustion properties, 2005 V2:126
contamination in compressed air, 2000 V3:201
dissolved gases in water, 2005 V2:200
forcing upward through terminal stack, 2005 V2:47
hazardous, 2005 V2:239
nitrous fumes, 2005 V2:242
sulfuric acid, 2005 V2:242
volatile organic compounds, 2005 V2:201
gaskets
fire-protection water supply, 2000 V3:228–229
fuel piping, 2000 V3:169
special-waste systems, 2005 V2:238
gasoline, 2005 V2:12, 2000 V3:154, 168
gasoline blends, 2000 V3:154, 168
gasoline systems
aboveground tank systems, 2000 V3:165–169
connections and access, 2000 V3:166
construction, 2000 V3:165
corrosion protection, 2000 V3:165
filling and spills, 2000 V3:166–167
leak prevention and monitoring, 2000 V3:167–168
materials, 2000 V3:165
overfill prevention, 2000 V3:167
product dispensing systems, 2000 V3:168
tank protection, 2000 V3:169
vapor recovery, 2000 V3:168
venting, 2000 V3:167
codes and standards, 2000 V3:154
components, 2000 V3:155
definitions and classifications, 2000 V3:153–154
designing
installation considerations, 2000 V3:172–173
piping materials, 2000 V3:169
piping sizing, 2000 V3:169–170
submersible pump sizing, 2000 V3:170
testing, 2000 V3:170–172
overview, 2000 V3:153
references, 2000 V3:173
resources, 2000 V3:173
underground tank systems, 2000 V3:155–165
leak detection and system monitoring, 2000 V3:158–163
product dispensing systems, 2000 V3:163–165
storage tanks, 2000 V3:155–158
vapor recovery systems, 2000 V3:163
gate valves (GV), 2004 V1:9, 2005 V2:100, 102, 240
gauge pressure, 2000 V3:200
gauge taps, 2000 V3:115
gauges (ga, GA, GAGE). *See also* gages (ga, GA, GAGE)
fuel product level gauging, 2000 V3:167, 168
gauge pressure, 2005 V2:175
hazardous materials, 2000 V3:90
medical gas systems, 2000 V3:72
symbols for, 2004 V1:15
vacuum systems, 2005 V2:132
gear journals, 2004 V1:196
gear pumps, 2005 V2:170
gearbox silencing enclosures, 2004 V1:197
gears, acoustic problems, 2004 V1:196
Geiger-Mueller counters, 2005 V2:247
gel-coated plastic fixtures, 2001 V4:2
general conditions in contract documents, 2004 V1:62
General Conditions of the Contract for Construction, 2004 V1:62
General Conference of Weights and Measures (CGPM), 2004 V1:32
general corrosion, 2004 V1:153, 2005 V2:205–206
General Electric Company, 2004 V1:211
general laboratory-grade water, 2005 V2:229
General phase in value engineering, 2004 V1:213
General section in specifications, 2004 V1:68
General Services Administration (GSA), 2004 V1:263
General Storage (NFPA 231), 2000 V3:2, 29
generalized total costs, 2004 V1:223
generally-accepted standards, defined, 2004 V1:25
Geogehegan, R.F., 2005 V2:256
geography
cost estimates and, 2004 V1:98
in plumbing cost estimation, 2004 V1:94
geological stability of sites, 2005 V2:29

geothermal energy, 2004 V1:131
Get Your Process Water to Come Clean, 2005 V2:234
GFCI (government furnished, contractor installed), 2004 V1:71
"giga" prefix, 2004 V1:34
glass borosilicate piping, 2005 V2:13, 14, 83
glass-bulb sprinklers, 2000 V3:9
glass-lined pipes, 2000 V3:48
glass piping
  characteristics, 2001 V4:45–48
  expansion, 2001 V4:48
  fittings, 2001 V4:48, 49–50
  roughness, 2005 V2:86
  special wastes, 2005 V2:244, 249
glass washers
  demineralized water, 2000 V3:46
  health-care facilities, 2000 V3:32, 36
  heat recovery systems, 2004 V1:266
  laboratory rooms, 2000 V3:37
  pure water systems for, 2000 V3:46
glazed fixture surfaces, 2001 V4:1
Glidden, R., 2005 V2:196
globe valves (GLV), 2004 V1:9, 2005 V2:100, 102
glossaries
  acoustics in plumbing systems, 2004 V1:206–210
  cold water systems, 2005 V2:67
  conserving energy, 2004 V1:136–137
  corrosion, 2004 V1:151–154
  fuel-gas systems, 2005 V2:142–144
  health-care facilities, 2000 V3:83–86
  industrial wastewater, 2000 V3:88
  measurement units, 2004 V1:32
  plumbing terminology, 2004 V1:17–31
  references for, 2004 V1:40
  seismic protection, 2004 V1:191
  vents and venting, 2005 V2:38–43
glove boxes, 2005 V2:250, 251
GLSP (good large-scale production), 2005 V2:251
glues, 2005 V2:201
GLV (globe valves), 2004 V1:9
gold, 2004 V1:141
Gold-level LEED certification, 2004 V1:263
good engineering practice, 2005 V2:238
good large-scale production (GLSP), 2005 V2:251
"good value," defined, 2004 V1:213
goods, costs of, 2004 V1:222
gooseneck spouts, 2001 V4:14
Gorry, M., 2005 V2:234
governing fixtures, 2005 V2:95–97
government furnished, contractor installed (GFCI), 2004 V1:71
gpd, GPD (gallons per day), 2004 V1:15
gpg (grains per gallon), 2005 V2:201
gph, GPH (gallons per hour), 2004 V1:15
gph, standard (std gph, SGPH), 2004 V1:15
gpm (gallons per minute)
  converting to fixture units, 2005 V2:93, 2000 V3:218, 234
  converting to metric units, 2000 V3:29
  fountains, 2000 V3:115
  orifice size and, 2000 V3:7
  wells, 2005 V2:164
gr, GR (grains). *See* grains
grab bars
  ambulatory accessible toilet compartments, 2004 V1:115
  bathtub accessibility, 2004 V1:117
  clearance, 2004 V1:122
  health care facilities, 2000 V3:34
  shower stalls, 2004 V1:121–122
  standards for, 2004 V1:114–122
  water closet and toilet accessibility, 2004 V1:114
grades
  defined, 2004 V1:25
  maintaining for piping, 2001 V4:25
grain size, 2000 V3:132
grains (gr, GR)
  converting to SI units, 2004 V1:39
  grains per gallon, 2005 V2:201
  symbols for, 2004 V1:15
grandstands, numbers of fixtures for, 2001 V4:19
granular filters
  compared to diatomaceous earth filtration, 2000 V3:135–137
  overview, 2000 V3:132–134
  swimming pool usage, 2000 V3:131–134
  types of, 2000 V3:139
granulated carbon filters, 2005 V2:228, 231–232. *See also* activated carbon filtration
granule tests, 2001 V4:5
graphic annunciators, 2000 V3:24
graphic conventions in plumbing drawings, 2004 V1:108
graphite, 2004 V1:141
graphite anodes, 2004 V1:150
graphitic corrosion, 2004 V1:153
graphitization
  cast iron, 2004 V1:141
  defined, 2004 V1:153
graphs, water supply, 2000 V3:5, 6
grates
  anti-vortex grating, 2000 V3:110
  buffing, 2005 V2:11
  grate open areas for floor drains, 2005 V2:10–11
  materials for, 2005 V2:13
  on swimming pool drains, 2000 V3:143
  sanitary drainage systems, 2005 V2:10–11
gravel filters, 2000 V3:132
gravels, 2005 V2:29
gravimetric measurement of solids, 2005 V2:204
gravitational acceleration units, 2004 V1:1
gravitational constants (*g,* G), 2004 V1:1, 15
gravity
  acceleration of water, 2005 V2:1–2
  forces in earthquakes, 2004 V1:186
  loads, 2004 V1:155
gravity circulation, 2004 V1:5
gravity drainage, 2005 V2:238, 2000 V3:140
gravity drops, 2000 V3:156
gravity-film heat exchangers, 2004 V1:266
gravity-flow systems, 2001 V4:32, 49
gravity flushes, 2004 V1:195, 2001 V4:6–8
gravity returns, 2000 V3:186–187, 188
gravity sand filtration, 2000 V3:132, 134
gravity separators in oil spills, 2005 V2:256

Gravity Sewer Pipe, 2001 V4:32
gravity sewers, 2005 V2:152
gravity tank systems
  fire-protection connections, 2000 V3:225, 227
  fire-protection water supply, 2000 V3:232
  operation of, 2005 V2:74–76
  suction piping and, 2005 V2:171
gravity valves, 2000 V3:118
gravity water filters, 2005 V2:167–168
gray cast-iron pressure pipe, 2001 V4:32
Gray, G.D., 2005 V2:35
gray-water systems
  amount of generated gray water, 2005 V2:25
  benefits of water reuse, 2004 V1:135
  codes and standards, 2005 V2:25–26
  designing for supply and consumption, 2005 V2:28–30
  economic analysis of, 32–34
  green uses of gray water, 2004 V1:264
  health-care facilities, 2000 V3:43, 45
  introduction, 2005 V2:25
  overview, 2004 V1:267
  precautions, 2005 V2:35
  public concerns and acceptance, 2005 V2:35
  reasons for using, 2005 V2:25
  reclaimed water, 2004 V1:135
  references, 2005 V2:35–36
  system description and components, 2005 V2:26
  treatment systems, 2005 V2:30–32
Gray-water Systems, 2005 V2:35
grease
  exclusion from gray-water systems, 2005 V2:25
  fats in kitchens, 2000 V3:36
  grease traps, defined, 2004 V1:25
  interceptors. *See* grease interceptors
grease interceptors
  codes, 2004 V1:43
  commercial kitchen sinks and, 2001 V4:12
  defined, 2004 V1:25
grease traps
  codes, 2004 V1:43
  commercial kitchen sinks and, 2001 V4:12
greatest temperature difference (GTD), 2004 V1:15
Green Building Council, 2004 V1:263
Green Building Rating System (LEED), 2004 V1:263–265
green design, 2004 V1:263–267
green roof designs, 2004 V1:266–267
green sands, 2005 V2:215
green water in pools, 2000 V3:148
Greene, Norbert D., 2004 V1:154
Greening Federal Facilities, 2004 V1:134, 137
gridded systems, 2000 V3:8
grinder pumps
  defined, 2004 V1:25
  in sewage tanks, 2005 V2:152
Grossel, S.F., 2005 V2:256
ground failure, 2004 V1:158
ground floor space. *See* clear floor space
ground-motion time history, 2004 V1:160
ground-mounted water storage tanks, 2005 V2:170
ground ruptures, 2004 V1:158
ground shaking, 2004 V1:158–159, 161
ground water
  defined, 2005 V2:198
  feed water for pure water systems, 2005 V2:230
  gray-water irrigation systems and, 2005 V2:25
  monitoring, 2000 V3:162
  private water systems, 2005 V2:163
  storage tanks and, 2000 V3:172
  swimming pool locations and, 2000 V3:128
  underground tanks and, 2000 V3:155
groundspace for wheelchairs. *See* clear floor space
group washups, 2001 V4:11
grouts in wells, 2005 V2:166
growth rate of fires, 2000 V3:2
GSA (General Services Administration), 2004 V1:263
GSA Guide Specification Number 3-1515-71 (Public Building Service), 2004 V1:199
GTD (greatest temperature difference), 2004 V1:15
guaranty bonds, 2004 V1:62
guard posts for hydrants, 2000 V3:228, 229
A Guide to Airborne, Impact and Structure-Borne Noise Control in Multifamily Dwellings, 2004 V1:199
guide-vane tips, acoustic modifications, 2004 V1:197
Guidelines for Seismic Restraints of Mechanical Systems, 2004 V1:191
Gut Feel Index, 2004 V1:254
gutters (pools)
  drains, 2000 V3:142
  filtration and, 2000 V3:137
  skimmers and, 2000 V3:137
  surge tanks and, 2000 V3:137
gutters (roofs), 2005 V2:63
GV (gas vents), 2004 V1:8
GV (gate valves), 2004 V1:9, 2005 V2:240
gymnasiums, 2005 V2:109, 2001 V4:19
gypsum board, lining with lead, 2005 V2:248

H

H (enthalpy), 2004 V1:14
h (hecto) prefix, 2004 V1:34
H (henrys), 2004 V1:33
h (hours), 2004 V1:15, 34
h (velocity head), 2004 V1:5
H-I alloy, 2004 V1:144
H/m (henrys per meter), 2004 V1:33
ha (hectares), 2004 V1:34
hair strainers, 2000 V3:150
HALAR piping, 2000 V3:48
half-circle rotary sprinkler heads, 2000 V3:102
half-dome ends on tanks, 2000 V3:156
half-full conditions (HF), 2004 V1:1
half lives, defined, 2005 V2:248
halogenated agents, 2000 V3:22, 27, 70, 83
halogens, 2005 V2:120
halon 1211, 2000 V3:22
halon 1301, 2004 V1:25, 2000 V3:22
Halon 1301 Fire Extinguishing Systems (NFPA 12A), 2000 V3:23, 29
halon system types, 2004 V1:25–26
halothane, 2000 V3:70
hammer. *See* water hammer
hand-held extinguishers, 2000 V3:19, 20
hand-held shower heads, 2004 V1:120
hand tools for vacuum cleaning systems, 2005 V2:190

hand trenching, labor productivity rates, 2004 V1:95–97
Handbook for Mechanical Engineers, 2004 V1:2, 3, 5, 40
Handbook of Chlorination, 2005 V2:104
Handbook of Corrosion Resistant Pipeline, 2000 V3:97
Handbook of Fundamentals, 2004 V1:2, 5, 6, 40
Handbooks (ASHRAE), 2005 V2:144
handicapped individuals. *See* people with disabilities
handling section in specifications, 2004 V1:70, 89–90
hands-free controls on sinks, 2000 V3:33, 34
handwashing lavatories, 2000 V3:32, 36, 45
hangers. *See* supports and hangers
hard conversions, 2004 V1:32
hard-temper tubing, 2005 V2:13, 50, 2000 V3:73
hardness of water
  boiler feed water, 2005 V2:226
  degrees of hardness, 2005 V2:199–200
  ion exchange treatment, 2005 V2:215
  pH and alkalinity, 2005 V2:207
  private water systems, 2005 V2:168
  swimming pools and, 2000 V3:147
  water softener treatments, 2005 V2:220
Harris, Nigel, 2005 V2:196
Hastelloy B, 2005 V2:242
Hastelloy C, 2004 V1:141, 144
hazardous materials, emergency fixtures and, 2001 V4:17
hazardous wastes
  defined, 2000 V3:88
  permits, 2000 V3:89
hazards
  accidental acid spills, 2005 V2:239–240
  asbestos, 2001 V4:26
  chemical material safety data sheets, 2000 V3:90
  classes of hazard occupancies, 2004 V1:29, 2000 V3:17
  cold-water systems, 2005 V2:68
  controlled substance spills, 2005 V2:195–196
  diatomaceous earth filters, 2000 V3:134
  exposed piping and accessibility, 2004 V1:117
  fire hazards, 2004 V1:24, 2000 V3:2–3
  flammable and volatile liquids, 2005 V2:254–256
  gas boosters, 2005 V2:131
  gases in septic tanks, 2005 V2:155
  gray-water systems, 2005 V2:35
  hazardous gases, 2005 V2:239
  hazardous materials, defined, 2000 V3:88
  hazardous substances, defined, 2000 V3:88
  hazardous wastes, defined, 2000 V3:88
  hot-water systems, 2005 V2:107, 117–124
  plumbing systems and, 2004 V1:266
  radiation, 2005 V2:246–247
  radioactive waste-drainage systems, 2005 V2:248–249
  sanitary precautions for wells, 2005 V2:166–167
  types of acids, 2005 V2:240–242
  vacuum cleaning system issues, 2005 V2:195
Hazen-Williams formula
  defined, 2004 V1:2, 2005 V2:6
  friction losses, 2000 V3:118
  pipe sizing and, 2005 V2:83
HB (hose bibbs), 2004 V1:10
HCFCs (hydrochlorofluorocarbons), 2000 V3:22
hd, HD (head). *See* pressure (PRESS, PRES, P)
HDPE (high density polyethylene), 2000 V3:252, 254, 2001 V4:58, 61
head (hd, HD). *See* pressure (PRESS, PRES, P)
head loss. *See* pressure drops or differences (PD, DELTP)
headroom around pipes, 2001 V4:25
headwall gas systems, 2000 V3:56–57
health-care facilities
  defined, 2000 V3:84
  drainage systems, 2000 V3:39–42
  fixtures and equipment, 2000 V3:31–39
  glossary, 2000 V3:83–86
  Legionella control in, 2005 V2:117–122
  medical gas and vacuum systems, 2000 V3:49–83
  plumbing overview, 2000 V3:32
  references, 2000 V3:86
  resources, 2000 V3:86
  water-supply systems, 2000 V3:43–48
Health-Care Facilities (NFPA 99), 2000 V3:50, 56, 66–67, 68, 77
health hazards. *See* hazards
hearing disabilities, 2004 V1:107
heart-and-lung machines, 2000 V3:39
heat (HT)
  compression, 2000 V3:204
  conversion factors, 2004 V1:36
  heat detectors, 2000 V3:25
  latent, 2004 V1:15, 137
  measurements, 2004 V1:33
  protecting against, 2005 V2:16
  sensible, 2004 V1:16, 137
  symbols for, 2004 V1:15
  water-heater heat recovery, 2005 V2:110
heat-activated air dryers, 2000 V3:204
heat-actuated devices (H.A.D), 2000 V3:13
heat and flush method, 2005 V2:120
heat distortion of plastic pipe, 2001 V4:60
Heat Exchange Institute, 2005 V2:186
heat exchangers and exchange systems
  air dryers, 2000 V3:204
  corrosion inhibitors, 2004 V1:151
  geothermal energy, 2004 V1:131
  in green building, 2004 V1:266
  heat exchanger loop gas booster systems, 2005 V2:132, 133
  mineral deposits and, 2000 V3:147
  swimming pools, 2000 V3:138
  for vacuum pumps, 2005 V2:181
  vibration isolation, 2004 V1:205
  waste heat usage, 2004 V1:131–134
heat fusion joints
  heat-fused socket joints, 2005 V2:242
  PEX piping, 2001 V4:61
  special wastes and, 2000 V3:40
heat gain (HG, HEATG)
  latent (LHG, HGL), 2004 V1:15
  sensible (SHG, HGS), 2004 V1:15, 16
  symbols for, 2004 V1:15
heat loss (HL, HEATL)
  defined, 2004 V1:15
  heat loss retardants, 2000 V3:150
  swimming pools, 2000 V3:144
  water heater energy savings and, 2004 V1:265
  water heater location and, 2004 V1:129
heat pumps, waste heat usage, 2004 V1:134

heat recovery systems, 2004 V1:134, 266
heat-trace systems, 2005 V2:115
heat transfer (Q)
  condensate drainage and, 2000 V3:189
  heat transfer coefficients (*U,* U), 2004 V1:15
  symbols for, 2004 V1:15
heat-up method of condensate drainage, 2000 V3:191
heated water. *See* hot-water systems
heaters (HTR), 2004 V1:15. *See also* water heaters
HEATG (heat gain). *See* heat gain
heating engineers, 2000 V3:27–28
heating feed water
  for microbial control, 2005 V2:224
  for pure water systems, 2005 V2:231
heating hot water return (HHWR), 2004 V1:9
heating hot water supply (HHWS), 2004 V1:9
heating systems. *See* HVAC systems
heating, ventilation, and air-conditioning systems. *See* HVAC systems
heating water. *See* water heaters
HEATL (heat loss), 2004 V1:15
heavy clay loams, 2000 V3:100
heavy equipment earthquake recommendations, 2004 V1:163
heavy metals, 2000 V3:95
heavy process gas service, 2000 V3:249
heavy process service gas, 2005 V2:126
hectares, 2004 V1:34
"hecto" prefix, 2004 V1:34
heel inlets on traps, 2005 V2:15
heel-proof grates, 2005 V2:10
heel-proof strainers, 2005 V2:54
height (hgt, HGT, HT)
  of fountains, 2000 V3:120
  grab bars for accessibility, 2004 V1:114
  laundry equipment, 2004 V1:123
  sinks, 2004 V1:117
  symbols for, 2004 V1:15
  toilet seats, 2004 V1:114
helium, 2000 V3:56
Henriques, F.C., Jr., 2005 V2:122, 124
henrys, 2004 V1:33
Henry's law, 2005 V2:81
henrys per meter, 2004 V1:33
HEPA filters, 2005 V2:188–189, 252
heptafluorocarbons (HFCs), 2000 V3:22
heptafluoropropane, 2000 V3:22
herbicides, 2005 V2:156
Hershey Meters Co., 2005 V2:104
hertz, 2004 V1:33, 206
Hesser, Henry H., 2005 V2:196
hexametaphosphate, 2005 V2:168
HF (half-full conditions), 2004 V1:1
HFCs (heptafluorocarbons), 2000 V3:22
HG (heat gain). *See* heat gain
Hg, HG (mercury), 2004 V1:15
HG (high-pressure gas), 2004 V1:8
HGL (latent heat gain), 2004 V1:15
HGS (sensible heat gain), 2004 V1:15, 16
hgt, HGT (height). *See* height
HHWR (heating hot water return), 2004 V1:9
HHWS (heating hot water supply), 2004 V1:9
HI (film coefficients), 2004 V1:14
Hicks, Tyler G., 2005 V2:64
high-backflow hazard, 2000 V3:222
high-capacity wells, 2005 V2:164
high-demand classifications, 2005 V2:109, 110
high-density polyethylene (HDPE), 2000 V3:252, 254
high-efficiency water heaters, 2004 V1:265, 267
high-energy beta radiation, 2005 V2:246
high-expansion foam extinguishers, 2000 V3:21
high-hazard fires, 2000 V3:16
high-hose retrievers, 2000 V3:165
high-level water tank alarms, 2000 V3:90
high-piled storage, 2000 V3:230
high-pressure carbon dioxide systems, 2000 V3:20–21
high-pressure condensate (HPC), 2004 V1:9
high-pressure cylinders, 2000 V3:49
high-pressure gas (HG), 2004 V1:8
high-pressure nitrogen systems, 2000 V3:68
high-pressure piping, 2000 V3:196–197
high-pressure steam (hps, HPS), 2004 V1:9, 15, 2000 V3:175, 182
high-pressurization air drying, 2000 V3:203–204
high-purity water. *See* water purification
high-radiation areas, 2005 V2:247, 249
high-rate dispensers, 2000 V3:169
high-rate filters, 2000 V3:113, 132
high-rise buildings, 2005 V2:133
High-rise Plumbing, 2005 V2:64
high-silicas cast iron piping, 2000 V3:40, 42
high-silicon cast iron piping, 2005 V2:13, 14
high-silicon iron anodes, 2004 V1:150
high-suds detergents, 2005 V2:45–46
High Temperature Condensate Return (TES 582), 2000 V3:197
high-temperature hot water (hthw, HTHW), 2004 V1:15
high-to-low pressure loss in vacuum systems, 2005 V2:184–185
high vacuum, 2005 V2:182, 186
high-velocity filters, 2000 V3:139
high-velocity fixtures, acoustic design and, 2004 V1:195
high-velocity jetted well digging, 2005 V2:165
high-volume sprinklers in irrigation, 2000 V3:100
highest order functions, 2004 V1:227
Hillman, 2004 V1:191
hip baths, 2000 V3:35
history
  of earthquake damage, 2004 V1:161–163
  of fire-protection systems, 2000 V3:1–2
HL (heat loss), 2004 V1:15
HO (film coefficients), 2004 V1:14
Hodnott, Robert M., 2004 V1:191
Hoffman Industries, 2005 V2:196
Hoffman Steam Heating Systems Design Manual and Engineering Data (TES 181), 2000 V3:197
hoists for immersion baths, 2000 V3:35
hold-down straps on storage tanks, 2000 V3:172
holding rooms, 2000 V3:58
holes
  in coatings, 2004 V1:147
  for perc tests, 2005 V2:149
holidays
  in coatings, 2004 V1:147, 2000 V3:172

in labor costs, 2004 V1:94
hollow-fiber modules
in cross-flow filtration, 2005 V2:223
in reverse osmosis, 2005 V2:205, 221, 222
homogeneity in rate of corrosion, 2004 V1:145
horizontal drains
cross-sections of, 2005 V2:2
fixture loads, 2005 V2:6, 8–9
flow in, 2005 V2:2
hydraulic jumps in, 2005 V2:6
minimum slope of piping, 2005 V2:6–7
sloping drains in sanitary drainage systems, 2005 V2:5–8
steady flow in, 2005 V2:6
horizontal filters, 2000 V3:131
horizontal loads of piping, 2004 V1:184, 185–186
horizontal pressure-media filters, 2005 V2:211
horizontal pumps
centrifugal, 2000 V3:140
defined, 2004 V1:24
split-case pumps, 2004 V1:24, 2000 V3:25, 115, 142
horizontal turbine meters, 2005 V2:95, 96
horsepower (hp, HP)
air horsepower (ahp, AHP), 2004 V1:14
brake horsepower (bhp, BHP), 2004 V1:6, 14
converting to SI units, 2004 V1:39
indicated horsepower (ihp, IHP), 2004 V1:15
shaft horsepower (sft hp, SFT HP, SHP), 2004 V1:16
symbols for, 2004 V1:15
hose bibbs (HB), 2004 V1:10, 2000 V3:36, 2001 V4:25
hose demand, 2000 V3:17
hose outlets, 2004 V1:12
hose stations, dry, 2004 V1:13, 2000 V3:27
hose streams in firefighting, 2000 V3:230
hose thread outlets, 2001 V4:14
hose valves, 2000 V3:18
hoses
bed pans, 2000 V3:38
compressed air pipe sizing, 2000 V3:210
fuel dispensers, 2000 V3:165
medical gas tubing, 2000 V3:77
retrievers, 2000 V3:165
vacuum cleaning hose capacity, 2005 V2:190
vacuum cleaning hose materials, 2000 V3:146
vacuum cleaning systems. *See* tubing
hosing out cartridge filters, 2000 V3:113
hospitals, 2005 V2:15, 109, 118, 2001 V4:20, 21. *See also* health-care facilities
hot fluids, glass piping and, 2001 V4:47
hot-vapor atmospheric vents, 2004 V1:9
hot-water heat exchangers, 2000 V3:121
hot water recirculating (HWR), 2004 V1:8, 265
hot-water returns, 2004 V1:8
hot-water supply (HW)
heating hot water supply, 2004 V1:8
potable water, 2000 V3:45
symbols for, 2004 V1:8
hot-water systems
avoiding standby losses, 2004 V1:127
circulation systems, 2005 V2:115
codes and standards, 2005 V2:124
conserving energy, 2004 V1:124–125, 127, 128
corrosion rates, 2004 V1:145
earthquake damage, 2004 V1:162
equations, 2005 V2:109–110
exposed piping and accessibility, 2004 V1:117
heat exchangers, 2000 V3:121
hot-water properties, 2005 V2:117
hot-water temperatures, 2004 V1:120, 2005 V2:111, 112–114, 2000 V3:36, 45, 139
introduction, 2005 V2:107
Legionella pneumophila, 2005 V2:117–122
maintaining temperatures, 2005 V2:115
mixed-water temperatures, 2005 V2:111
pipe codes, 2004 V1:45
pipe vibration isolation, 2004 V1:205
relief valves, 2005 V2:115–116
safety and health concerns, 2005 V2:117–124
scalding water, 2005 V2:122–124
sizing water heaters, 2005 V2:108–109
thermal efficiency, 2005 V2:116–117
thermal expansion, 2005 V2:116
types of domestic systems, 2004 V1:129–134
waste heat usage, 2004 V1:131–134
water heater heat recovery, 2005 V2:110
water heaters, 2005 V2:111–114
hot-water temperatures
accessible shower compartments, 2004 V1:120
charts, 2005 V2:112–114
health-care facilities, 2000 V3:36, 45
high-temperature hot water, 2004 V1:15
maintaining temperatures, 2005 V2:115
mixed-water temperatures, 2005 V2:111
scalding water, 2005 V2:122–124
swimming pools, 2000 V3:139
hotels
acoustic plumbing design for, 2004 V1:196
hot water demand, 2005 V2:109
numbers of fixtures for, 2001 V4:20
septic tank/soil-absorption systems for, 2005 V2:156–157
vacuum calculations for, 2005 V2:190
hourly data in sizing water heaters, 2005 V2:108–109
hours (h, HR), 2004 V1:15, 34
house drains. *See* building drains
house pumps, 2005 V2:74, 76
house tanks, 2005 V2:74–76
house traps. *See* building traps
housed-spring mountings, 2004 V1:204
houses. *See* buildings
housing project sewers, 2005 V2:156–157
housings for gas boosters, 2005 V2:130
housings for gas filters, 2000 V3:250
HOW logic path, 2004 V1:230, 231
How to Design Spencer Central Vacuum Cleaners, 2005 V2:196
hp, HP (horsepower). *See* horsepower
HPC (high-pressure condensate), 2004 V1:9
hps, HPS (high-pressure steam), 2004 V1:9, 15
HR (hours), 2004 V1:15, 34
HT (heat). *See* heat
HT (height). *See* height
hthw, HTHW (high-temperature hot water), 2004 V1:15. *See also* hot-water temperatures

HTR (heaters), 2004 V1:15. *See also* water heaters
hub-and-spigot piping and joints. *See also* bell-and-spigot joints and piping
  acid wastes and, 2000 V3:42
  cast-iron soil pipe, 2001 V4:27, 29–31
  defined, 2004 V1:26
  sanitary piping, 2005 V2:13
Hubbard baths, 2005 V2:109
hubless piping
  bracing cast-iron pipe, 2004 V1:177
  cast-iron soil pipe, 2001 V4:27, 28, 31
  hubless, defined, 2004 V1:26
  riser bracing for hubless pipes, 2004 V1:178
  sanitary piping, 2005 V2:13
HUD (Housing and Urban Development), 2004 V1:105, 106
humidity
  humidity ratios (*W,* W), 2004 V1:15
  relative (rh, RH), 2004 V1:15
Hunter, Roy B., 2005 V2:3, 4, 48, 104
Hunter's Curve, 2005 V2:92
Hurricane filters, 2005 V2:211
hutene, 2005 V2:126
HVAC engineers, 2000 V3:27–28, 213
HVAC systems
  copper pipes, 2001 V4:35, 36
  exhaust ducts, 2005 V2:193
  glass pipes, 2001 V4:47
  heating systems, 2000 V3:178
  steel pipe, 2001 V4:48
HW (hot water supply), 2004 V1:8
HWR (hot water recirculating), 2004 V1:8, 265
hybrid vaporizers, 2000 V3:61
hydrant wrenches, 2000 V3:4
hydrants
  butt caps, 2000 V3:4, 219
  coefficients of discharge, 2000 V3:4, 5
  fire-protection water supply, 2000 V3:226–228
  fire pumps for, 2000 V3:25
  flow tests, 2000 V3:4, 5, 217, 219
  guards, 2000 V3:228, 229
  hydrant butts, 2000 V3:7, 8
  outlets, 2000 V3:5
  public hydrants, 2004 V1:12
  valves, 2004 V1:24
  wall hydrants, 2004 V1:10, 12
hydraulic balancing in fountains, 2000 V3:117–118
hydraulic calculations
  fountain displays, 2000 V3:121
  sprinkler systems, 2000 V3:15, 16–17
hydraulic design
  sprinkler systems, 2000 V3:15–18
  swimming pool filters, 2000 V3:140
Hydraulic Institute, 2005 V2:104
hydraulic irrigation valves, 2000 V3:103
hydraulic jumps in flow, 2005 V2:2, 6, 47
hydraulic mean depth of flow, 2004 V1:1
hydraulic radii (R), 2004 V1:1
hydraulic shock. *See* water hammer
hydraulic shock, calculating, 2004 V1:6
hydraulics of wells, 2005 V2:165–166
hydrazine, 2005 V2:226
Hydro 35 (National Weather Service), 2000 V3:242
hydrobromic acid, 2005 V2:242
hydrocarbons
  classifications, 2000 V3:153–154
  contamination in compressed air, 2000 V3:201
  medical gas system tests, 2000 V3:83
hydrochloric acid
  in laboratory wastes, 2005 V2:242
  in pools, 2000 V3:146, 148
  in regeneration, 2005 V2:210, 217
  in water chemistry, 2005 V2:199
hydrochlorofluorocarbons (HCFCs), 2000 V3:22
hydrodynamic noise generation, 2004 V1:197
hydrogen, 2005 V2:126, 199, 215, 239, 2000 V3:91
hydrogen embrittlement, 2004 V1:153
hydrogen film buildup, 2004 V1:139
hydrogen fluoride, 2000 V3:22
hydrogen overvoltage, 2004 V1:153
hydrogen peroxide, 2005 V2:223, 2000 V3:48
hydrogen sulfide, 2005 V2:200, 208, 209
Hydronics Institute, 2000 V3:178, 197
hydrophilic well piping, 2000 V3:109
hydropneumatic-tank systems, 2005 V2:72, 73–74, 170
hydroquinone, 2005 V2:226
hydrostatic monitoring systems, 2000 V3:160, 161
hydrostatic pressure, 2005 V2:4, 2000 V3:191
hydrostatic relief valves, 2000 V3:144
hydrostatic tests, 2000 V3:171
hydrotherapeutic showers, 2005 V2:109
hydrotherapy immersion baths, 2000 V3:35
hydroxides, 2005 V2:199, 2000 V3:91
hydroxyl, 2005 V2:215, 225, 239
hyperbaric, 2000 V3:84, 85
hyperchlorination, 2005 V2:122, 2000 V3:123
hypobaric, 2000 V3:84
hypochlorinators, 2000 V3:148, 149, 150–151
hypochlorous acid, 2000 V3:146, 148
Hz (hertz), 2004 V1:33, 206
Hz, HZ (frequencies), 2004 V1:15, 33

I

IAPMO (International Association of Plumbing and Mechanical Officials), 2004 V1:54, 58, 2005 V2:36, 2001 V4:18
ICBO (International Conference of Building Officials), 2004 V1:191
ICC (International Code Council), 2004 V1:55, 59, 60
ice. *See* freezing temperatures
ice makers, 2000 V3:32
icfm (inlet cubic feet per minute)
  dynamic air compressors, 2000 V3:66
  medical air compressors, 2000 V3:65
  vacuum piping systems, 2005 V2:177
ID (inside diameters), 2004 V1:14
idea evaluation checklists, 2004 V1:237–241
idea generators, 2004 V1:232
ideal gas law, 2005 V2:73
identifying parts of gray-water systems, 2005 V2:26–28, 35
ignition (torch) testing, 2001 V4:2
ihp, IHP (indicated horsepower), 2004 V1:15
illegal connections to water meters, 2005 V2:68
Illinois Plumbing Code, 2005 V2:118

illuminance
conversion factors, 2004 V1:36
measurements, 2004 V1:33
Illustrated National Plumbing Code Design Manual, 2005 V2:64
imaginary costs, 2004 V1:223
imaging-science facilities, 2005 V2:248
immediate strip concrete methods, 2001 V4:32
immersion baths, 2000 V3:32, 35, 38
immersion-type vacuum separators, 2005 V2:188
immiscible liquids, 2005 V2:198
impact heads in sprinkler systems, 2000 V3:102–103
impaired individuals. *See* people with disabilities
impellers
acoustic modifications for blades, 2004 V1:197
pump impeller diameters, 2004 V1:6
sources of noise in pumps, 2004 V1:197
imperviousness factor, 2000 V3:242–243
impingement attack corrosion, 2004 V1:141, 153
Implementation Follow-up phase in value engineering, 2004 V1:213
Implementation Presentation phase in value engineering, 2004 V1:213
importance
assigning in function analysis, 2004 V1:225
of equipment or systems in seismic force calculations, 2004 V1:183
impoundment basins, 2000 V3:167
impressed current systems, 2004 V1:147, 150
impulse traps, 2000 V3:182
impurities in water, 2005 V2:198–201
in-ground vapor monitoring, 2000 V3:162
in. Hg (inches of mercury), 2005 V2:175, 178
in-line filters, 2000 V3:66
in-line pumps, 2004 V1:24
in-line shut-off valves, 2000 V3:71
in-wall piping, acoustic design and, 2004 V1:195
in^3 (cubic inches), 2004 V1:14
inch-pound units (IP)
converting, 2005 V2:176, 2000 V3:29
flow rates and pressure measurements, 2000 V3:200
use of, 2005 V2:175
inches
converting to metric units, 2000 V3:29
converting to SI units, 2004 V1:39
of mercury (in. Hg), 2004 V1:39, 2005 V2:175, 178
per hour (in./h), 2000 V3:99
incident angles (INANG), 2004 V1:15
incineration systems, 2004 V1:130–131
incinerator toilets, 2004 V1:265
income, in hot water demand classifications, 2005 V2:109
inconel, 2004 V1:141, 144
independent functions in FAST approach, 2004 V1:230
indicated horsepower (ihp, IHP), 2004 V1:15
indirect discharges, 2000 V3:89
indirect drains (D), 2004 V1:8
indirect-fired gas water heaters, 2000 V3:138, 146
indirect waste pipes, 2004 V1:26, 2001 V4:12
indirect waste receptors, 2005 V2:15, 2001 V4:17. *See also* floor sinks
individual aerobic waste treatment plants, 2005 V2:157–158
Individual Home Wastewater Characterization and Treatment, 2005 V2:161
individual vents, 2004 V1:26. *See also* revent pipes
air admittance valves, 2005 V2:46
defined, 2005 V2:40
indoor gas boosters, 2005 V2:133
indoor swimming pools. *See also* swimming pools
components for, 2000 V3:139
considerations, 2000 V3:129
induced siphonage, 2004 V1:26
industrial acid-waste drainage systems
acid-waste treatment, 2005 V2:244–245
continuous acid-waste treatment systems, 2005 V2:246
defined, 2005 V2:239
health and safety concerns, 2005 V2:239–240
large facilities, 2005 V2:244, 245
types of acids, 2005 V2:240–242
industrial chemical-waste systems, 2005 V2:253
industrial facilities
asbestos concrete piping, 2001 V4:26
firefighting demand flow rates, 2000 V3:232
firefighting water drainage, 2005 V2:253–254
hot water demand, 2005 V2:109
industrial steam systems, 2000 V3:175
numbers of fixtures for, 2001 V4:19, 21
radiation in, 2005 V2:248
water content in wastes, 2000 V3:99
Industrial Risk Insurers, 2005 V2:127
Industrial Risk Insurers (IRI), 2000 V3:16
industrial service gas, 2005 V2:126
industrial waste, defined, 2004 V1:26
industrial wastewater treatment
codes and standards, 2000 V3:95
definitions, 2000 V3:88
designing systems, 2000 V3:90–91
government publications, 2000 V3:96
industry and technical handbooks, 2000 V3:97
overview, 2000 V3:87
permits, 2000 V3:87
references, 2000 V3:95–97
regulatory framework, 2000 V3:87–90
resources, 2000 V3:97
system elements, 2000 V3:91–95
inert gases, 2000 V3:22
Inert Gases: Argon, Nitrogen and Helium (CGA P-9), 2000 V3:81, 82, 86
inert materials, 2000 V3:47
inertia
conversion factors, 2004 V1:36
measurements, 2004 V1:33
inerting atmospheres, 2000 V3:20
infant bathtubs, 2000 V3:32, 34
infectious and biological waste systems. *See also* disinfecting; microorganisms
biosafety levels, 2005 V2:251
codes and standards, 2005 V2:251
components, 2005 V2:252
introduction, 2005 V2:250–251
liquid-waste decontamination systems, 2005 V2:252
infectious disease rooms, 2000 V3:45
inflexibility, creativity and, 2004 V1:231

Information phase in value engineering, 2004 V1:213, 214–222
information sources in value engineering, 2004 V1:214, 221
infrared controls on faucets and fixtures, 2004 V1:135, 264
Ingersoll-Rand Company, 2005 V2:144, 2000 V3:214
inhibitors (corrosion), 2004 V1:151, 153
initial vacuum pressure, 2005 V2:193
ink tests, 2001 V4:5, 9
inlet cubic feet per minute (icfm), 2005 V2:177, 2000 V3:65, 66
inlets. *See also* outlets; stations
  gas or vacuum. *See* stations
  inlet filters in pools, 2000 V3:203, 211
  inlet filters on vacuum systems, 2005 V2:181
  inlet inverts on septic tanks, 2005 V2:154
  inlet pressure in cold-water systems, 2005 V2:78
  inlet pressure in gas boosters, 2005 V2:134
  inlet times, 2000 V3:244, 245
  louver velocity, 2000 V3:212
  number of in vacuum systems, 2005 V2:184
  for reflecting pools and fountains, 2000 V3:110–111
  for storage tanks, 2005 V2:171
  for swimming pools, 2000 V3:137, 143, 145
  for vacuum cleaning systems, 2005 V2:189, 190, 191, 193
  in vacuum sizing calculations, 2005 V2:184, 186
Innovation & Design Process (LEED), 2004 V1:263
innovation in green building, 2004 V1:266
Innovative Wastewater Technologies, 2004 V1:264
input motion of earthquakes, 2004 V1:160
insanitary, defined, 2004 V1:26
inside-caulk drains, 2005 V2:13
inside-caulk outlets, 2005 V2:13
inside diameters (ID), 2004 V1:14, 2000 V3:156
inside film coefficients, 2004 V1:14
inspecting. *See also* cleanouts
  checklists, 2004 V1:102–103
  hazardous waste systems, 2000 V3:90
  sewage-disposal systems, 2005 V2:160–161
installation
  anchor bolts, seismic problems, 2004 V1:190
  condensate traps, 2000 V3:195
  estimating productivity rates, 2004 V1:97
  grab bars, 2004 V1:121–122
  installation costs, 2004 V1:223
  lavatories, 2001 V4:11
  liquid fuel storage systems, 2000 V3:172–173
  medical gas piping, 2000 V3:73
  pressure-regulated valves, 2005 V2:78–79
  section in specifications, 2004 V1:91
  showers, 2001 V4:16
  steam traps, 2000 V3:195
  storage tank checklist, 2000 V3:173
  urinals, 2001 V4:9–10
  water closets, 2001 V4:6–7
Installation, 2001 V4:32
Installation of Centrifugal Fire Pumps (NFPA 20), 2000 V3:25, 29
Installation of Closed-head Foam-water Sprinkler Systems (NFPA 16A), 2000 V3:21, 29
Installation of Private Fire Mains (FM 3-10), 2000 V3:225
Installation of Private Fire Service Mains and Their Appurtenances (NFPA 24), 2000 V3:29, 225
Installation of Sprinkler Systems (NFPA 13), 2000 V3:2, 12, 15, 16, 21, 29, 232
Installation of Standpipe and Hose Systems (NFPA 14), 2000 V3:2, 18, 29
Installation of Underground Gasoline Tanks and Piping at Service Stations (API 1615), 2000 V3:173
instantaneous water heaters, 2005 V2:111
institutional facilities
  estimating sewage quantities, 2005 V2:159
  numbers of fixtures for, 2001 V4:20, 21
  septic tank systems for, 2005 V2:156–157
instructions to bidders, 2004 V1:62
instrument sterilizers, 2000 V3:36, 38
instruments, nitrogen-pressure-driven, 2000 V3:68
insulation
  airborne sound, 2004 V1:193
  dielectric insulation, 2004 V1:146
  energy savings and, 2004 V1:265
  in geothermal energy systems, 2004 V1:131
  hot-water systems, 2004 V1:127
  noise insulation, 2005 V2:14
  pure water systems, 2005 V2:233
  short-circuiting installations, 2004 V1:151
  thickness and energy conservation, 2004 V1:127
insurance
  certificates, 2004 V1:62
  in labor costs, 2004 V1:94
insurance carriers, 2000 V3:1, 2, 22, 216
intake silencers on compressors, 2000 V3:202
intake sump acoustic problems, 2004 V1:197
intensity-duration-frequency curves, 2000 V3:242, 243
intensity (luminous), 2004 V1:33
intensive-care rooms
  fixtures, 2000 V3:35
  health-care facilities, 2000 V3:32
  medical gas stations, 2000 V3:51, 58
interceptors, 2004 V1:26. *See also specific kinds of interceptors*
interface controls for medical gas systems, 2000 V3:73
intergranular corrosion, 2005 V2:205
interlocking, gas boosters and, 2005 V2:133
interlocks for gas shutoffs, 2005 V2:127–128
intermediate chambers in dry-pipe systems, 2000 V3:11
intermediate coats, 2004 V1:147
intermediate gas regulators, 2000 V3:251
intermediate-level sprinklers, 2004 V1:29
intermittent heating in pools, 2000 V3:145
intermittent sand filters, 2005 V2:157
International Association of Plumbing and Mechanical Officials (IAPMO), 2004 V1:54, 58, 2005 V2:36, 2001 V4:18
International Building Code, 2004 V1:183
International Code Council (ICC), 2004 V1:55, 59, 2005 V2:104
International Conference of Building Officials (ICBO), 2004 V1:191
International Organization for Standardization (ISO), 2004 V1:194
International Pipe Standard (IPS), 2004 V1:15
International Plumbing Code, 2001 V4:18

International Safety Equipment Association (ISEA), 2004 V1:59
international swimming meets, 2000 V3:128
International System of Units (SI)
conversion factors, 2004 V1:39–40
converting, 2004 V1:39, 2005 V2:176, 2000 V3:29
equations, 2004 V1:1
listing, 2004 V1:32–40
non-SI units, 2004 V1:34
prefixes and symbols, 2004 V1:34
pressure and flow rate measurements, 2000 V3:200
style and use, 2004 V1:34, 2005 V2:175
interrelationships of functions, 2004 V1:227, 230
interruptible fuel-gas service, 2005 V2:125
interruptible gas services, 2000 V3:249
interstitial monitoring, 2000 V3:160–161
interstitial spaces in tanks, 2000 V3:156, 165
inventory control in storage tanks, 2000 V3:161–162
invertebrates, 2005 V2:199
inverted bucket traps, 2000 V3:182, 186, 194
inverts
defined, 2004 V1:26
on septic tanks, 2005 V2:154
An Investigation of the Adequacy of Performance of Reduced-size Vents Installed on a Ten-Story Drain, Waste and Vent System, 2005 V2:48
Investigation phase in value engineering, 2004 V1:213, 235, 243, 254
inward projecting pipes
resistance coefficients, 2005 V2:101
iodine, 2005 V2:120, 2000 V3:149
iodine 131, 2005 V2:248
ion-exchange and removal systems, 2005 V2:215–221
continuous deionization, 2005 V2:219–220
design considerations, 2005 V2:220–221
regenerable ion exchange, 2005 V2:215
regeneration cycle, 2005 V2:216–219
resins, 2005 V2:215–216
service deionization, 2005 V2:219
small drinking water systems, 2005 V2:228
total dissolved solids and, 2005 V2:204
water softening, 2005 V2:220
ionization, copper-silver, 2005 V2:120, 122
ionized salts (NaCI), 2000 V3:46
ions
defined, 2004 V1:153
in electromotive force series, 2004 V1:144
in pH values, 2005 V2:239
Iowa Institute of Hydraulic Research, 2005 V2:80
IP units, 2005 V2:175, 176, 2000 V3:200
IPS. *See* International Pipe Standard (IPS); iron pipe size (IPS)
IPS outlets, 2005 V2:14
iron
corrosion, 2004 V1:139
in electromotive force series, 2004 V1:144
in galvanic series, 2004 V1:141
removing, 2005 V2:208
sludge and, 2005 V2:205
in soils, 2005 V2:149
in water, 2005 V2:168, 199, 200
iron bacteria, 2005 V2:199
iron coagulants, 2005 V2:209
iron oxide, 2004 V1:139, 2000 V3:147
iron oxide films, 2004 V1:145
iron pipe size (IPS), 2004 V1:15, 2001 V4:59, 61
iron piping
corrosion, 2004 V1:139
ductile iron water and sewer pipe, 2001 V4:32–33
iron-removal filters, 2000 V3:147
irradiation treatment of water, 2005 V2:168, 223–224, 228, 232, 233
Irrigation Association
The ABC's of Lawn Sprinkler Systems, 2000 V3:105
address, 2000 V3:105
irrigation systems
design information, 2000 V3:104–105
gray-water systems and, 2005 V2:29–30, 35
green roof designs, 2004 V1:266
methods, 2000 V3:100–101
overview, 2000 V3:99
rainwater harvesting, 2004 V1:135, 267
references, 2000 V3:105
resources, 2000 V3:105
sample information sheet, 2000 V3:106
soil considerations, 2000 V3:99–100
system components, 2000 V3:101–104
water conservation and, 2004 V1:264
water quality and requirements, 2000 V3:99
water supply, 2000 V3:105
ischoric processes, 2000 V3:199
ISEA (International Safety Equipment Association), 2004 V1:59
island venting, 2000 V3:42
ISO 3822/1 (Laboratory Tests on Noise Emission by Appliances and Equipment Used in Water Supply Installations), 2004 V1:194
ISO (International Organization for Standardization), 2004 V1:194
isoascorbic acid, 2005 V2:226
isobaric processes, 2000 V3:199
isolating medical gas zones, 2000 V3:71
isolation rooms, 2000 V3:32, 45, 51
isolation valves, 2000 V3:49, 115
isolation, vibration
dishwasher isolation mounts, 2004 V1:195
flexibility and, 2004 V1:199
isolation hangers, 2004 V1:203, 204
isolation springs, 2004 V1:166
isolators within hangers, 2004 V1:166
in piping systems, 2004 V1:202–206
problems in seismic protection, 2004 V1:188–191, 189, 206
types of vibration control devices, 2004 V1:203–206
washing machine isolation mounts, 2004 V1:195
isolators, 2000 V3:213
isosceles triangles, calculating area, 2004 V1:4
isothermal processes, 2000 V3:199
isotopes, 2005 V2:246, 248
ITT Fluid Handling
Training Manual TES 181: Hoffman Steam Heating Systems Design Manual and Engineering Data, 2000 V3:197

Training Manual TES 582: High Temperature Condensate Return, 2000 V3:197
Izod impact, 2001 V4:60

J

J (joules), 2004 V1:33
J/K (joules per kelvin), 2004 V1:33
J/kg K (joules per kg per kelvin), 2004 V1:33
Jackson, T., 2005 V2:48
Jackson turbidity units (JTUs), 2005 V2:204
janitors' closets, 2000 V3:32, 2001 V4:13
Janoschek, R., 2005 V2:234
Jayawardena, N., 2005 V2:234
JCAHO (Joint Commission for the Accreditation of Hospitals Organization), 2005 V2:118, 122, 2000 V3:33, 50
jet pumps, 2005 V2:165
jetted wells, 2005 V2:165
job preparation checklists, 2004 V1:99
jockey pumps, 2004 V1:24, 2000 V3:26
Joint Commission for the Accreditation of Hospitals Organization (JCAHO), 2005 V2:118, 122, 2000 V3:33, 50
joints
  acid-waste systems, 2005 V2:242
  asbestos concrete piping, 2001 V4:26
  bonded joints and cathodic protection, 2004 V1:150
  bronze joints and fittings, 2001 V4:37–38
  cast-iron soil pipes, 2001 V4:27
  caulked joints on floor drains, 2005 V2:15
  chemical-waste systems, 2005 V2:253
  copper drainage tubes, 2001 V4:45, 46
  copper joints, 2001 V4:37–38
  copper water tube, 2001 V4:37
  CPVC piping, 2001 V4:62
  cross-linked polyethylene, 2001 V4:61
  cross-linked polyethylene/aluminum/cross-linked polyethylene (PEX-AL-PEX), 2001 V4:61–62
  ductile iron water and sewer pipe, 2001 V4:32–33
  earthquake damage to, 2004 V1:162
  earthquake protection and, 2004 V1:167
  expansion joints, 2005 V2:16, 54
  fill and pipe joints, 2005 V2:14
  for fountains, 2000 V3:119
  glass pipe, 2001 V4:47–48
  heat-fused socket joints, 2005 V2:242
  inspection, 2000 V3:80
  labor productivity rates, 2004 V1:96
  lead pipe, 2001 V4:49
  materials, 2004 V1:43
  medical gas tubing, 2000 V3:77, 2001 V4:45
  natural gas systems, 2005 V2:130, 2000 V3:254
  o-ring gaskets, 2004 V1:266
  plastic pipes, 2001 V4:59–60
  pure-water systems, 2000 V3:47
  PVC piping, 2001 V4:62
  radioactive waste systems, 2005 V2:249
  red brass pipe, 2001 V4:27
  reinforced concrete pipe, 2001 V4:32
  restrainers, 2000 V3:228–229
  sanitary, 2000 V3:48
  sanitary drainage systems, 2005 V2:13–14
  screwed mechanical joints, 2005 V2:242
  seamless copper pipe, 2001 V4:34
  special-waste drainage systems, 2005 V2:238
  steel pipe, 2001 V4:48
  welded joints in radioactive waste systems, 2005 V2:249
Joukowsky's formula, 2005 V2:79–80
joules, 2004 V1:33
joules per kelvin, 2004 V1:33
joules per kg per kelvin, 2004 V1:33
journeyman plumbers, 2004 V1:26
JTUs (Jackson turbidity units), 2005 V2:204
judgementalism, 2004 V1:232–235
Judgment phase in value engineering, 2004 V1:213
juveniles. *See* children, fixtures and

K

k, K (conductivity), 2004 V1:14, 16, 33
K (dynamic response to ground shaking), 2004 V1:159, 161
K (kelvin), 2004 V1:15, 34
k (kilo) prefix, 2004 V1:34
K factor (coefficient of permeability), 2005 V2:166
K factor (sprinkler heads), 2000 V3:17
K piping. *See* Type K copper
Kalinske, A.A., 2005 V2:19, 80
Kaminsky, G., 2005 V2:256
KE (kinetic energy), 2004 V1:2, 5
kelvin (K), 2004 V1:15, 33
kerosene, 2005 V2:12, 2000 V3:154
keyboards, inflexible thinking and, 2004 V1:231
kg (kilograms). *See* kilograms
kg/m (kilograms per meter), 2004 V1:33
kg/m^2 (kilograms per meter squared), 2004 V1:33
kg/m^3 (kilograms per meter cubed), 2004 V1:33
kg/ms (kilogram-meters per second), 2004 V1:33
kg/s (kilograms per second), 2004 V1:33
kill tanks, 2005 V2:252
"kilo" prefix, 2004 V1:34
kilocalories, converting to SI units, 2004 V1:39
kilograms (kg)
  defined, 2004 V1:33
  kilograms per cubic meter, 2004 V1:33
  kilograms per meter, 2004 V1:33
  kilograms per meter squared, 2004 V1:33
  kilograms per second, 2004 V1:33
kilometers (km)
  converting to SI units, 2004 V1:39
  kilometers per hour, 2004 V1:34
kilopascals (kPa)
  converting meters of head loss to, 2004 V1:2
  converting to psi, 2000 V3:29
  in SI units, 2000 V3:200
  vacuum pump ratings, 2005 V2:178
  vacuum work forces, 2005 V2:176
kiloponds, converting to SI units, 2004 V1:39
kilowatt hours (kWh, KWH), 2004 V1:15, 34
kilowatts (kW, KW), 2004 V1:15
kinematic viscosity
  converting to SI units, 2004 V1:39
  measurements, 2004 V1:33
  water temperature variations, 2005 V2:83, 85

Kinematic Viscosity Centistokes, 2000 V3:154
kinetic energy (KE)
calculating, 2004 V1:2
velocity head and, 2004 V1:5
kip ft, KIP FT (thousand foot-pounds), 2004 V1:16
kip, KIP (thousand pounds), 2004 V1:16
KIPFT (thousand foot-pounds), 2004 V1:16
kitchen sinks
faucets, 2001 V4:13
hot water demand, 2005 V2:109
types, 2001 V4:11–12
kitchens. *See* food-processing areas and kitchens
km/h (kilometers per hour), 2004 V1:34
knee space for wheelchairs, 2004 V1:109
knockout panels for swimming pool filters, 2000 V3:140
knockout pots in vacuum systems, 2005 V2:181
Konen, Thomas K., 2005 V2:36, 48
Kowalsky, L., 2000 V3:125
kPa (kilopascals). *See* kilopascals
Kullen, Howard P., 2004 V1:154
kW, KW (kilowatts), 2004 V1:15
kWh, KWH (kilowatt hours), 2004 V1:15, 34
KYNAR piping, 2000 V3:48

L

L (length). *See* length
L (liters). *See* liters
L/min (liters per minute), 2000 V3:66, 69, 200
L piping. *See* Type L copper
L/s (liters per second), 2000 V3:7, 200
L-shaped bath seats, 2004 V1:122
LA (laboratory compressed air), 2004 V1:8
labels
labeled, defined, 2004 V1:26
labeled fire pumps, 2000 V3:25
medical gas tubing, 2000 V3:77, 81
medical gas valves, 2000 V3:71
parts of gray-water systems, 2005 V2:35
labor and materials payment bonds, 2004 V1:62
labor costs
defined, 2004 V1:222
factors in, 2004 V1:94
ongoing and one-time, 2004 V1:223
overtime, 2004 V1:94
in plumbing cost estimation, 2004 V1:93
productivity rates, 2004 V1:95–97
in take-off estimating method, 2004 V1:94
in value engineering, 2004 V1:212
labor rooms
fixtures, 2000 V3:36
health-care facilities, 2000 V3:32
medical gas stations, 2000 V3:52, 58
laboratories
acid-waste drainage systems, 2005 V2:239, 2000 V3:39–42
acid-waste treatment, 2005 V2:244–245, 2000 V3:40–41
continuous acid-waste treatment systems, 2005 V2:246
discharge to sewers, 2000 V3:40
health and safety concerns, 2005 V2:239–240
large facilities, 2005 V2:244, 245
metering, 2000 V3:41–42
piping and joint material, 2005 V2:242–244
sink traps, 2000 V3:42
solids interceptors, 2000 V3:41, 43
system design considerations, 2005 V2:244
types of acids, 2005 V2:240–242
waste and vent piping, 2000 V3:42
classroom water demand, 2000 V3:45
compressed air use factors, 2000 V3:209
defined, 2000 V3:84
fixtures and pipe sizing, 2005 V2:238
gas service outlets, 2000 V3:37–39
in health-care facilities, 2000 V3:32, 37–39
infectious waste systems, 2005 V2:250–251
lab animals, 2005 V2:251
medical gas stations, 2000 V3:51
natural gas systems, 2005 V2:128–129
plastic pipes, 2001 V4:58
pure water systems for, 2005 V2:228–234, 2000 V3:46
radioactive isotopes in, 2005 V2:245
vacuum systems
codes and standards, 2005 V2:182
diversity factor calculations for vacuums, 2005 V2:184–185
leakage, 2005 V2:186, 187
piping, 2005 V2:183
pump assemblies, 2005 V2:182
sizing, 2005 V2:184–187
vacuum-pump systems, 2000 V3:70
water systems filtration, 2005 V2:211
laboratory compressed air (LA), 2004 V1:8
Laboratory Studies of the Hydraulic Performance of One-story and Split-level Residential Plumbing Systems with Reduced-size Vents, 2005 V2:48
Laboratory Testing on the Noise Emitted by Valves, Fittings, and Appliances Used in Water Supply Installations, 2004 V1:194
Laboratory Tests on Noise Emission by Appliances and Equipment Used in Water Supply Installations, 2004 V1:194
laboratory vacuum (LV), 2004 V1:9, 2005 V2:180–181
ladders
aboveground storage tanks, 2000 V3:165
swimming pools, 2000 V3:145–146
lagging (pipe wrappings), 2004 V1:196, 201–202, 2005 V2:50
lagoons, 2005 V2:157
laid mat filters, 2000 V3:131
lakes, 2005 V2:29
LAL test, 2005 V2:199
laminar flow devices, 2000 V3:33
laminar flow in pipes, 2004 V1:2, 2005 V2:84
landscaping
irrigation. *See* irrigation systems
water efficient, 2004 V1:263–264
landslides, 2004 V1:158
lanes in swimming pools, 2000 V3:128
Langelier saturation index (LSI), 2005 V2:206–207, 2000 V3:123
Langelier, W.F., 2005 V2:206
Laque, F.L., 2004 V1:154
large buildings

acid-waste systems, 2005 V2:244, 245
fixture drainage loads, 2005 V2:3
large private sewage-disposal systems, 2005 V2:156–157
sovent single-stack plumbing systems, 2005 V2:17
large-drop sprinklers, 2004 V1:29, 2000 V3:2
large-scale biohazard facilities, 2005 V2:251
Large Welded Petroleum Tanks (API 12D), 2000 V3:95
lat, LAT (leaving air temperature), 2004 V1:15
latent heat (LH, LHEAT), 2004 V1:15, 137, 2000 V3:175, 189
latent heat gain, 2004 V1:15
lateral and longitudinal sway bracing, 2004 V1:181–182, 184–186
lateral force
calculating for seismic protection, 2004 V1:183
defined, 2004 V1:191
problems in seismic protection, 2004 V1:189
lateral lines, 2000 V3:85
lateral sewers, 2004 V1:26
lateral stability of suspended equipment, 2004 V1:164
laundry sinks or trays, 2001 V4:13
laundry systems and washers
accessibility, 2004 V1:123
acoustic ratings of machines, 2004 V1:195
clothes washer fixture-unit loads, 2005 V2:3
fixture pipe sizes and demand, 2005 V2:94
gray water use, 2004 V1:135, 267, 2005 V2:25
health-care facilities, 2000 V3:32, 36
heat recovery systems, 2004 V1:266
hot water demand, 2005 V2:109
laundry sinks and clothes washers, 2001 V4:13
laundry tray fixture-unit loads, 2005 V2:3
rates of sewage flows, 2005 V2:160
sound damping materials, 2004 V1:196
suds problems, 2005 V2:45–46
waste heat usage, 2004 V1:131–134
water fixture unit values, 2000 V3:217
water temperatures, 2000 V3:45
lavatories. *See also* sinks and wash basins
accessibility, 2004 V1:117
faucets and overflows, 2001 V4:10–11, 13
fixture pipe sizes and demand, 2005 V2:94
fixture-unit loads, 2005 V2:3
flow rates, 2001 V4:10
gray-water systems, 2004 V1:135, 2005 V2:28
health-care facilities, 2000 V3:32, 33, 38
hot water demand, 2005 V2:109
installation requirements, 2001 V4:11
minimum numbers of, 2001 V4:18–22
patient rooms, 2000 V3:34
recovery rooms, 2000 V3:36
reduced water usage, 2004 V1:126–127
shapes and sizes, 2001 V4:10–11
standards, 2001 V4:2
temperatures, 2000 V3:45
typical gray-water supply, 2005 V2:28
typical use, 2005 V2:28
Law of Inverse Proportions, 2004 V1:224
lawn imperviousness factors, 2000 V3:243
lawn sprinkler supply (LS), 2004 V1:8
layer-type dezincification, 2004 V1:142
layers of effluent in septic tanks, 2005 V2:153
layers of fill, 2005 V2:14
lb, LBS (pounds). *See* pounds
leaching trenches. *See* soil absorption systems
leaching wells, 2004 V1:26. *See also* dry wells
lead
corrosion, 2004 V1:139
in electromotive force series, 2004 V1:144
in galvanic series, 2004 V1:141
joint seals, 2001 V4:27, 28
lead-lined concrete blocks, 2005 V2:248
lead-lined lath for plaster, 2005 V2:248
lead piping, 2004 V1:266, 2005 V2:50, 83, 2001 V4:48–49
lead shielding on radioactive drainage systems, 2005 V2:247–248
lead-tin solders, 2004 V1:141
leaders. *See* downspouts and leaders; vertical stacks
calculating flows, 2005 V2:53
Leadership in Energy and Environmental Design (LEED), 2004 V1:263–265
leakage
clean agent gas fire suppression, 2000 V3:23
compressed air systems, 2000 V3:209, 211
eliminating, 2004 V1:134
leaking oil into water, 2005 V2:254–256
waste anesthetic gas management, 2000 V3:71
water conservation and, 2004 V1:124
leakage detection
aboveground tank systems, 2000 V3:167–168
annuciators, 2000 V3:167
chemical wastes, 2005 V2:253
connectors, 2000 V3:166
industrial waste, 2000 V3:90
infectious waste drainage systems, 2005 V2:251
ion exchange systems, 2005 V2:220–221
special-waste drainage systems, 2005 V2:237
underground liquid fuel storage tanks, 2000 V3:158–163
leakage tests
cold-water systems, 2005 V2:103
private water systems, 2005 V2:172
storage tanks, 2000 V3:172
vacuum systems, 2005 V2:186, 187
least mean temperature difference (LMTD), 2004 V1:15
least temperature difference (LTD), 2004 V1:15
leaving air temperature (lat, LAT), 2004 V1:15
leaving water temperature (lwt, LWT), 2004 V1:15
lecture halls, numbers of fixtures for, 2001 V4:19
LEED (Leadership in Energy and Environmental Design), 2004 V1:263–265
leg baths, 2005 V2:109, 2000 V3:32, 35, 38
leg clearances
drinking fountains and water coolers, 2004 V1:112
toilet and bathing rooms, 2004 V1:113
Legionella pneumophila, 2005 V2:107, 117–122
Legionellae Control in Health Care Facilities, 2005 V2:118
legislation regarding people with disabilities, 2004 V1:106–107
legs in piping systems, 2000 V3:47
legs on tanks
cast-iron tank legs, 2004 V1:163
problems in seismic protection, 2004 V1:188, 189

Lehr, Valentine A., 2005 V2:36
length (lg, LG, L)
  conversion factors, 2004 V1:36
  in measurements, 2004 V1:33
  of stacks, 2004 V1:3
  symbols for, 2004 V1:15
  of vent piping, 2004 V1:3
Level I vacuum systems, 2000 V3:85
Level III alarm systems, 2000 V3:83
Level III vacuum systems, 2000 V3:86
level sensors
  boiler feed pumps, 2000 V3:188
  hazardous materials, 2000 V3:90
  tank gauges, 2000 V3:158
levels in water tanks, 2005 V2:171
levels of radiation, 2005 V2:247
Lewis, G.N., 2004 V1:153
LF (linear feet), 2004 V1:15
lg, LG (length). *See* length
LH (latent heat), 2004 V1:15, 137
LHEAT (latent heat), 2004 V1:15, 137
LHG (latent heat gain), 2004 V1:15
libraries, numbers of fixtures for, 2001 V4:19
life-cycle costs, 2004 V1:137
life safety
  in fire protection, 2000 V3:1
  residential sprinkler systems, 2000 V3:2
lifts of fill, 2005 V2:14
light conversion factors, 2004 V1:36
light hazard occupancies
  defined, 2004 V1:29
  firefighting hose streams, 2000 V3:230
  portable fire extinguishers, 2000 V3:27, 28
light heating oil, 2000 V3:154
light process gas service, 2000 V3:249
light service gas, 2005 V2:126
light wall pipe (Schedule 10), 2001 V4:48
lighting systems in pools and fountains, 2000 V3:112, 121, 125, 145
lightwall pipes, 2000 V3:17
lime (calcium carbonate), 2000 V3:147
lime-soda method of water softening, 2005 V2:168, 220
limestone chips, 2005 V2:244
limited-care facilities, 2000 V3:84
limited-discharge roof drains, 2000 V3:247
limiting conditions in seismic protection, 2004 V1:189, 190
limulus amoebocyte lysate test, 2005 V2:199
lin ft (linear feet), 2004 V1:15
Lin, S.H., 2005 V2:234
line-pressure sensors, 2000 V3:72
line regulators, 2000 V3:251
linear acceleration
  conversion factors, 2004 V1:35
  measurements, 2004 V1:33
linear expansion in PVC pipe, 2001 V4:62
linear feet (lin ft, LF), 2004 V1:15
linear velocity measurements, 2004 V1:33
lined piping, 2001 V4:26
lined steel
  storage tanks and hazardous wastes, 2000 V3:91
  sulfuric acid and, 2000 V3:93
linen holding areas, 2000 V3:32
lining materials for dug wells, 2005 V2:164
Linstedt, K.C., 2005 V2:161
lint interceptors, 2000 V3:36, 150
liq, LIQ (liquid). *See* liquids
liquefaction, 2004 V1:158
liquefied petroleum gas. *See also* fuel-gas piping systems
  codes and standards, 2004 V1:43
  defined, 2005 V2:144
  gas boosters, 2005 V2:130–131
  glossary, 2005 V2:142–144
  overview, 2005 V2:137, 141
  physical properties, 2005 V2:125
  pipes, 2001 V4:35, 36
  pressures, 2005 V2:127
  sizing systems, 2005 V2:142
  storage, 2005 V2:142
Liquefied Petroleum Gas Code, 2005 V2:127
liquid chlorine, 2000 V3:123
liquid contamination in compressed air, 2000 V3:201
liquid fuel systems. *See* diesel-oil systems; gasoline systems
liquid monitoring, 2000 V3:160
liquid oxygen (LOX)
  defined, 2000 V3:85
  fire hazards, 2000 V3:61
  medical gas systems, 2000 V3:60
  symbol, 2004 V1:8
liquid petroleum, 2000 V3:154
liquid piston compressors, 2000 V3:201
liquid ring compressors, 2000 V3:67, 201
liquid ring pumps, 2005 V2:180, 181, 183
liquid waste
  decontamination systems, 2005 V2:252
  defined, 2004 V1:26
  levels in septic tanks, 2005 V2:154
liquid waterproofing, 2000 V3:144
liquids (liq, LIQ)
  symbols for, 2004 V1:15
  vacuuming, 2005 V2:188
listed, defined, 2004 V1:26
listing agencies, 2004 V1:26
liters
  converting to gallons units, 2000 V3:29
  converting to SI units, 2004 V1:39
  liters per minute (L/min, Lpm), 2005 V2:176, 2000 V3:66, 69, 200
  liters per second (L/s), 2000 V3:7, 200
  non-SI units, 2004 V1:34
live loads
  on roof, 2005 V2:53
  in pipe selection, 2001 V4:26
living roof designs, 2004 V1:266–267
lm (lumens), 2004 V1:33
LMTD (least mean temperature difference), 2004 V1:15
ln, LN (logarithms, natural), 2004 V1:15
LO (lubricating oil), 2004 V1:8, 2005 V2:12
loading tables
  fixture-unit values in drainage systems, 2005 V2:3
  vertical stacks, 2005 V2:4
loads
  computer analysis of loads, 2004 V1:186
  connected loads, defined, 2005 V2:144

design considerations in seismic protection, 2004 V1:186–188
horizontal loads of piping, 2004 V1:184
live loads on roof, 2005 V2:53
load factors, defined, 2004 V1:26
settlement loads, 2004 V1:186
sway bracing, 2004 V1:185–186
vertical seismic load, 2004 V1:184
vibration control materials, 2004 V1:203
loams, 2000 V3:100
local alarms, 2000 V3:83. *See also* area alarms
local application systems (carbon dioxide), 2000 V3:20
local application systems (halon), 2004 V1:26
local authorities, 2005 V2:29, 237
local barometric pressure in vacuums, 2005 V2:176
local rainfall rate tables, 2005 V2:53–57
localized corrosion, 2005 V2:206
location of piping, earthquake protection and, 2004 V1:167
lock-out regulators, 2000 V3:252
locker rooms, 2000 V3:32
Loevenguth, 2004 V1:191
log, LOG (logarithm to base 10), 2004 V1:15
logarithms
logarithm to base 10 (log, LOG), 2004 V1:15
natural (ln, LN), 2004 V1:15
long runs in vacuum cleaning systems, 2005 V2:194
long-turn tee-wyes, 2005 V2:4
longitudinal bracing
defined, 2004 V1:191
longitudinal and transverse bracing, 2004 V1:180
longitudinal brace points, 2004 V1:168
longitudinal-only bracing, 2004 V1:180
seismic protection, 2004 V1:172
sway bracing, 2004 V1:184–186
longitudinal forces, 2004 V1:191
Looking to Treat Wastewater? Try Ozone, 2005 V2:234
Loomis, A. W., 2005 V2:104
loop systems
fire mains, 2000 V3:8
loop vents, 2004 V1:31, 2005 V2:39, 44–45, 2000 V3:42
louvers in air compression, 2000 V3:212
LOV (lubricating oil vents), 2004 V1:8
low backflow hazard, 2000 V3:222
low-demand classifications, 2005 V2:109 110
low-expansion borosilicate glass, 2001 V4:47
Low-expansion Foam (NFPA 11), 2000 V3:21, 29
low-expansion foams, 2000 V3:21
low-flow fixtures
green building and, 2004 V1:264
low-flow control valves, 2000 V3:103
low-flow shutdown systems, 2005 V2:73
low-flush toilets and water closets
acoustic design, 2004 V1:195
ultra-low-flow water closets, 2004 V1:134–136, 264
low-pressure carbon dioxide systems, 2000 V3:20–21
low-pressure condensate (LPC), 2004 V1:9
low-pressure fire pumps, 2000 V3:25
low-pressure gas cutoffs, 2005 V2:127
low-pressure gas (G), 2004 V1:8
low-pressure natural gas systems, 2005 V2:125–130
low-pressure steam (lps, LPS), 2004 V1:9, 15, 2000 V3:175, 182, 187
low-pressure tanks, 2000 V3:153
low-suction-pressure switches, 2005 V2:73
low-temperature hot water (lthw, LTHW), 2004 V1:15
low-velocity pressure sand filters, 2000 V3:139
low-voltage lighting, 2000 V3:121
low-water cutoffs, 2000 V3:124
lower order functions, 2004 V1:230
Lowther plate units, 2005 V2:224
LOX (liquid oxygen), 2004 V1:8
LP-gases at Utility Gas Plants, 2005 V2:144
LPC (low-pressure condensate), 2004 V1:9
lpg. *See* liquefied petroleum gas
Lpm (liters per minute). *See* liters
lps, LPS (low-pressure steam), 2004 V1:9, 15
LS (lawn sprinkler supply), 2004 V1:8
LSI (Langelier saturation index), 2005 V2:206–207
LTD (least temperature difference), 2004 V1:15
lthw, LTHW (low-temperature hot water), 2004 V1:15
lubricating oil (LO), 2004 V1:8, 2005 V2:12
lubricating oil vents (LOV), 2004 V1:8
lubricators
in compressed air pipe sizing, 2000 V3:210
compressed air systems, 2000 V3:207
lumens, 2004 V1:33
luminance measurements, 2004 V1:33
luminous flux, 2004 V1:33
luminous measurements, 2004 V1:33
lux, 2004 V1:33
LV (laboratory vacuum), 2004 V1:9
LWDS (liquid-waste decontamination systems), 2005 V2:252
LWT (leaving water temperature), 2004 V1:15
lx (lux), 2004 V1:33
lye (sodium hydroxide), 2000 V3:150

M

M alkalinity, 2005 V2:199
M (mega) prefix, 2004 V1:34
m (meters). *See* meters (measurements)
m (milli) prefix, 2004 V1:34
M piping. *See* Type M copper
m/s (meters per second), 2004 V1:33
m/s^2 (meters per second squared), 2004 V1:33
m^2 (meters squared), 2004 V1:33
m^2/s (meters squared per second), 2004 V1:33
m^3 (cubic meters), 2004 V1:33
m^3/kg (cubic meters per kilogram), 2004 V1:33
m^3/min (cubic meters per minute), 2000 V3:200
m^3/s (cubic meters per second), 2004 V1:33
MA. *See* medical compressed air
Mach numbers (Mach, MACH), 2004 V1:15
MacHatton, J.G., 2005 V2:161
machine trenching, labor productivity rates, 2004 V1:95–97
magnesium
corrosion, 2004 V1:139
dry-power extinguishing systems, 2000 V3:20
in electromotive force series, 2004 V1:144
in galvanic series, 2004 V1:141
lifespan of anodes, 2004 V1:150
sacrificial anodes, 2004 V1:147
in water, 2005 V2:199, 200

zeolite process and, 2005 V2:168
magnesium alloys, 2004 V1:141
magnesium anodes, 2000 V3:131
magnesium bicarbonate, 2005 V2:200
magnesium carbonate, 2005 V2:199, 200, 206
magnesium chloride, 2005 V2:200
magnesium hydroxide, 2005 V2:199
magnesium sulfate, 2005 V2:199
magnetic drive meters, 2005 V2:95, 96
magnetic field pulsation, 2004 V1:196
magnetic field strength measurements, 2004 V1:33
magnetic flux density, 2004 V1:33
magnetic flux measurements, 2004 V1:33
magnetism, conversion factors, 2004 V1:35
magnetostrictive tank gauging, 2000 V3:160
main drains
head loss and, 2000 V3:115
reflecting pools and fountains, 2000 V3:110
swimming pools, 2000 V3:137, 143, 145
main relief valves, 2000 V3:25
main shut-off valves, 2000 V3:71
main vents, 2004 V1:26, 2000 V3:184
mains. *See also* water mains
defined, 2004 V1:26, 2000 V3:85
fire mains, 2000 V3:8
force mains, 2000 V3:234, 236–240, 241
natural gas mains, 2000 V3:253
pipe, 2004 V1:12
steam, 2000 V3:182, 187
maintenance
air compressors, 2000 V3:213
costs, 2004 V1:223
fountains and pools, 2000 V3:107
section in specifications, 2004 V1:70, 90
swimming pool filters, 2000 V3:139
maintenance hot-water temperatures, 2005 V2:115
major or prime costs, 2004 V1:222
makeup
defined, 2004 V1:137
reducing use of, 2004 V1:264
makeup water systems
condensation usage, 2004 V1:267
piping for, 2000 V3:116
pools and fountains, 2000 V3:112, 119, 124–125
swimming pools, 2000 V3:144
malleable (mall)
defined, 2004 V1:26
malls, 2005 V2:28–29, 2001 V4:20
Management of Small Waste Flows, 2005 V2:36
Manas, Vincent T., 2005 V2:47, 64, 104
manganese, 2005 V2:168, 208
manholes
acid-waste systems, 2005 V2:243, 244
chemical-waste systems, 2005 V2:253
cleanouts, 2000 V3:240, 241
drop manholes, 2000 V3:234, 238
precast manholes, 2000 V3:234, 237
sampling manholes, 2000 V3:41–42, 44
sanitary sewer systems, 2000 V3:234–236, 237
shallow manholes, 2000 V3:234, 238
spacing, 2000 V3:236, 240
steps and covers, 2000 V3:111, 236
venting, 2000 V3:236, 239
waterproof, 2000 V3:236, 239
manifolds
compressed air, 2000 V3:65
nitrogen systems, 2000 V3:68
nitrous oxide systems, 2000 V3:64, 65
oxygen, 2000 V3:59, 62–63, 64
Manning formula
alternative sewage-disposal systems, 2005 V2:152
ditches, 2000 V3:247–248
open-channel flow, 2004 V1:1, 2005 V2:6, 7
sloping drains, 2005 V2:7, 2000 V3:233
storm-drainage pipes, 2000 V3:244–245, 246
manual-control irrigation valves, 2000 V3:103
manual fill lines, 2000 V3:124
manual fill valves, 2000 V3:124
manual flushometer valves, 2001 V4:8
Manual of Practice
introduction, 2004 V1:61
section shell outline, 2004 V1:88–92
Uniformat, 2004 V1:64
Manual of Septic Tank Practice, 2005 V2:160
Manual on the Design and Construction of Sanitary and Storm Sewers, 2005 V2:64
manual overfill prevention, 2000 V3:167
manual overrides, 2000 V3:104
manual pull stations, 2000 V3:19
manual release stations, 2000 V3:24
manual tank gauging, 2000 V3:159
manual trap primers, 2005 V2:10
manufacturers
in specifications, 2004 V1:70, 90
Manufacturers Standardization Society of the Valve and Fittings Industry, Inc. (MSS), 2004 V1:26, 55, 59, 2001 V4:45
Manufacturing, 2001 V4:32
manufacturing facilities, 2000 V3:87
manways in tanks, 2000 V3:156, 157, 163, 169
maps
frost lines, 2000 V3:226
seismic risk maps, 2004 V1:155–157
soils, 2005 V2:148
marble acrylic fixtures, 2001 V4:2
marble fixtures, 2001 V4:2
mark-ups, in plumbing cost estimation, 2004 V1:93–94, 94
markets
in creativity checklist, 2004 V1:234
sanitation in, 2005 V2:15
markings, corrosion and, 2004 V1:146
Marks, Lionel S., 2004 V1:1, 2, 3, 5, 40
mass
conversion factors, 2004 V1:36
mass law in acoustics, 2004 V1:193
mass per unit area measurements, 2004 V1:33
mass per unit length measurements, 2004 V1:33
in measurements, 2004 V1:33
non-SI units, 2004 V1:34
mass flow, 2005 V2:176
mass flow rates (mfr, MFR)
measurements, 2004 V1:33
symbols for, 2004 V1:15
massive soil structure, 2005 V2:148

master alarms
defined, 2000 V3:83
medical gas systems, 2000 V3:49, 72, 81
master plumbers, 2004 V1:26
MasterFormat
defined, 2004 V1:64
specifications sections, 2004 V1:68–71
MasterFormat 2004, 2004 V1:64–65, 77–88
MasterFormat expansion task team (MFETT), 2004 V1:64
MasterFormat Level Four (1995), 2004 V1:76
MasterFormat Level One (1995), 2004 V1:73
MasterFormat Level Three (1995), 2004 V1:76
MasterFormat Level Two (1995), 2004 V1:73–75
Masterspec, 2004 V1:71
material costs
defined, 2004 V1:222
in plumbing cost estimation, 2004 V1:93
in take-off estimating method, 2004 V1:94
in value engineering, 2004 V1:212
material safety data sheets, 2000 V3:90
materials. *See specific materials or system fixtures*
detail/product/material specification checklist, 2004 V1:220
fixtures, 2001 V4:1–2
ongoing and one-time costs, 2004 V1:223
in plumbing cost estimation, 2004 V1:93
value engineering questions, 2004 V1:213–214
Materials & Resources design (LEED), 2004 V1:263
materials section in specifications, 2004 V1:70, 90–91
maximum (max., MAX), 2004 V1:15
maximum design flow, 2005 V2:133
maximum discharge rates, 2004 V1:5
maximum outlet pressure in gas boosters, 2005 V2:134
maximum resistance values, 2005 V2:203
mbars (millibars), 2005 V2:176
mc (millicuries), 2005 V2:247
McClelland, Nina I., 2005 V2:161
Mcf, MCF (thousand cubic feet), 2004 V1:16
Mcm, MCM (thousand circular mils), 2004 V1:16
McSweeney, D.P., 2005 V2:196
MDPE (medium density) 2406 pipe, 2001 V4:58
mean effective temperatures (MET), 2004 V1:15
mean temperature difference (MTD), 2004 V1:15
measurable nouns in function analysis, 2004 V1:224, 225
measurement units
compressed air, 2000 V3:200
converting, 2000 V3:29
earthquake measurement, 2004 V1:160–161
flow rates, 2005 V2:176–178
International System of Units, 2004 V1:32–40
microorganisms, 2005 V2:199
non-SI units, 2004 V1:34
pressure, 2000 V3:200
pure water, 2000 V3:46
radiation, 2005 V2:247
types of conversions, 2004 V1:32
units and symbols, 2004 V1:33
usage of, 2005 V2:175–177
vacuum pressure, 2005 V2:176–178
water impurities, 2005 V2:201
measuring tank leakage, 2000 V3:159–162
Measuring Water Purity by Specific Resistance, 2005 V2:234
mechanical aerators, 2005 V2:208
mechanical areas
sediment buckets, 2005 V2:11
trap primers in drains, 2005 V2:12
mechanical code agencies, 2004 V1:42
mechanical emulsions, 2000 V3:93
Mechanical Engineering Reference Manual, 2005 V2:144
mechanical filtration, 2000 V3:112, 123
mechanical foam extinguishers, 2000 V3:21
mechanical joints, 2004 V1:168, 266, 2000 V3:40, 228–229
mechanical rooms, earthquake protection, 2004 V1:166
mechanical rotary-type vacuum pumps, 2005 V2:180
mechanical spaces, 2000 V3:111
mechanical steam and condensate return, 2000 V3:186–189
mechanical steam traps, 2000 V3:182
mechanical tank gauging, 2000 V3:159–160
mechanical water makeup, 2000 V3:124
mechanically-dispersed oil, 2005 V2:255
Meckler, Milton, 2004 V1:40
medical air systems. *See also* medical compressed air (MA)
color coding, 2000 V3:56
concentrations, 2000 V3:82
defined, 2000 V3:84
medical compressed air (MA)
altitude and, 2000 V3:66
compressors, 2000 V3:49, 84
storage, 2000 V3:65–68
surgical use, 2000 V3:57
symbol, 2004 V1:8
system description, 2000 V3:65
peak demand, 2000 V3:53
pipe sizing, 2000 V3:74
stations, 2000 V3:50, 51–52
testing, 2000 V3:82–83
medical cabinets, 2004 V1:113
medical compressed air (MA)
altitude and, 2000 V3:66
compressors, 2000 V3:49, 84
storage, 2000 V3:65–68
surgical use, 2000 V3:57
symbol, 2004 V1:8
system description, 2000 V3:65
medical-gas systems
certification, 2000 V3:77–83
codes and standards, 2000 V3:83
color coding, 2000 V3:54, 56
design checklist, 2000 V3:49–50
dispensing equipment, 2000 V3:54–59
ceiling-mounted, 2000 V3:57–59
nitrogen equipment, 2000 V3:59
patient headwall systems, 2000 V3:56–57
station terminals, 2000 V3:54–56
types, 2000 V3:58
diversity factors, 2000 V3:75
earthquake bracing for, 2004 V1:166
gas flow rates, 2000 V3:50–54
gas storage, 2000 V3:59–68
medical compressed air, 2000 V3:65–68
nitrogen, 2000 V3:68

nitrous oxide, 2000 V3:64–65
oxygen, 2000 V3:59–63
health-care facilities, 2000 V3:49–83
number of stations, 2000 V3:50
piping, 2000 V3:73–77
installation, 2000 V3:73
materials, 2000 V3:74–77
sizing, 2000 V3:73–74
system control valves, 2000 V3:71–72
typical storage layout, 2000 V3:60
warning systems, 2000 V3:72–73
waste anesthetic gas management, 2000 V3:70–71
medical-gas tube, 2000 V3:77, 81, 2001 V4:45
medical laboratories. *See* health-care facilities; laboratories
medical schools. *See* health-care facilities
medical vacuum (MV), 2004 V1:9
medical waste systems. *See* infectious and biological waste systems
Medicare taxes, in labor costs, 2004 V1:94
medicine sinks, 2000 V3:35
Medium and High-expansion Foam Systems (NFPA 11A), 2000 V3:21, 29
medium-backflow hazard, 2000 V3:222
medium-demand classifications, 2005 V2:109, 110
medium-expansion foams, 2000 V3:21
medium-pressure condensate (MPC), 2004 V1:9
medium-pressure gas (MG), 2004 V1:8, 2005 V2:125–130
medium-pressure steam (mps, MPS), 2004 V1:9, 15, 2000 V3:175
medium-temperature hot water (mthw, MTHW), 2004 V1:15
medium vacuum, 2005 V2:175
"mega" prefix, 2004 V1:34
megaohm-cm, 2005 V2:203
Mellar, 2000 V3:97
membrane filtration
cross-flow filters, 2005 V2:211, 223
gray-water systems, 2005 V2:30
in health care facilities, 2000 V3:47
membrane flux, 2005 V2:221
membrane productivity, 2005 V2:231
membrane selection in reverse osmosis, 2005 V2:223
overview, 2005 V2:221–223
pure water systems, 2005 V2:231
reverse osmosis, 2005 V2:221–223
tangential-flow filters, 2005 V2:211
total dissolved solids and, 2005 V2:204
membrane flux, 2005 V2:221
membrane productivity, 2005 V2:231
Membrane Technologies in the Power Industry, 2005 V2:234
membranes in waterproofing, 2005 V2:16
memory metal couplings, 2000 V3:77
mercantile facilities
numbers of fixtures for, 2001 V4:20
single-occupant toilet rooms, 2001 V4:23
mercury (Hg, HG), 2004 V1:15
mercury vapor lamps, 2005 V2:224
Mermel, H., 2005 V2:256
Meslar, H.W., 2005 V2:256
MET (mean effective temperatures), 2004 V1:15
metal-edged weirs, 2000 V3:109
metal flashing on roof drains, 2005 V2:51
metallic pipes. *See also specific metals*
bedding, 2000 V3:234, 235
pure-water systems, 2000 V3:47
metals. *See also specific metals*
corrosion losses, 2004 V1:139
galvanic series table, 2004 V1:141
metallic coatings, 2004 V1:147
Metcalf, 2005 V2:161
meter set assemblies, 2005 V2:144
metered faucet requirements, 2004 V1:264
meters (general devices)
acid wastes, 2000 V3:41–42
fuel dispensers, 2000 V3:165
natural gas, 2005 V2:127, 2000 V3:249, 250
meters (measurements)
converting units, 2000 V3:29
meters, 2004 V1:33
meters of head, 2004 V1:2
meters per second, 2004 V1:33
meters per second squared, 2004 V1:33
meters squared, 2004 V1:33
meters squared per second, 2004 V1:33
meters (water)
domestic cold water systems, 2005 V2:68–69
flow pressure loss tables, 2005 V2:69
irrigation, 2000 V3:105
locations for, 2000 V3:217
pressure and, 2005 V2:95
pressure losses, 2000 V3:224
methane, 2005 V2:126. *See also* fuel-gas piping systems
Method for Measuring the Minimum Oxygen Concentration to Support Candle-like Combustion of Plastics (ASTM D2863), 2000 V3:85
Methods of Estimating Loads in Plumbing Systems, 2005 V2:104
methoxyflurane, 2000 V3:70
methyl orange alkalinity, 2005 V2:199
Metric Conversion Act, 2004 V1:32
metric tons, 2004 V1:34
metric units. *See* International System of Units
Meyers, Vance A., 2005 V2:64
Meyrick, C.E., 2005 V2:234
MFETT (MasterFormat expansion task team), 2004 V1:64
mfr, MFR (mass flow rates), 2004 V1:15, 33
mg/L (milligrams per liter), 2005 V2:201
MG (medium-pressure gas), 2004 V1:8
MH (manholes). *See* manholes
mho (specific conductivity), 2005 V2:203
"micro" prefix, 2004 V1:34
microbial growth and control. *See also* bacteria; microorganisms; viruses in feed water
cooling towers, 2005 V2:227
drinking water, 2005 V2:228
feed water, 2005 V2:231
pure water systems, 2005 V2:232
utility water, 2005 V2:225
water softeners, 2005 V2:220, 221
water treatments, 2005 V2:223–225
microbiological fouling of water, 2005 V2:205, 227
microbiological laboratories, 2005 V2:251. *See also* laboratories

micromhos, 2005 V2:203
microns
converting to SI units, 2004 V1:39
vacuum units, 2005 V2:176
microorganisms. *See also* bacteria; microbial growth and control; viruses in feed water
infectious waste drainage systems, 2005 V2:250–251
pure water systems, 2005 V2:232, 2000 V3:47
water analysis of, 2005 V2:198–199
water treatments, 2005 V2:223–225, 228
microscopes, electron, 2000 V3:38, 39, 45, 51
MIL F-1183 Bronze Fittings for Brazed Joints, 2001 V4:27, 34
miles
converting to SI units, 2004 V1:39
miles per hour (mph, MPH), 2004 V1:15
Millepore filters, 2005 V2:204
"milli" prefix, 2004 V1:34
millibars (mbar)
converting to SI units, 2004 V1:39
vacuum units, 2005 V2:176
millicuries (mc), 2005 V2:247
milligrams per liter (mg/L), 2005 V2:201
millimeters
converting to inches, 2000 V3:29
converting to SI units, 2004 V1:39
millirems (mrem), 2005 V2:247
Mills, Lawrence E., 2004 V1:214
min (minutes), 2004 V1:34
min., MIN (minimum), 2004 V1:15
mineral deposits
swimming pools, 2000 V3:131, 147–148
well water, 2000 V3:131
mineral salts, 2005 V2:204, 206
mineral solids, 2005 V2:205
mineral wool, 2004 V1:193
minimum (min., MIN), 2004 V1:15
minimum design flow, 2005 V2:133
minor backflow hazard, 2000 V3:222
minutes, 2004 V1:34
Mironer, Alan, 2005 V2:104
mirrors, 2004 V1:113
misaligned wells, pumps for, 2005 V2:169
miscellaneous gases, 2000 V3:84
mist eliminators, 2005 V2:210
MIUS Technology Evaluation: Collection, Treatment and Disposal of Liquid Wastes, 2005 V2:161
mixed-bed deionization (single-step), 2005 V2:215, 216, 218, 2000 V3:46
mixed media filters, 2000 V3:132, 133, 139
mixes in specifications, 2004 V1:91
mixing faucets, 2000 V3:34
mixing flows of water
conserving energy, 2004 V1:126
mixed-water temperatures, 2005 V2:111
mixing stations, 2000 V3:36
moderate backflow hazard, 2000 V3:222
Modern Vacuum Practice, 2005 V2:196
modifications section in project manual, 2004 V1:63
Moffat, R., 2005 V2:196
mole (mol), 2004 V1:33
molecular weights of elements, 2005 V2:199
moments of inertia
conversion factors, 2004 V1:36
measurements, 2004 V1:33
momentum measurements, 2004 V1:33
monel, 2004 V1:141, 144
monitor-type intermediate gas regulators, 2000 V3:251
monitoring
aboveground tank systems, 2000 V3:167–168
ground water, 2000 V3:162
underground liquid fuel storage tanks, 2000 V3:158–163
measuring leakage, 2000 V3:158–163
piping leaks, 2000 V3:162
remote leakage, 2000 V3:162–163
monthly inventory tank tightness testing, 2000 V3:161–162
Montreal Protocol, 2000 V3:22
Moody, L. F., 2005 V2:84–86
mop basins, 2001 V4:12
mop sinks, 2005 V2:28, 2000 V3:32, 34
morgues and mortuaries, 2005 V2:15
Moritz, A.R., 2005 V2:122, 124
motels
acoustic plumbing design, 2004 V1:196
numbers of fixtures for, 2001 V4:20
septic tanks, 2005 V2:156–157
vacuum calculations for, 2005 V2:190
motion
in creativity checklist, 2004 V1:234
in earthquakes, 2004 V1:158–159
Motor Fuel Dispensing Facilities and Repair Garages Code (NFPA 30A), 2000 V3:154
motor lubrication oil, 2000 V3:154
motor-operated filter bag shakers, 2005 V2:188
motor-operated valves, 2004 V1:9
motorized valves, 2000 V3:119
motors
earthquake protection, 2004 V1:164
fan acoustic problems, 2004 V1:197
motor journals, 2004 V1:196
pump motor controls, 2005 V2:73
in pumps, 2004 V1:196
rotor acoustic modifications, 2004 V1:197
mounting. *See also* installation
fire extinguishers, 2000 V3:27, 28
water closets, 2001 V4:4
MPC (medium-pressure condensate), 2004 V1:9
mph, MPH (miles per hour), 2004 V1:15
MPS (medium-pressure steam supply), 2004 V1:9
mps, MPS (medium-pressure steam), 2004 V1:15
mrem (millerems), 2005 V2:247
MSDS (material safety data sheets), 2000 V3:90
MSS (Manufacturers Standardization Society of the Valve and Fittings Industry, Inc.), 2004 V1:26, 55, 59
MTD (mean temperature difference), 2004 V1:15
mthw, MTHW (medium-temperature hot water), 2004 V1:15
MU (viscosity), 2004 V1:2, 16, 33, 2000 V3:154
mudballing in filters, 2000 V3:132, 150
muds in feed water, 2005 V2:205
mufflers on vacuum systems, 2000 V3:70
multi-effect distillation, 2005 V2:210–211, 214

multi-graded sand filtration, 2005 V2:211
multi-level pools, 2000 V3:108, 109
multimedia filtration, 2005 V2:211, 231
multiple. *See also entries beginning with* double-, multi-, *or* two-
multiple-compartment septic tanks, 2005 V2:154–155
multiple-degree-of-freedom systems, 2004 V1:160, 161
multiple-family dwellings. *See* apartment buildings
multiple-gang-service outlets, 2000 V3:56
multiple pools, 2000 V3:108
multiple pressure-regulated valve installation, 2005 V2:78
multiple-pump systems, 2005 V2:72–73
multiple-tray waterfall aerators, 2005 V2:208
multiplication in SI units, 2004 V1:34
multipurpose dry chemicals, 2000 V3:19, 27
multistage pressure breakdown systems for pump plants, 2004 V1:197–198
multistory buildings. *See* large buildings
municipal sewers. *See* public sewers
municipal water supply
  fire-protection connections, 2000 V3:225
  irrigation usage, 2000 V3:105
  sprinkler systems, 2000 V3:3
  types of, 2000 V3:8
  water mains and pressure, 2000 V3:216
muriatic acid, 2005 V2:217, 242, 2000 V3:148, 149, 150
museums, numbers of fixtures for, 2001 V4:19
mussels, 2005 V2:199
MV (medical vacuum), 2004 V1:9

N

n (nano) prefix, 2004 V1:34
N (newtons), 2004 V1:33
N (nitrogen). *See* nitrogen
N (numbers), 2004 V1:15
n c, N C (normally closed), 2004 V1:15
n i c, N I C (not in contract), 2004 V1:15
N m (newton-meters), 2004 V1:33
n o, N O (normally open), 2004 V1:15
$N^{1.85}$ graph paper, 2000 V3:5
N_2O (nitrous oxide), 2004 V1:9
na, N/A (not applicable), 2004 V1:15
NACE Basic Corrosion Course, 2004 V1:154
NACE (National Association of Corrosion Engineers), 2004 V1:150, 154
NACE Standard RP-01, 2004 V1:150
NaCI (ionized salts), 2000 V3:46
nails, protecting against, 2005 V2:16
Nalco Chemical Co., 2005 V2:234
Nalco Water Handbook, 2005 V2:234
"nano" prefix, 2004 V1:34
nanofilter membranes, 2005 V2:201, 211, 221–223, 223
naphtha, 2005 V2:12
National Association of Corrosion Engineers (NACE), 2004 V1:150, 154
National Association of Home Builders Research Foundation, 2005 V2:47
National Association of Plumbing-Heating-Cooling Contractors. *See* Plumbing-Heating-Cooling Contractors–National Association (PHCC-NA)
National Board of Boiler and Pressure Vessel Inspectors (NBBPVI), 2005 V2:116
National Bureau of Standards
  electromotive force series, 2004 V1:153
  publications, 2005 V2:19, 48, 104
  stack capacities study, 2005 V2:4
National Coarse of U.S. Thread, 2004 V1:17
National Collegiate Athletic Association (NCAA), 2000 V3:151
National Committee for Clinical Laboratory Standards, Inc. (NCCLS), 2005 V2:197, 229, 230
National Easter Seal Society, 2004 V1:111
National Electrical Code (NEC), 2005 V2:124, 2000 V3:115, 121
National Energy Conservation Policy Act, 2004 V1:124
National Fire Alarm Code (NFPA 72), 2000 V3:24, 29
National Fire Protection Association, Inc.
  address, 2004 V1:59, 2000 V3:86, 97
  air compressors in dry-pipe systems, 2000 V3:12
  defined, 2004 V1:26
  design density requirements, 2000 V3:16
  designing systems and, 2000 V3:1
  firefighting water tanks, 2005 V2:170
  gas approvals, 2005 V2:126
  hot-water system standards, 2005 V2:124
  liquefied petroleum gas storage, 2005 V2:142
  list of standards, 2004 V1:55–56
  medical gas station guidelines, 2000 V3:50
  publications, 2004 V1:40
    Automatic Sprinkler and Standpipe Systems, 2000 V3:29
    NFPA Fire Protection Handbook, 2000 V3:8, 29
    NFPA Standard no. 10: Standard for Portable Fire Extinguishers, 2000 V3:27, 29
    NFPA Standard no. 11: Low-expansion Foam, 2000 V3:21, 29
    NFPA Standard no. 11A: Medium and High-expansion Foam Systems, 2000 V3:21, 29
    NFPA Standard no. 12: Carbon Dioxide Extinguishing Systems, 2000 V3:20, 29
    NFPA Standard no. 12A: Halon 1301 Fire Extinguishing Systems, 2000 V3:23, 25, 29
    NFPA Standard no. 13: Installation of Sprinkler Systems, 2004 V1:191, 2000 V3:2, 12, 15, 16, 21, 29, 232
    NFPA Standard no. 14: Installation of Standpipe and Hose Systems, 2000 V3:2, 18, 29
    NFPA Standard no. 15: Water Spray Fixed Systems for Fire Protection, 2000 V3:2, 29
    NFPA Standard no. 16: Deluge Foam-water Sprinkler Systems and Foam-water Spray Systems, 2000 V3:21, 29
    NFPA Standard no. 16A: Installation of Closed-head Foam-water Sprinkler Systems, 2000 V3:21, 29
    NFPA Standard no. 17: Dry Chemical Extinguishing Systems, 2000 V3:20, 29
    NFPA Standard no. 20: Installation of Centrifugal Fire Pumps, 2000 V3:25, 29
    NFPA Standard no. 24: Installation of Private Fire Service Mains and Their Appurtenances, 2000 V3:29, 225
    NFPA Standard no. 30: Flammable and Combustible Liquids Code, 2000 V3:2, 21,

29, 95, 153, 154, 165, 167, 173
NFPA Standard no. 30A: Motor Fuel Dispensing Facilities and Repair Garages Code, 2000 V3:154
NFPA Standard no. 50: Standard for Bulk Oxygen Systems at Consumer Sites, 2000 V3:61, 86
NFPA Standard no. 54: National Fuel Gas Code, 2005 V2:126–127, 2000 V3:248, 254
NFPA Standard no. 58: Liquefied Petroleum Gas Code, 2005 V2:127
NFPA Standard no. 65: Standard for the Processing and Finishing of Aluminum, 2000 V3:20
NFPA Standard no. 72: National Fire Alarm Code, 2000 V3:24, 29
NFPA Standard no. 88A: Standard for Parking Structures, 2005 V2:127
NFPA Standard no. 99: Standard for Health-care Facilities, 2000 V3:50, 56, 66–67, 68, 77, 86, 2001 V4:45
NFPA Standard no. 99C: Gas and Vacuum Systems, 2001 V4:45
NFPA Standard no. 231: General Storage, 2000 V3:2, 29
NFPA Standard no. 231C: Rack Storage of Materials, 2000 V3:2, 29
NFPA Standard no. 255: Standard Method of Test of Surface Burning Characteristics of Building Materials, 2000 V3:77
NFPA Standard no. 291: Standard on Flow Testing and Marking of Fire Hydrants, 2000 V3:3
NFPA Standard no. 329: Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases, 2000 V3:154
NFPA Standard no. 385: Standard for Tank Vehicles for Flammable and Combustible Liquids, 2000 V3:154
NFPA Standard no. 480: Standard for the Storage, Handling and Processing of Magnesium Solids and Powders, 2000 V3:20
NFPA Standard no. 481: Standard for the Production, Processing, Handling and Storage of Titanium, 2000 V3:20
NFPA Standard no. 482: Standard for the Production, Processing, Handling and Storage of Zirconium, 2000 V3:20
NFPA Standard no. 651: Standard for the Machining and Finishing of Aluminum and the Production and Handling Aluminum Products, 2000 V3:20
NFPA Standard no. 2001: Clean Agent Extinguishing Systems, 2000 V3:22, 23, 25, 29
sprinkler piping, 2004 V1:183–184
sprinkler system statistics, 2000 V3:2
National Fuel Gas Code (NFPA 54), 2005 V2:126–127
natural gas system design, 2000 V3:248
pipe materials, 2000 V3:254
National Ground Water Association (NGWA), 2005 V2:172
National Institutes of Health, 2005 V2:182, 251
National Insulation Contractors' Association (NICA), 2004 V1:127
National Oceanic and Atmospheric Administration (NOAA), 2005 V2:57–61, 2000 V3:242
NOAA, National Weather Service 5-60 Minute Precipitation Frequency for the Eastern and Central United States, 2005 V2:64
Technical Paper no. 40, 2000 V3:243
National Plumbing Code, 2005 V2:47, 64, 104
National Pollutant Discharge Elimination System (NPDES), 2000 V3:88, 2000 V3:89
National Sanitation Foundation (NSF)
address, 2004 V1:59
hot-water system requirements, 2005 V2:124
list of standards, 2004 V1:56
PVC plastic ratings, 2000 V3:145
recycled wastewater quality, 2005 V2:26
Standard 61, 2001 V4:26
swimming pool components, 2000 V3:131
National Sanitation Foundation Testing Laboratory (NSFTL), 2004 V1:26
National Society of Professional Engineers (NSPE), 2004 V1:62, 63
National Spa and Pool Institute (NSPI)
address, 2000 V3:151
ANSI/NSPI-1: Standard for Public Swimming Pools, 2000 V3:125, 151
ANSI/NSPI-5: Standard for Residential, In-ground Swimming Pools, 2000 V3:151
Report no. 18: Corrosion in Swimming Pools and General Guide to Materials Selection, 2000 V3:145
swimming pool codes, 2000 V3:127
National Standard Plumbing Code, 2005 V2:47
National Standards Bureau
reduced size venting study, 2005 V2:18–19
National Technical Information Service (NTIS), 2000 V3:97
National Weather Service *Hydro 35,* 2000 V3:242
National Weather Service (NWS), 2005 V2:50
natural drainage (corrosion), 2004 V1:153
natural frequency of vibration control materials, 2004 V1:202
natural gas. *See* fuel-gas piping systems; natural gas systems
natural gas systems, 2000 V3:248–254
altitude factors, 2005 V2:129
appliance demand table, 2005 V2:128
appliances, 2005 V2:128
approvals, 2005 V2:126
codes and standards, 2005 V2:127, 2000 V3:248
compressed gas fires, 2000 V3:21
compressed gases defined, 2000 V3:199
demand in multiple family dwellings, 2005 V2:135, 136
design considerations, 2005 V2:130
efficiency, 2005 V2:127
equivalent lengths for valves and fittings, 2005 V2:135
glossary, 2005 V2:142–144
high-rise buildings and, 2005 V2:133
laboratory usage, 2005 V2:128–129
liquefied petroleum gas, 2005 V2:137, 142
low and medium pressure systems, 2005 V2:125–130

meters, 2005 V2:127, 2000 V3:250
operating pressures, 2005 V2:126–127
overview, 2000 V3:248
physical properties of gas and propane, 2005 V2:125
pipe sizing, 2005 V2:134–137, 2000 V3:252–254
preliminary information, 2000 V3:215–216
pressure, 2005 V2:128
sample gas utility letter, 2000 V3:249, 258–259
specific gravity, 2005 V2:137, 141
storage tanks, 2005 V2:142
system components, 2000 V3:250–252
drip pots, 2000 V3:252
gas boosters, 2005 V2:130–131, 130–134
gas line filters, 2000 V3:250
gas meters, 2000 V3:250
gas pressure regulators, 2000 V3:250–252
natural gas pipes, 2001 V4:35, 36
piping and fittings materials, 2005 V2:129–130
pressure control valves, 2005 V2:127
pressure regulating valves, 2005 V2:127
regulator relief vents, 2005 V2:129
testing and purging, 2000 V3:252, 253
types of services, 2000 V3:249
natural gas water heaters. *See* gas-fired water heaters
natural logarithms, 2004 V1:15
natural osmosis, 2005 V2:221
natural period of vibration, 2004 V1:160
Natural Resources Defense Council, 2000 V3:88
natural water, 2005 V2:197, 230
naturally-vented multiple tray aerators, 2005 V2:208
naval rolled brass, 2004 V1:144
NBBPVI (National Board of Boiler and Pressure Vessel Inspectors), 2005 V2:116
NBR (acrylonitrile butadiene rubber), 2000 V3:169
NBS (National Bureau of Standards). *See* National Bureau of Standards
NC (noise criteria), 2004 V1:15, 206
NC (number of circuits), 2004 V1:15
NCAA (National Collegiate Athletic Association), 2000 V3:151
NCCLS (National Committee for Clinical Laboratory Standards, Inc.), 2005 V2:197, 229, 230
NEC (National Electrical Code), 2005 V2:124
negative gauge pressure, 2005 V2:176
negative pressure. *See* vacuum
negativity in value engineering presentations, 2004 V1:258
NEMA 4 listing, 2005 V2:131
NEMA 4X listing, 2005 V2:116
NEMA 12 listing, 2005 V2:131
NEMA Class 1, Division 1, Group D listing, 2005 V2:130
neoprene compression gaskets, 2001 V4:27
neoprene floor and hanger mounts, 2004 V1:203, 204, 205
neoprene gaskets, 2000 V3:42
nephelometric test, 2005 V2:203
nephelometric turbidity units (NTUs), 2005 V2:203
net positive suction head (NPSH), 2004 V1:199, 206, 2005 V2:170, 2000 V3:140
neutralizing acid in waste water
discharge from laboratories, 2000 V3:40
health-care facility systems, 2000 V3:40
laboratories, 2000 V3:40–41
methods of treatment, 2005 V2:244–245
sizing tanks, 2000 V3:42
solids interceptors, 2000 V3:41, 43
tank and pipe materials, 2000 V3:91–92
types of acids, 2005 V2:239–245
neutralizing tanks, 2000 V3:42
neutrons, 2005 V2:246
New York City, ultra-low-flow toilets in, 2004 V1:134–135
New York State Department of Environmental Conservation
address, 2000 V3:97
Technology for the Storage of Hazardous Liquids, 2000 V3:96
newton-meters, 2004 V1:33
newtons, 2004 V1:33
NF nomographs, 2005 V2:229
NFPA. *See* National Fire Protection Association, Inc.
NGWA (National Ground Water Association), 2005 V2:172
ni-resist cast iron, 2004 V1:144
ni-resist ions, 2004 V1:141
Nibco Inc., 2005 V2:104
NICA (National Insulation Contractors' Association), 2004 V1:127
niche lights for pools, 2000 V3:121, 145
nickel
corrosion, 2004 V1:139
electromotive force series, 2004 V1:144
galvanic series, 2004 V1:141
in stainless steel, 2001 V4:2
nickel-bronze grates, 2005 V2:13, 15
nightclubs, numbers of fixtures for, 2001 V4:19
Nine Dots exercise, 2004 V1:232, 261
nippled-up sprinklers, 2004 V1:13
nipples for cast iron radiators, 2000 V3:179
nitrates, 2005 V2:199, 200
nitric acid, 2004 V1:146, 2005 V2:242
nitrifying bacteria, 2005 V2:199
nitrile butadiene (Buna-N), 2000 V3:169
nitrogen (N)
color coding outlets, 2000 V3:56
control cabinets, 2000 V3:58
cylinder supplies, 2000 V3:60
defined, 2000 V3:84
dry nitrogen, 2000 V3:252
gas blankets in water tanks, 2005 V2:233
high-pressure dispensing equipment, 2000 V3:59
laboratory outlets, 2000 V3:37–39
medical gas pipe sizing, 2000 V3:74, 75, 77
medical gas stations, 2000 V3:51–52
medical gas storage, 2000 V3:68
oil-free, 2001 V4:45
purging vacuum pumps, 2005 V2:182
in raw water, 2005 V2:200
surgical use, 2000 V3:57
symbol, 2004 V1:9
testing concentrations, 2000 V3:82
in water chemistry, 2005 V2:199
nitrogen NF, 2000 V3:65, 84
nitrous fumes, 2005 V2:242
nitrous oxide (N^2O)
color coding outlets, 2000 V3:56
cylinder supplies, 2000 V3:60

defined, 2000 V3:84
medical gas pipe sizing, 2000 V3:74, 76
medical gas storage, 2000 V3:64–65
surgical use, 2000 V3:57
symbol, 2004 V1:9
testing concentrations, 2000 V3:82
waste anesthetic gas management, 2000 V3:70
nL/min (normal liters per minute), 2000 V3:200
nm^3/min (normal cubic meters per minute), 2000 V3:200
no-flow pressure in pressure-regulated valves, 2005 V2:67
no-hub joints, earthquake protection and, 2004 V1:168
no-hub outlets, 2005 V2:14
no., NO (numbers), 2004 V1:15
"no observed adverse effect level," 2000 V3:22
no-slump concrete, 2001 V4:32
NOAA (National Oceanic and Atmospheric Administration), 2005 V2:57–61
NOAA, National Weather Service 5-60 Minute Precipitation Frequency for the Eastern and Central United States, 2005 V2:64
rainfall records, 2000 V3:242
Technical Paper no. 40, 2000 V3:243
NOAEL (no observed adverse effect level), 2000 V3:22
noble potential, defined, 2004 V1:153
noise. *See* acoustics in plumbing systems
noise criteria (NC), 2004 V1:15, 206. *See also* preferred noise criteria (PNC) curves
nominal diameter (DN), 2005 V2:175
nominal pipe size (NPS), 2005 V2:175, 2001 V4:61, 62
nominal values, 2004 V1:32
nomographs, 2005 V2:34
non-agreement states, 2005 V2:248
non-ambulatory disabilities, 2004 V1:107
non-aqueous liquid wastes, 2000 V3:87
non-aspirating nozzles, 2000 V3:21
non-circular grab bars, 2004 V1:121
non-circulating water systems, 2004 V1:127
non-continuous joints, 2004 V1:150
non-depletable energy sources, 2004 V1:137
Nondiscrimination on the Basis of Disability by Public Accommodations and in Commercial Facilities, 2004 V1:106
non-electrolytes, 2005 V2:197
non-flammable medical gas, 2000 V3:49
Non-flammable Medical Gas Piping Systems (CSA Z305.1), 2000 V3:86
non-looped piping systems, 2000 V3:16
non-measurable nouns in function analysis, 2004 V1:224
non-metallic coatings, 2004 V1:147
non-oxidizing chemicals in microbial control, 2005 V2:223
non-oxidizing piping, 2005 V2:249
non-porous piping, 2005 V2:249
non-porous soils, 2000 V3:105
non-potable cold water (NPCW), 2004 V1:9
non-potable hot water (NPHW), 2004 V1:9
non-potable hot water return (NPHWR), 2004 V1:9
non-potable water systems. *See* gray-water systems
non-pressure asbestos concrete pipe, 2001 V4:26
non-pumping wells, 2005 V2:165–166
non-puncturing membrane flashing, 2005 V2:16
non-reactive silica, 2005 V2:200
non-reinforced concrete pipe, 2001 V4:32
non-rigid couplings, 2004 V1:186
non-SI units, 2004 V1:34
non-sprinklered spaces, 2004 V1:12
Non-structural Damage to Buildings, 2004 V1:191
non-tilting grates, 2005 V2:11
non-vitreous china fixtures
defined, 2001 V4:1
standards, 2001 V4:2
"normal," compared to "standard," 2000 V3:200
normal cubic meters per minute (nm^3/min), 2000 V3:200
normal liters per minute (nL/min), 2000 V3:200
normally closed (n c, N C), 2004 V1:15
normally open (n o, N O), 2004 V1:15
not applicable (na, N/A), 2004 V1:15
not in contract (n i c, N I C), 2004 V1:15
not to scale (NTS), 2004 V1:15
nouns in function analysis, 2004 V1:224, 225, 231
nourishment stations in health-care facilities, 2000 V3:32
nozzles
defined, 2004 V1:29
dry-chemical systems, 2000 V3:19
fountains, 2000 V3:108–109, 112, 117–118, 119–120
fuel dispensers, 2000 V3:165
irrigation sprinklers, 2000 V3:103
pressure, 2000 V3:19, 219
pressure flow tables, 2000 V3:4, 7
sprinklers, 2000 V3:9
standpipe systems, 2000 V3:19
water level in pools and, 2000 V3:112
NPCW (non-potable cold water), 2004 V1:9
NPDES (National Pollutant Discharge Elimination System), 2000 V3:88, 2000 V3:89
NPHW (non-potable hot water), 2004 V1:9
NPHWR (non-potable hot water return), 2004 V1:9
NPS (nominal pipe size), 2005 V2:175
NPSH (net positive suction head), 2004 V1:199, 206, 2005 V2:73, 170, 2000 V3:140
NRC (Nuclear Regulatory Commission), 2005 V2:247, 248
NSF. *See* National Sanitation Foundation (NSF)
NSPE (National Society of Professional Engineers), 2004 V1:62, 63
NSPI. *See* National Spa and Pool Institute (NSPI)
NT (number of tubes), 2004 V1:15
NTIS (National Technical Information Service), 2000 V3:97
NTS (not to scale), 2004 V1:15
NTUs (nephelometric turbidity units), 2005 V2:203
nuclear power plants
regulatory requirements, 2005 V2:245
seismic protection, 2004 V1:156
Nuclear Regulatory Commission, 2005 V2:247, 248
numbers (no., NO, N)
of circuits (NC), 2004 V1:15
in CSI format, 2004 V1:65
in measurements, 2004 V1:32
of swimmers, 2000 V3:127–128
symbol, 2004 V1:15
of tubes (NT), 2004 V1:15
numerical weights in value engineering, 2004 V1:243
nurse stations, 2000 V3:32
nurseries
fixtures for, 2000 V3:34

health-care facilities, 2000 V3:32
medical gas stations, 2000 V3:52, 58
sinks, 2000 V3:38
nursing homes. *See* health-care facilities
Nussbaum, O.J., 2005 V2:234
NWS (National Weather Service), 2005 V2:50

O

O-rings, 2001 V4:37
o-ring gaskets, 2004 V1:266
O_2. *See* oxygen (O_2, OX)
oa, OA (outside air), 2004 V1:15
oakum seals, 2001 V4:27, 28
objectives in FAST approach, 2004 V1:230
obstructions to wheelchairs, 2004 V1:111, 112
occupancy classification (sprinkler systems), 2004 V1:29, 2000 V3:2, 17
occupancy of pools, 2000 V3:127–128
occupants
in hot water demand classifications, 2005 V2:109
loads of buildings, 2001 V4:18
Occupational Safety and Health Administration (OSHA), 2005 V2:242, 2000 V3:153, 156
occupied domestic spaces, acoustic plumbing design for, 2004 V1:196
ocean water, irrigation systems and, 2005 V2:30
octave-band sound levels, 2004 V1:194
octaves, 2004 V1:206
OD (outside diameters), 2004 V1:14
odor control in drinking water, 2005 V2:168, 227
OFCI (owner furnished, contractor installed), 2004 V1:71
off-peak power usage, 2004 V1:128–129
office buildings
hot water demand, 2005 V2:109
numbers of fixtures for, 2001 V4:19, 21–22
Office of Statewide Health Planning and Development (OSHPD), 2004 V1:191
offset stacks, 2005 V2:5
offsets, 2004 V1:26
offshore facilities, 2004 V1:150
ohm-centimeter units (Ω-cm), 2000 V3:46
ohm-meters, 2004 V1:33
Ohm's Law, 2004 V1:144
OHMS (resistance or resistors), 2004 V1:15, 33
oil
as seal liquid in liquid ring pumps, 2005 V2:181
contamination in compressed air, 2000 V3:201
intercepting in acid-waste systems, 2005 V2:245
intercepting in sanitary drainage systems, 2005 V2:12
oil-water separation, 2000 V3:93
skimming, 2000 V3:93
spills and containment, 2005 V2:254–256
storm-drainage systems and, 2005 V2:49
vegetable oil, 2005 V2:10
Oil- and Gas-Fired Single-Burner Boilers, 2005 V2:129
oil-free compressors, 2000 V3:67, 201
oil interceptors, 2005 V2:12, 254
oil-mist filters in vacuums, 2005 V2:181
oil-removal filters, 2000 V3:203
oil systems. *See* diesel-oil systems; gasoline systems
oil-wet solids, 2005 V2:255
oilless compressors, 2000 V3:67
oilless pumps, 2005 V2:180
oleums, 2005 V2:240, 241
on-site facility treatment systems. *See* special-waste drainage systems
On Site Wastewater Facilities for Small Communities and Subdivisions, 2005 V2:161
on-site water reclamation. *See* gray-water systems
once-thru-oil pumps, 2005 V2:181
one-compartment sinks, 2001 V4:11
one-family dwellings, numbers of fixtures for, 2001 V4:20, 21
one-occupant toilet rooms, 2001 V4:18, 23
one-pass cooling for equipment, 2004 V1:264
one-piece water closets, 2001 V4:3
one-pipe steam systems, 2000 V3:178–180, 183, 186, 188
one-stage distillation, 2005 V2:210
one-tank residential filters, 2000 V3:134
one-time costs, 2004 V1:223
one-wall tanks, 2000 V3:156
ongoing costs, 2004 V1:223
Ongontz valves, 2000 V3:125
open-channel flow, 2004 V1:1, 2005 V2:6
open-circuit potential, defined, 2004 V1:153
open-head sprinklers, 2000 V3:21
open proprietary specifications, 2004 V1:67, 68
open-spring floor and hanger mounts, 2004 V1:203, 204
open sprinklers, 2004 V1:29
open-type base pumps, 2005 V2:166
open-web steel joists in pipe bracing, 2004 V1:176
openings for tool access. *See* cleanouts
operating costs, 2004 V1:223
operating-pressure steam classification, 2000 V3:175–178
equipment ratings, 2000 V3:178
vacuum systems, 2000 V3:178
vapor systems, 2000 V3:175–178
operating rooms
articulated ceiling medical gas systems, 2000 V3:59
fixtures, 2000 V3:35–36
medical gas stations, 2000 V3:52, 58
medical vacuum, 2000 V3:54
water demand, 2000 V3:45
operators of vacuum systems, 2005 V2:190
oral surgery equipment, 2000 V3:39, 52
orbital welding process, 2005 V2:249
orders in creativity checklist, 2004 V1:234
ordinary hazard occupancies
defined, 2004 V1:29
firefighting hose streams, 2000 V3:230
portable fire extinguishers, 2000 V3:27, 28
ordinary lobe pumps, 2005 V2:180
organic free water, 2005 V2:229
organic materials in water, 2000 V3:46
organic polyelectrolytes, 2005 V2:209
organisms in water, 2005 V2:198–199, 2000 V3:146. *See also* microorganisms
orifices
on hydrants, 2000 V3:7
on nozzles, 2000 V3:7
ornamental sprinklers, 2004 V1:29
ORP (oxidation reduction potential), 2000 V3:122, 123
orthotolidin tests, 2005 V2:103
oscillating-type monitors, 2000 V3:21

oscillation in pumps, 2004 V1:201
OSHA (Occupational Safety and Health Administration), 2005 V2:242, 2000 V3:153, 156
OSHPD (Office of Statewide Health Planning and Development), 2004 V1:191
osmosis, defined, 2005 V2:221
osmotic pressure, 2005 V2:221
Otis, Richard J., 2005 V2:161
OTO pumps, 2005 V2:180, 181
Otten, Gerald, 2005 V2:234
Otto plate units, 2005 V2:224
ounces (oz, OZ)
  converting to SI units, 2004 V1:40
  symbols for, 2004 V1:15
out-of-sequence work conditions, cost estimates for projects and, 2004 V1:98
outdoor gas booster installation, 2005 V2:133
outdoor swimming pools. *See also* swimming pools
  components for, 2000 V3:139
  considerations, 2000 V3:129
outfall sewers, 2004 V1:26
outlet pressures
  outlet pressure regulators, 2000 V3:14, 15
  standpipe systems, 2000 V3:19
outlets. *See also* inlets; stations
  flow rates at outlets, 2004 V1:3, 5
  gas or vacuum. *See* stations
  pools and fountains, 2000 V3:110–111
  pressure in cold-water systems, 2005 V2:78
  septic tanks, 2005 V2:154
  symbols for, 2004 V1:11
  velocity of flow from outlets, 2004 V1:6
outpatient-services rooms, 2000 V3:32, 45
outside air (oa, OA), 2004 V1:15
outside diameters (OD), 2004 V1:14
outside film coefficients, 2004 V1:14
"outside the box" thinking, 2004 V1:232
"outstanding value," defined, 2004 V1:213
overall system thermal efficiency, 2004 V1:136
overengineering, perception of, 2004 V1:260
overestimating needs, 2004 V1:224
overfill prevention, 2000 V3:90, 2000 V3:167, 2000 V3:167
overflow
  for bathtubs, 2001 V4:16
  for lavatories, 2001 V4:10–11
  for pools and fountains, 2000 V3:112, 125
  storm drains. *See* secondary storm-drainage systems
overhead
  costs in value engineering, 2004 V1:212, 222
  in plumbing cost estimation, 2004 V1:93
overhead steam return lines, 2000 V3:196
overheating vacuum exhausters, 2005 V2:189
overland flow rates for sites, 2000 V3:242, 244, 245
overlap in toilet accessibility, 2004 V1:114
overload protection in fountain pumps, 2000 V3:120
oversized steam traps, 2000 V3:196
overspray areas in irrigation, 2000 V3:104
overtime labor costs, in take-off estimating method, 2004 V1:94
overturning, preventing, 2004 V1:163, 189
overvoltage, defined, 2004 V1:153
owner furnished, contractor installed (OFCI), 2004 V1:71
owners
  perception of engineering, 2004 V1:260
  value engineering and, 2004 V1:212
OX (oxygen). *See* oxygen (O_2, OX)
oxidation, defined, 2004 V1:153
oxidation reduction potential (ORP), 2000 V3:122, 123
oxidized sewage, 2004 V1:27
oxidizing chemicals in microbial control, 2005 V2:223
oxidizing gases, 2000 V3:84
OXY/ACR pipes, 2001 V4:36
OXY/MED pipes, 2001 V4:36
OXY, MED piping, 2001 V4:36
oxygen concentration cells, 2004 V1:153
oxygen-delivery equipment, 2000 V3:85
oxygen-enriched atmospheres, 2000 V3:85
Oxygen-fuel Gas Systems for Weldings and Cuttings, 2005 V2:144
oxygen index, 2000 V3:85
oxygen (O_2, OX)
  bulk oxygen systems, 2000 V3:61–62, 63
  color coding outlets, 2000 V3:56
  corrosion process, 2004 V1:145, 2005 V2:200
  cylinder-manifold supply systems, 2000 V3:62–63, 64
  defined, 2000 V3:84–85
  medical gas pipe sizing, 2000 V3:74, 75, 76
  medical gas stations, 2000 V3:50, 51–52
  medical gas storage, 2000 V3:59–63
  medical gas systems, 2000 V3:49
  medical reserve supply, 2000 V3:60
  oxygen pitting, 2000 V3:190
  oxygen USP, 2000 V3:65, 84
  oxygenated water, 2005 V2:168, 2000 V3:116
  reducing with carbon dioxide, 2000 V3:20
  removing, 2005 V2:209
  saturation with, 2005 V2:208
  surgical use, 2000 V3:57
  symbols for, 2004 V1:8
  testing concentrations, 2000 V3:82
  in water, 2005 V2:199
oxygen scavengers, 2005 V2:226
oxygen toxicity, 2000 V3:85
oz, OZ (ounces), 2004 V1:15, 40
ozonation
  cooling tower water, 2005 V2:227
  Legionella and, 2005 V2:122
  pure water systems, 2005 V2:232
  small drinking water systems, 2005 V2:228
  water treatments, 2005 V2:168, 224–225
ozone
  generators, 2005 V2:224
  layer, 2000 V3:22
  in pools and fountains, 2000 V3:123–124

P

P alkalinity, 2005 V2:199
P (peta) prefix, 2004 V1:34
p (pico) prefix, 2004 V1:34
P (pressure). *See* pressure
p-traps
  floor drains with, 2004 V1:11
  laboratory sinks, 2000 V3:42
Pa (pascals), 2004 V1:33

PA (pipe anchors), 2004 V1:10
Pa s (pascal-seconds), 2004 V1:33
packed-bed, activated-carbon filters, 2005 V2:211, 215
packed tower aeration, 2005 V2:228
packerhead method, 2001 V4:32
packing material
  sound damping, 2004 V1:196
  in vacuum deaerators, 2005 V2:209
padding
  for glass pipe, 2001 V4:47
  for vibration control, 2004 V1:203, 204
pain, thresholds of, 2005 V2:122
painting cast iron radiators, 2000 V3:179
paints in septic tanks, 2005 V2:156
Pair, Claude H., 2000 V3:105
panels, lining with lead, 2005 V2:248
paper towel clogs, 2005 V2:11
paraffin, 2005 V2:12
paragraph numbering in CSI format, 2004 V1:65
parallel approaches for wheelchairs, 2004 V1:109, 110
parallel-condensate trapping, 2000 V3:196
parallel-flow piping designs, 2000 V3:178, 183
parallel installation of pressure-regulated valves, 2005 V2:78
parallel-shaft gears, 2004 V1:196
parapet wall scuppers, 2005 V2:51, 55
Parekh, B.S., 2005 V2:234
Pareto principle, 2004 V1:224, 258
Pareto, Vilfredo, 2004 V1:224
parking lot drainage pipes, 2001 V4:32
Parmalee heads, 2000 V3:1
part-circle rotary sprinkler heads, 2000 V3:102
partial pressures law, 2005 V2:81
partially-sprinklered spaces, 2004 V1:12
participation in value engineering presentations, 2004 V1:258
particle size in sand filters, 2000 V3:132
particulate radiation, 2005 V2:247
particulate silica, 2005 V2:200
particulates
  contamination in compressed air, 2000 V3:201
  in water, 2005 V2:198, 203–204
parts per million (ppm, PPM), 2004 V1:15, 2005 V2:201, 2000 V3:46
pascal-seconds, 2004 V1:33
pascals, 2004 V1:33
passenger terminals, numbers of fixtures for, 2001 V4:19
passivation, 2004 V1:146–147
passive, defined, 2004 V1:153
passive verbs in function analysis, 2004 V1:224
pathogens, 2005 V2:147, 198
paths
  of acoustic problems, 2004 V1:199
  of discharge, 2000 V3:4
patient rooms
  bathing areas, 2000 V3:32
  fixtures for, 2000 V3:34
  health-care facilities, 2000 V3:32
  medical gas stations, 2000 V3:52, 58
  medical vacuum, 2000 V3:54
  patient head wall stations, 2000 V3:58
patient vacuum (VAC), 2000 V3:85
paved areas
  imperviousness factors, 2000 V3:243
  storm drainage, 2005 V2:49
PB (polybutylene). *See* polybutylene (PB)
PCT (percentages), 2004 V1:15
PCUs (platinum cobalt units), 2005 V2:204
PD (pressure drops or differences). *See* pressure drops or differences
PD (pump discharge lines), 2004 V1:8
PDI (Plumbing and Drainage Institute). *See* Plumbing and Drainage Institute (PDI)
PE-AL-PE (polyethylene/aluminum/polyethylene), 2001 V4:62
PE (polyethylene). *See* polyethylene (PE)
PE (potential energy), 2004 V1:2, 5
pea gravel backfill, 2000 V3:172
Peabody, A.W., 2004 V1:154
peak consumption in gas boosters, 2005 V2:133
peak demand
  flushometer valves and, 2001 V4:8
  medical air, 2000 V3:53, 66
  medical gas, 2000 V3:49
  medical vacuum, 2000 V3:55
  swimming pools, 2000 V3:127–128
  urinals, 2001 V4:10
  vacuum systems, 2000 V3:70
penal institutions, 2001 V4:20, 22
pendent sprinklers, 2004 V1:13, 29, 2000 V3:13
penetration of irrigation water, 2000 V3:99, 105
penetrations of walls and floors, 2000 V3:25
people with disabilities
  ambulatory-accessible toilet compartments, 2004 V1:114
  ANSI 117.1-1998, 2004 V1:109–123
  bathing rooms, 2004 V1:112–113
  bathtub and shower seats, 2004 V1:122–123
  bathtub design, 2004 V1:117–119
  design for, 2004 V1:107
  drinking fountains and water coolers, 2004 V1:109–112
  exposed piping and accessibility, 2004 V1:117
  fixture design standards and, 2001 V4:2
  grab bars, 2004 V1:114–122
  history of design and construction standards, 2004 V1:105–106
  introduction to plumbing for, 2004 V1:105
  laundry equipment, 2004 V1:123
  lavatories and sinks, 2004 V1:117
  legislation, 2004 V1:106–107
  references, 2004 V1:122
  shower compartments, 2004 V1:119–122
  swimming pool bathhouses, 2000 V3:130
  swimming pools, 2000 V3:128
  urinal design, 2004 V1:116
  water closets and toilets, 2004 V1:113–116, 2001 V4:5
per-area costs, 2004 V1:97–98
per-fixture estimations, cost estimations, 2004 V1:97
percentages (%, PCT), 2004 V1:15
perception
  in creativity, 2004 V1:231
  of engineers, 2004 V1:260
perchloric acid, 2005 V2:242
percolation

defined, 2004 V1:27
rates for soils, 2005 V2:147–150
Perfect Gas law, 2000 V3:66
perfect vacuums, 2005 V2:175, 2000 V3:200
perfluorocarbons (PFCs), 2000 V3:22
perfluorohexane, 2000 V3:22
performance bonds, 2004 V1:62
performance criteria in specifications, 2004 V1:69, 88
Performance of Reduced-size Venting in Residential Drain, Waste and Vent System, 2005 V2:47
performance specifications, 2004 V1:66
performance tests. *See* testing
perimeter diking, 2000 V3:90
permeability
coefficient of (K factor), 2005 V2:166
converting to SI units, 2004 V1:40
permeable strata in soils, 2005 V2:149
permeance, converting to SI units, 2004 V1:40
permits
industrial wastewater, 2000 V3:87
RCRA hazardous waste, 2000 V3:89
Perry's Chemical Engineering Handbook, 2000 V3:97
persons with disabilities. *See* people with disabilities
pesticides in septic tanks, 2005 V2:156
"peta" prefix, 2004 V1:34
petroleum-based fuel systems. *See* diesel-oil systems; gasoline systems
petroleum products, 2000 V3:154
PEX-AL-PEX (cross-linked polyethylene/aluminum/cross-linked polyethylene), 2001 V4:61–62
PEX (cross-linked polyethylene), 2001 V4:61
PFCs (perfluorocarbons), 2000 V3:22
PG (pressure gauges with gauge cocks), 2004 V1:10
pH
acid wastes, 2005 V2:244–245
adjustments in pool water, 2000 V3:123
adjustments to waste, 2005 V2:238
alkalinity and, 2005 V2:199
boiler feed water, 2005 V2:226
control systems, 2000 V3:123
copper piping and, 2000 V3:145
in corrosion rates, 2004 V1:145
defined, 2004 V1:153
discharge from laboratories, 2000 V3:40
feed water for pure water systems, 2005 V2:231
industrial wastewater systems, 2000 V3:91–92
limits for sanitary drainage systems, 2000 V3:42
measuring, 2005 V2:202–203, 2000 V3:123
predicting water deposits, 2005 V2:206–208
saturation, 2005 V2:207
swimming pools, 2000 V3:147
testing in pools, 2000 V3:147
values in waste, 2005 V2:239
pH Control of Chemical Waste, 2005 V2:256
ph, PH (phases, electrical), 2004 V1:15
pharmaceutical facilities, 2000 V3:87
pharmaceutical pure water, 2005 V2:228–234, 2000 V3:46
Pharmaceutical Water, 2005 V2:234
pharmaceutical water pipe, 2001 V4:58
pharmacies
fixtures, 2000 V3:35
health-care facilities, 2000 V3:32
medical gas stations, 2000 V3:52
Phase 1 vapor recovery, 2000 V3:154, 163, 166, 168
Phase 2 vapor recovery, 2000 V3:154, 163, 168
phases, electrical (ph, PH), 2004 V1:15
PHCC-NA. *See* Plumbing-Heating-Cooling Contractors–National Association (PHCC-NA)
phenolics as thermoset, 2001 V4:58
phenolphthalein alkalinity, 2005 V2:199
Philadelphia systems, 2005 V2:18
phosphates, 2004 V1:151, 2005 V2:199
phosphoric acid, 2005 V2:199, 242
phosphorus, 2005 V2:199
phosphorus 32, 2005 V2:248
photographic badges for radiation levels, 2005 V2:247
photolytic oxidation, 2005 V2:204
photovoltaic water heaters, 2004 V1:265
physical characteristics of drinking water, 2005 V2:227, 228
physical therapy rooms, 2000 V3:32, 35
physically challenged people. *See* people with disabilities
physics laboratories, 2005 V2:182. *See also* laboratories
"pico" prefix, 2004 V1:34
pig lead, 2001 V4:48
pilot-operated gas regulators, 2000 V3:250, 251
pilot-operated makeup valves, 2000 V3:124
pilot-operated pressure-regulated valves, 2005 V2:78
pilot-valve discs, 2000 V3:9
pints, converting to SI units, 2004 V1:40
pipe anchors (PA), 2004 V1:10
pipe dope, 2005 V2:201
pipe friction pressure drop, 2005 V2:67
pipe glue, 2005 V2:201
pipe guides, 2004 V1:10
pipe hangers. *See* supports and hangers
pipe joints
acid-waste systems, 2005 V2:242
chemical-waste systems, 2005 V2:253
fill and, 2005 V2:14
heat-fused socket joints, 2005 V2:242
inspection, 2000 V3:80
material codes and standards, 2004 V1:43
natural gas systems, 2000 V3:254
pure-water systems, 2000 V3:47
radioactive waste systems, 2005 V2:249
restrainers, 2000 V3:228–229
sanitary, 2000 V3:48
screwed mechanical joints, 2005 V2:242
special-waste drainage systems, 2005 V2:238
thermal expansion and, 2005 V2:16
welded joints, 2005 V2:249
pipe nipple codes, 2004 V1:43
pipe shafts, 2000 V3:73
pipe sleeves
acoustic design, 2004 V1:201
earthquake recommendations, 2004 V1:162
pipe solvents, 2005 V2:201
pipe supports. *See* supports and hangers
pipe wrappings, 2004 V1:196, 201–202, 2005 V2:50
pipes and piping. *See also* sizing; *specific kinds of piping or piping functions*
bedding, 2000 V3:234, 235
calculating water capacity per foot, 2000 V3:12

cleaning and covering exposed ends, 2001 V4:25
codes and standards, 2004 V1:42–45
compressed air systems, 2000 V3:206–213
computer analysis of piping systems, 2004 V1:186
condensate drainage, 2000 V3:191–196
corrosive wastes, 2000 V3:40
cost estimation, 2004 V1:93
damage to pipes, 2001 V4:25
defined, 2000 V3:85
draining, 2001 V4:25
exposed piping on storage tanks, 2000 V3:165
fire-protection systems, 2000 V3:8, 23, 24
fountain display and filter systems, 2000 V3:111–112, 116–119
hazardous waste incompatibilities, 2000 V3:90, 91
heat loss and, 2000 V3:122
high-pressure piping, 2000 V3:196–197
installation requirements, 2001 V4:25
laboratory waste and vent piping, 2000 V3:42
leakage, 2004 V1:134
liquid fuel systems, 2000 V3:169–170
medical gas systems, 2000 V3:73–77
monitoring leakage, 2000 V3:162
natural gas, 2005 V2:129–130, 134–137, 138–141, 2000 V3:252–254
pipe schedules, 2000 V3:16, 18
piping symbols, 2004 V1:7–13
propane, 2005 V2:142, 143
pure-water systems, 2000 V3:47–48
roof drains and pipes, 2005 V2:50
roughness, 2005 V2:86
seismic protection, 2004 V1:155, 166–182
specifications, 2001 V4:25–26
sprinkler system pipes, 2000 V3:12, 15, 17
steam systems, 2000 V3:177, 195
storm sewers, 2000 V3:244–245, 246
sustainable design and, 2004 V1:264
swimming pools, 2000 V3:145
symbols (PIPE), 2004 V1:15
tightness testing, 2000 V3:172
types
  asbestos concrete, 2001 V4:26
  brass (copper alloy) pipe, 2005 V2:13, 2001 V4:27
  cast-iron soil pipe, 2001 V4:27–31
  chlorinated polyvinyl-chloride (CPVC), 2005 V2:201, 2000 V3:48, 2001 V4:59–60, 62
  concrete pipe. *See* concrete piping
  copper drainage tube, 2001 V4:45, 46
  copper pipe. *See* copper piping
  copper water tube, 2001 V4:34–44
  cross-linked polyethylene/aluminum/cross-linked polyethylene (PEX-AL-PEX), 2001 V4:61–62
  cross-linked polyethylene (PEX), 2001 V4:61–62
  ductile iron water and sewer pipe. *See* ductile iron piping
  glass pipe, 2005 V2:244, 249, 2001 V4:45–50
  gray cast-iron pressure pipe, 2001 V4:32
  lead piping, 2004 V1:266, 2005 V2:50, 83, 2001 V4:48–49
  medical gas tubing, 2000 V3:77, 81, 2001 V4:45
  plastic. *See* plastic piping
  polybutylene pipes, 2001 V4:58–60
  polyethylene/aluminum/polyethylene (PE-AL-PE), 2001 V4:62
  polyvinyl chloride (PVC), 2005 V2:50, 201, 2000 V3:116, 119, 145, 2001 V4:59–60, 62
  steel pipe. *See* steel piping
  vitrified clay piping, 2005 V2:83, 253, 2000 V3:245, 2001 V4:49, 56–57
  vacuum piping, 2005 V2:184
piping-arrangement steam classifications, 2000 V3:178–186
  one-pipe systems, 2000 V3:178–180
  traps, 2000 V3:182–186
  two-pipe systems, 2000 V3:180–182
Piping Handbook, 2005 V2:144
Piping Specifications and Installation Practices, 2000 V3:97
Piping Systems Fundamentals and Application, 2005 V2:104
piston reciprocating compressors, 2000 V3:201
piston-style water hammer arresters, 2005 V2:81, 82
pit-type fire-department connections, 2004 V1:12
pitch
  defined, 2004 V1:27
  pitch down or up, 2004 V1:11
  radioactive waste systems, 2005 V2:250
  special-waste drainage systems, 2005 V2:238
  vacuum cleaning systems, 2005 V2:195
pitless adapters, 2005 V2:166, 167
pitot pressure, 2000 V3:5, 7, 220
pitot tubes, 2000 V3:4, 217, 219
pitting, defined, 2004 V1:153
pitting corrosion, 2004 V1:141, 2005 V2:206, 2000 V3:190
PIV (post indicator valves), 2000 V3:228
PL (Public Laws). *See* Public Laws
places of worship, numbers of fixtures for, 2001 V4:19, 22
plain air chamvers, 2005 V2:81
plain-end steel pipe, 2001 V4:55
plane angles, 2004 V1:33, 36
plans. *See* construction contract documents; plumbing drawings
plant noise, 2004 V1:197–198
planting area drains, 2005 V2:55
plantings, types of, 2000 V3:104
plaster, lining with lead, 2005 V2:248
plaster traps, 2000 V3:36
plastic filtration tanks, 2000 V3:131
plastic fixtures
  standards, 2001 V4:2
  types of, 2001 V4:2
plastic piping
  bedding, 2000 V3:234, 235
  codes, 2004 V1:43
  compressed air systems, 2000 V3:210
  corrosion, 2005 V2:172
  fittings, 2001 V4:58
  fountain piping, 2000 V3:116
  fuel product dispensing and, 2000 V3:169
  gas piping, 2000 V3:253, 254
  joints, 2001 V4:59–60
  laboratory wastes, 2000 V3:42
  Manning formula and, 2000 V3:245

polyolefin piping, 2001 V4:61
roughness, 2005 V2:86
sanitary drainage systems, 2005 V2:13
storm-drainage systems, 2005 V2:50
types, 2001 V4:58–65
water hammer and, 2005 V2:80
plastic pumps, 2000 V3:115
plastic swimming pool main drains, 2000 V3:143
plastic valves, 2000 V3:145–146
plastic wraps on toilet seats, 2001 V4:5
plate and frame modules in reverse osmosis, 2005 V2:221, 222
plate tectonics, 2004 V1:156–158
platform diving, 2000 V3:128
platinum, 2004 V1:141
platinum cobalt units (PCUs), 2005 V2:204
Platinum-level LEED certification, 2004 V1:263
platy soils, 2005 V2:148
plot plans, irrigation systems and, 2005 V2:29
plug-type dezincification, 2004 V1:142
plug valves (PV), 2004 V1:9
plumbing
appliances, 2004 V1:27
appurtenances, 2004 V1:27
code agencies, 2004 V1:42
cost estimation, 2004 V1:93–98
defined, 2004 V1:27
designs, 2004 V1:100–102
fittings. *See* fittings
fixtures. *See* fixtures
plumbing systems defined, 2004 V1:27
specifications. *See* specifications
symbols, 2004 V1:7–13
terminology, 2004 V1:17–31
Plumbing and Drainage Institute (PDI), 2005 V2:104
abbreviation for, 2004 V1:27
address, 2004 V1:59
list of standards, 2004 V1:56–57
PDI symbols for water hammer arresters, 2005 V2:82
Plumbing and Piping Industry Council (PPIC), 2004 V1:170, 191
Plumbing Design and Installation Reference Guide, 2005 V2:64
Plumbing Design Manual, 2005 V2:64
plumbing drawings
abbreviations, 2004 V1:14–16
checklists, 2004 V1:100–102
costs analysis phase, 2004 V1:241
defined, 2004 V1:61
function evaluation, 2004 V1:239–240
functional development, 2004 V1:254, 255
graphic conventions, 2004 V1:108
introduction, 2004 V1:61
in specifications, 2004 V1:69
Plumbing Efficiency through Gray-water Recycling, 2005 V2:35
plumbing engineering, 2004 V1:27, 2000 V3:27–28
Plumbing-Heating-Cooling Contractors–National Association (PHCC-NA), 2004 V1:57, 59, 95, 2005 V2:47
plumbing inspectors, 2004 V1:27
Plumbing Manual, 2005 V2:104
Plumbing Noise, 2004 V1:194
Plumbing Product Efficiency Act, 2001 V4:3, 8, 10, 11
plumbing specifications. *See* specifications
PNC (preferred noise criteria curves), 2004 V1:206
pneumatic pressures, 2005 V2:2–3, 2000 V3:68
pneumatic tank gauging, 2000 V3:160
pneumatic valves, 2000 V3:119
POC (points of connection), 2004 V1:11
point-of-use filters, 2000 V3:203, 210
point-of-use ultrafiltration, 2005 V2:211
point-of-use water heating, 2004 V1:129, 2000 V3:45
points of connection (POC), 2004 V1:11
polar solvents, 2000 V3:21
polarization
defined, 2004 V1:153
hydrogen film buildup, 2004 V1:139
polishing deionizers, 2005 V2:215, 220
polishing water in pure water systems, 2005 V2:231
pollution
contamination in compressed air, 2000 V3:201
dilution, 2000 V3:87
filtering air pollution, 2000 V3:66
priority pollutants, 2000 V3:88
sanitary precautions for wells, 2005 V2:166–167
storm-drainage systems and, 2005 V2:49
polyamide membranes, 2005 V2:223
polybutylene (PB), 2004 V1:27, 2001 V4:59–60
polyelectrolytes, 2005 V2:209
polyester fixtures, 2001 V4:2
polyethylene/aluminum/polyethylene (PE-AL-PE), 2001 V4:62
Polyethylene Encasement, 2001 V4:32
polyethylene (PE), 2004 V1:27, 2005 V2:92, 201, 2000 V3:254, 2001 V4:58–61
polyethylene storage tanks, 2005 V2:233
polymer membranes, 2005 V2:223
polymeric silica, 2005 V2:200
polymers, 2004 V1:27
polyolefin piping, 2001 V4:61
polypropylene piping
laboratories, 2005 V2:242, 2000 V3:40
pipe characteristics, 2001 V4:59–60
pure-water systems, 2000 V3:48
soil and waste piping, 2005 V2:13
sulfuric acid and, 2000 V3:92
USP water, 2005 V2:233
VOCs and, 2005 V2:201
water hammer and, 2005 V2:80
polypropylene storage tanks, 2005 V2:233, 2000 V3:91
polysulfone membranes, 2005 V2:223
polytropic processes, 2000 V3:200
polyvinyl chloride (PVC), 2005 V2:67
aboveground piping, 2005 V2:50
defined, 2004 V1:28
fixtures, 2001 V4:2
fountain piping, 2000 V3:116, 119
noise, 2005 V2:14
pipe characteristics, 2001 V4:59–60
piping, 2005 V2:201
pure-water systems, 2000 V3:48
sand filtration tanks, 2000 V3:131
sanitary drainage, 2005 V2:13

shower pans, 2001 V4:15
skimmers, 2000 V3:146
storage tanks and hazardous wastes, 2000 V3:91
sulfuric acid and, 2000 V3:92
sunlight and, 2000 V3:116
swimming pool piping, 2000 V3:145
types of piping, 2001 V4:62
volatile organic compounds, 2005 V2:201
weirs, 2000 V3:146
polyvinyl-fluoridine (PVDF), 2004 V1:28
polyvinylidene fluoride piping, 2005 V2:233, 2000 V3:48
ponding
on roofs, 2005 V2:53
storm water ponds, 2005 V2:49
ponds, stabilization, 2005 V2:157
Pool/Spa Operators Handbook, 2000 V3:125
pools, 2004 V1:27. *See also* reflecting pools; swimming pools
"poor value," defined, 2004 V1:213
pop-up sprinkler heads, 2000 V3:101, 102
population density, 2005 V2:109
porcelain enameled steel fixtures
defined, 2001 V4:2
standards, 2001 V4:2
pore size in filter membranes, 2005 V2:223
porous soils, 2000 V3:99–100
portable fire extinguishers, 2004 V1:13, 2000 V3:27
portable vacuum systems, 2000 V3:144
positive attachments, defined, 2004 V1:191
positive-displacement air compressors, 2000 V3:65, 201
positive-displacement meters, 2005 V2:68, 95, 96
post indicator valves (PIV), 2000 V3:228
pot and pan sinks, 2000 V3:36
potable water. *See* drinking water; private water systems; wells
potash alum, 2005 V2:209
potassium, 2005 V2:199, 200
potassium bicarbonate, 2005 V2:200
potassium carbonate, 2005 V2:200, 2000 V3:207
potassium chloride, 2005 V2:200
potassium hydroxide, 2005 V2:156
potassium permanganate, 2005 V2:168
potential energy (PE)
calculating, 2004 V1:2
velocity head and, 2004 V1:5
potentiometric surfaces of aquifers, 2005 V2:165
POTW (Publicly Owned Treatment Works), 2000 V3:89
POU filtration, 2005 V2:211
pounding forces in water. *See* water hammer
pounds (lb, LBS)
converting to SI units, 2004 V1:40
pounds per square foot (psf, PSF), 2004 V1:15
pounds per square inch (psi, PSI), 2004 V1:2, 15, 2000 V3:29, 180, 200
pounds per square inch absolute (psia), 2004 V1:15, 2005 V2:176, 2000 V3:85, 200
pounds per square inch gauge (psig), 2004 V1:15, 2005 V2:176, 2000 V3:68, 85, 200
symbols for, 2004 V1:15
power
conversion factors, 2004 V1:36
converting to SI units, 2004 V1:39
measurements, 2004 V1:33
power company off-peak power savings, 2004 V1:128–129
power steam, 2005 V2:210
power usage, economizing on, 2004 V1:128–129
Powered Industrial Trucks, 2005 V2:144
powered vaporizers, 2000 V3:61
POWTS. *See* private onsite wastewater treatment systems
PP. *See* polypropylene piping
PPIC (Plumbing and Piping Industry Council), 2004 V1:170, 191
ppm, PPM (parts per million), 2004 V1:15, 2005 V2:201, 2000 V3:46
Practical Design of a High-purity Water System, 2005 V2:234
Practical Plumbing Design Guide, 2005 V2:64
pre-action systems, 2004 V1:29, 2000 V3:13, 15, 25
pre-action valves, 2004 V1:13
pre-bid information, 2004 V1:62
pre-cast concrete pipe, 2001 V4:32
pre-cast manholes, 2000 V3:234, 237
pre-cast water storage tanks, 2005 V2:170
pre-coat cakes in filtration, 2000 V3:134
pre-compressed, glass-fiber pads, 2004 V1:204
pre-engineered cathodically protected steel tanks, 2000 V3:155, 156
pre-engineered dry-chemical systems, 2000 V3:19
pre-engineered fountains, 2000 V3:107
pre-fabricated shower bases, 2001 V4:15
pre-fabricated shower enclosures, 2001 V4:15
pre-fabricated water storage tanks, 2005 V2:170
pre-heating input water, 2004 V1:266
pre-manufactured skimmers, 2000 V3:137
pre-treatment in pure water systems, 2005 V2:231
pre-treatment ordinances, 2000 V3:89
precipitates in water, 2005 V2:168, 207
precipitation. *See* rainwater and precipitation
precision in measurements, 2004 V1:32
predicting water deposits and corrosion, 2005 V2:206–208
preferred noise criteria (PNC) curves, 2004 V1:206
prefilters
air compressors, 2000 V3:203
feed water, 2005 V2:205
prefixes in SI units, 2004 V1:34
premium grade PVC piping, 2000 V3:48
preparation
checklists, 2004 V1:99
in plumbing cost estimation, 2004 V1:93
section in specifications, 2004 V1:91
in value engineering presentations, 2004 V1:258
Preparation phase in value engineering, 2004 V1:213
preparing for jobs, checklists, 2004 V1:99
PRES (pressure). *See* pressure
Presentation phase in value engineering, 2004 V1:213, 257–258, 259
President's Committee on Employment of the Handicapped, 2004 V1:105
press joints, 2004 V1:266
PRESS (pressure). *See* pressure
pressure (PRESS, PRES, P). *See also* pressure drops or differences
acoustic design for water pipes, 2004 V1:195–196
air-consuming devices, 2000 V3:206–207

barometric. *See* barometric pressure
booster pump systems, 2005 V2:70–77
carbon dioxide extinguishing systems, 2000 V3:20
compressed air, 2000 V3:200, 203, 207
conversion factors, 2004 V1:36
critical (CRIP), 2004 V1:15
domestic water supply, 2000 V3:217–221
dynamic (velocity) (vp, VP), 2004 V1:15
examples for pipe sizing, 2005 V2:97–99
expansion tanks, 2005 V2:76–77
fire pumps, 2000 V3:25
fixture requirements, 2005 V2:98
flow and air, 2005 V2:2
fluctuation warnings, 2000 V3:72
fountains, 2000 V3:118
friction head, 2004 V1:2, 6, 2005 V2:71
friction loss and, 2004 V1:2, 2005 V2:98
gas boosters, 2005 V2:130–131
gravity tank systems, 2005 V2:76
heavy flow drains, 2005 V2:8
hot-water system pressures, 2005 V2:107
hydraulic shock, 2004 V1:6
hydrostatic pressure, 2005 V2:4
induced siphonage, 2005 V2:47
interstitial tank monitoring, 2000 V3:161
measurements, 2004 V1:33, 2005 V2:4, 95, 175–177
natural gas, 2005 V2:126–127
natural gas pressure, 2000 V3:249, 252–253
natural gas systems, 2005 V2:128, 136, 138–141
nitrogen surgical instruments, 2000 V3:59
nitrous oxide, 2000 V3:64
nozzle pressure flow tables, 2000 V3:4
plastic piping systems, 2000 V3:48
pneumatic pressures in sanitary drains, 2005 V2:2–3
pressure-regulating valves, 2005 V2:78–79
pressure sensors, 2005 V2:72
pressure-volume relationships (gas laws), 2005 V2:131
pressure waves. *See* water hammer
pump affinity laws, 2004 V1:6
pump head, 2005 V2:71
relative discharge curves, 2000 V3:220
relief valves, 2005 V2:115–116, 116
sizing pipes and, 2005 V2:92–96
soil pressures, 2000 V3:155
sprinkler systems, 2000 V3:3, 17, 18
stack flow capacity and, 2005 V2:4
static (sp, SP), 2004 V1:15, 16
storm-drainage stacks, 2005 V2:52
submersible fuel pumps, 2000 V3:170
suds pressure zones, 2005 V2:45–46
swimming pool pumps, 2000 V3:140
symbols for, 2004 V1:15
tests
  fountain piping systems, 2000 V3:117
  medical gas systems, 2000 V3:80, 82
  storage tanks, 2000 V3:171
  water flow tests, 2005 V2:95
vacuum cleaning system requirements, 2005 V2:190
vacuum defined, 2005 V2:175
vacuum pressure measurement, 2005 V2:176–178
vapor (vap pr, VAP PR, VAP), 2004 V1:15
velocity head (h), 2004 V1:5
velocity of water in pipes and, 2005 V2:86, 92
water hammer and, 2005 V2:80
water mains, 2000 V3:216
water meters and, 2005 V2:96
water vapor in air and, 2000 V3:200–201
pressure-assist water closets, 2004 V1:136
pressure-balancing fixtures. *See* pressure-regulating or reducing valves (PRV)
pressure diatomaceous earth filtration, 2000 V3:132, 135, 139, 141
pressure differentials
condensate drainage, 2000 V3:191–193
fittings, 2004 V1:194
steam systems, 2000 V3:191
pressure drops or differences (PD, DELTP)
air filtration and, 2000 V3:207
backflow preventers and, 2000 V3:224
calculating, 2004 V1:2
compressed air systems, 2000 V3:78, 207, 210, 211, 212
defined, 2005 V2:144
double-check valves and, 2000 V3:224
examples for pipe sizing, 2005 V2:97–99
filter pumps, 2000 V3:115
fittings, 2000 V3:221
fountains, 2000 V3:118
fuel system checklist, 2000 V3:171
gas boosters, 2005 V2:133
gas line filters and, 2000 V3:250
installing taps, 2000 V3:221
measuring in water flow tests, 2005 V2:95
medical air, 2000 V3:74
medical gas, 2000 V3:73
natural gas systems, 2005 V2:128
piping runs, 2000 V3:221
sanitary drainage, 2005 V2:2
sprinkler hydraulic calculations, 2000 V3:18
strainers and, 2000 V3:224
swimming pool pumps, 2000 V3:140
symbols for, 2004 V1:15
vacuum cleaning systems, 2005 V2:191–193, 193–194
vacuum exhauster sizing, 2005 V2:193–194
vacuum piping, 2005 V2:184–186
vacuum pressures, 2005 V2:179, 184–186
valves and fittings, 2005 V2:99–102, 2000 V3:221
water meters, 2005 V2:95, 2000 V3:224
pressure gauges
with gauge cocks (PG), 2004 V1:10
measurements, 2005 V2:176
swimming pools, 2000 V3:140, 144
pressure loss. *See* pressure drops
pressure maintenance (jockey) pumps, 2004 V1:24
pressure media filters, 2005 V2:211
pressure piping
asbestos concrete, 2001 V4:26
glass pipe, 2001 V4:45
pressure-powered pumps, 2000 V3:188
pressure product-dispensing systems, 2000 V3:163–164
pressure-regulating or reducing valves (PRV), 2005 V2:67
acoustic design and pressure, 2004 V1:200
fountains, 2000 V3:119, 120
health-care water supplies, 2000 V3:44
irrigation systems, 2000 V3:103

natural gas systems, 2005 V2:127
shower valves, 2005 V2:71–72, 2001 V4:15
steam systems, 2000 V3:191, 195
symbols for, 2004 V1:9
tank size and, 2005 V2:74
tub valves, 2001 V4:16
types of, 2005 V2:78–79
Pressure Regulating Values for LPG, 2005 V2:127
pressure regulators
compressed air systems, 2000 V3:207
deluge valves, 2000 V3:14, 15
flushometer tanks, 2001 V4:8
natural gas systems, 2000 V3:250–252
water storage tanks, 2005 V2:171–172
pressure-relief valves (RV), 2004 V1:10
pressure sand filters, 2000 V3:112, 113, 132–133, 134, 139
Pressure Sewer Demonstration at the Borough of Phoenixville, Pennsylvania, 2005 V2:161
pressure sewers, 2005 V2:152
pressure swing air dryers, 2000 V3:207
pressure switches (PS), 2004 V1:10, 2000 V3:121
pressure tanks, 2000 V3:153
pressure-volume relationships (gas laws), 2005 V2:131
pressure water filters, 2005 V2:167
pressure waves. *See* water hammer
pressurized fuel delivery systems, 2000 V3:162, 170
pressurized steam return lines, 2000 V3:196
pri, PRI (primary), 2004 V1:15
prices, 2004 V1:222. *See also* costs and economic concerns
PRIM (primary), 2004 V1:15
primary (pri, PRI, PRIM), 2004 V1:15
primary barriers for infectious wastes, 2005 V2:251
primary tanks
aboveground types, 2000 V3:165, 167
construction, 2000 V3:156
interstitial monitoring, 2000 V3:160–161
underground tanks, 2000 V3:155
prime costs, 2004 V1:222
primers, 2004 V1:147
priming in dry-pipe systems, 2000 V3:12
priority pollutants, 2000 V3:88
prism-like soils, 2005 V2:148
prisons, numbers of fixtures for, 2001 V4:20, 22
privacy, urinals and, 2001 V4:9, 10
private onsite wastewater treatment systems (POWTS)
aerobic wastewater treatment plants, 2005 V2:157
collection and treatment alternatives, 2005 V2:152–153
defined, 2004 V1:27
distribution boxes, 2005 V2:156
estimating sewage quantities, 2005 V2:158–160
inspection, 2005 V2:160–161
introduction, 2005 V2:147
large systems, 2005 V2:156–157
primary collection and treatment systems, 2005 V2:147
private sewers, 2004 V1:27
septic tanks, 2005 V2:153–156
soil-absorption systems, 2005 V2:147–151
private use
defined, 2004 V1:27
lavatories, 2001 V4:10
private water systems
codes and standards, 2005 V2:163
drinking water demand, 2005 V2:167
initial operation and maintenance, 2005 V2:172
introduction, 2005 V2:163–164
matching water storage to pump flow, 2005 V2:170–171
performance specifications, 2005 V2:172
sources of supply, 2005 V2:163–164
system equipment, 2005 V2:168–172
water quality, 2005 V2:167–168
wells, 2005 V2:164–167
problems
in condensate drainage, 2000 V3:189–191
in seismic protection, 2004 V1:188–191, 189
Proceedings of the Third National Conference on Individual On Site Wastewater Systems, 2005 V2:161
process steam systems, 2000 V3:175
Procurement and Contracting Requirements Group, 2004 V1:65, 77
producer costs, 2004 V1:222
producer gas, 2005 V2:126
producers (vacuum)
defined, 2005 V2:188
locating, 2005 V2:190
sizing, 2005 V2:193–194
product costs, 2004 V1:222, 223
product dispensing systems
aboveground tank systems, 2000 V3:168
underground tank systems, 2000 V3:163–165
dispenser pans, 2000 V3:165
pressure dispensing, 2000 V3:164
product dispensers, 2000 V3:164–165
product level gauging, 2000 V3:167, 168
product standards, 2004 V1:66
product substitutions, 2004 V1:68
product water. *See* treated water
production wells in geothermal energy, 2004 V1:131
productivity rates, in cost estimation, 2004 V1:95–97
products
costs, 2004 V1:222, 223
detail/product/material specification checklist, 2004 V1:220
green building, 2004 V1:264–265
section in specifications, 2004 V1:69, 90–91
in specifications, 2004 V1:70
value engineering questions, 2004 V1:213–214
Professional Qualifications Standard for Medical Gas Systems Installers, Inspectors, Verifiers, Maintenance Personnel and Instructors, 2001 V4:45
profit markup in cost determinations, 2004 V1:222
programmers, irrigation systems, 2000 V3:105
project conditions section in specifications, 2004 V1:70, 90
project costs, 2004 V1:222
project manuals
contents of, 2004 V1:62–63
defined, 2004 V1:61
promenade drains, 2005 V2:55
propagation velocity, 2004 V1:6
propane, 2005 V2:126. *See also* fuel-gas piping systems
laboratory use, 2005 V2:128–129
physical properties, 2005 V2:125
sizing systems, 2005 V2:142, 143

propeller water meters, 2005 V2:68
property protection in fire protection, 2000 V3:1
prophylactic additives to water, 2005 V2:168
proportional solubility law, 2005 V2:81
proportions of septic tanks, 2005 V2:154
proprietary names in specifications, 2004 V1:66, 67
proprietary specifications, 2004 V1:67–68
propylene, 2005 V2:126
protected end of galvanic series, 2004 V1:141
protecting storage tanks, 2000 V3:169
protection
  section in specifications, 2004 V1:92
  value engineering contract document clauses, 2004 V1:258, 260
protective coatings, 2004 V1:147. *See also* coated metal
protective potential, defined, 2004 V1:153
protein-mixed chemical concentrates, 2000 V3:21
PRV (pressure-regulating or reducing valves). *See* pressure-regulating or reducing valves
prying actions in seismic protection, 2004 V1:188
PS (pressure switches), 2004 V1:10
pseudo-dynamic elastic analysis, 2004 V1:161
Pseudo Value Engineers, 2004 V1:258
psf, PSF (pounds per square foot)
  psf absolute (psfa, PSFA), 2004 V1:15
  psf gage (psfg, PSFG), 2004 V1:15
  symbols for, 2004 V1:15
psfa, PSFA (psf absolute), 2004 V1:15
psfg, PSFG (psf gage), 2004 V1:15
psi, PSI (pounds per square inch)
  cast iron radiators, 2000 V3:180
  converting to metric units, 2000 V3:29
  measurements, 2000 V3:200
  psi absolute (psia, PSIA), 2004 V1:15, 2005 V2:176, 2000 V3:85, 200
  psi gage (psig, PSIG), 2004 V1:15, 2005 V2:176, 2000 V3:68, 85, 200
  symbols for, 2004 V1:15
psia, PSIA (psi absolute), 2004 V1:15, 2005 V2:176, 2000 V3:85, 200
psig, PSIG (psi gage), 2004 V1:15, 2005 V2:176, 2000 V3:68, 85, 200
public, educating on gray-water systems, 2005 V2:35
public areas
  estimating sewage quantities, 2005 V2:159
  fixtures for, 2000 V3:33–34
  heel-proof grates, 2005 V2:10
  sediment buckets, 2005 V2:11
Public Building Service, 2004 V1:199
public facilities, numbers of fixtures for, 2001 V4:21
public hydrants, 2004 V1:12
Public Law 90-480, 2004 V1:106
Public Law 93-112, 2004 V1:106
Public Law 98, 2000 V3:154
Public Law 616, 2000 V3:154
public sewers
  availability of, 2000 V3:234
  defined, 2004 V1:27
  discharging into, 2005 V2:238
  neutralizing acid wastes for, 2005 V2:244–245
  public storm sewer systems, 2005 V2:49, 2000 V3:245–247
  radioactive waste systems and, 2005 V2:250
public swimming pools. *See* swimming pools
public use
  defined, 2004 V1:28
  lavatories, 2001 V4:10
public utilities, 2005 V2:125
Publicly Owned Treatment Works (POTW), 2000 V3:89
pubs, 2001 V4:19, 22
puddle flanges, 2000 V3:116
pull-out spray accessories, 2001 V4:12, 14
pulsation
  air compressors, 2000 V3:212
  electric fans, 2004 V1:196
  magnetic field pulsation, 2004 V1:196
pump discharge lines (PD), 2004 V1:8
pumper connections, 2004 V1:12
pumping
  septic tanks, 2005 V2:153
  wells, 2005 V2:165–166
pumping head, 2005 V2:169
pumps
  acoustics, 2004 V1:196–197, 196–198, 198, 200–201
  automatic shutdown, 2000 V3:90
  bases, 2005 V2:166, 169
  bearings, 2004 V1:197
  boiler feed pumps, 2000 V3:188–189
  booster pump systems, 2005 V2:70–77
  cavitation, 2000 V3:112
  circulating pump efficiency, 2004 V1:265
  condensate transfer pumps, 2000 V3:188
  cooling vacuum pumps, 2005 V2:181
  design of, 2004 V1:200
  earthquake protection, 2004 V1:164
  efficiency, 2004 V1:6–7
  ejector pumps, 2000 V3:236
  fire pumps, 2000 V3:25–26
  fountains, 2000 V3:108, 112, 120, 125
  geothermal energy systems, 2004 V1:131
  gravity tank systems, 2005 V2:74–76
  gray water use, 2004 V1:267
  house pumps, 2005 V2:74, 76
  hydropneumatic-tank systems, 2005 V2:72, 73–74
  impellers, 2004 V1:197
  liquid fuel systems, 2000 V3:170
  liquid-waste decontamination systems, 2005 V2:251
  matching water storage to pump flow, 2005 V2:170–171
  motor controls, 2005 V2:73
  multiple pump systems, 2005 V2:72–73
  plant noise, 2004 V1:197–198
  pulsation in, 2004 V1:197
  pump affinity laws, 2004 V1:6
  pump journals, 2004 V1:196
  pump speeds, 2004 V1:200–201
  purging vacuum pumps, 2005 V2:182
  secondary containment areas, 2000 V3:90
  starter controls, 2000 V3:120
  static deflection for vibration, 2004 V1:205
  storm drainage backup systems, 2005 V2:49
  strainers and suction screens, 2000 V3:116
  submersible, 2005 V2:166, 2000 V3:170, 2000 V3:170
  sulfuric acid and, 2005 V2:241
  sump pumps in sanitary drainage systems, 2005 V2:8

swimming pools, 2000 V3:129, 139, 140–142, 145–146
systems for water supplies, 2005 V2:168–170
timers, 2005 V2:73
vacuum pumps, 2000 V3:189
vibration isolation, 2004 V1:205, 206
well pumps, 2005 V2:168–170
Pumps and Pump Systems, 2004 V1:40
purchasers in cost equation, 2004 V1:223
pure tones, 2004 V1:208
pure-water systems. *See also* water purification
defined, 2005 V2:197
health-care facilities, 2000 V3:43, 46–48
piping materials, 2000 V3:47–48
types of pure water, 2000 V3:46
purging
medical gas zones, 2000 V3:72, 80, 81–82
natural gas systems, 2000 V3:252
vacuum pumps, 2005 V2:182
purified water (PW), 2005 V2:81, 82, 229–230, 2001 V4:47. *See also* pure-water systems; water purification
purity
compressed air, 2000 V3:207
testing medical gas systems, 2000 V3:82
push-on joints, 2000 V3:228–229
push-seal gasketed drains, 2005 V2:13
push-seal gasketed outlets, 2005 V2:13
putrefaction, 2004 V1:28
Putting Industrial Vacuum to Work, 2005 V2:196
puzzles
Nine Dots exercise, 2004 V1:232, 261
Six Sticks exercise, 2004 V1:232, 261
PV (plug valves), 2004 V1:9
PVC. *See* polyvinyl chloride (PVC)
PVC (polyvinyl chloride), 2005 V2:67, 80, 92
PVDF (polyvinyl-fluoridine), 2004 V1:28, 2005 V2:13, 80, 2000 V3:48
PVE (Pseudo Value Engineers), 2004 V1:258
PW (pure water), 2005 V2:229–230. *See also* pure-water systems; water purification
pyramids, calculating volume, 2004 V1:4
pyrogens, 2005 V2:198, 223, 2000 V3:46

Q

Q (heat transfer), 2004 V1:15
QAIR (air flow rates), 2004 V1:14
QAR (air flow rates), 2004 V1:14
QFL (fluid flow rates), 2004 V1:14
QGA, QGAS (gas flow rates), 2004 V1:14
qt, QT (quarts), 2004 V1:15, 40
quads, converting to SI units, 2004 V1:40
quality
in cost estimation, 2004 V1:98
quality assurance in specifications, 2004 V1:69–70, 89
quality control section in specifications, 2004 V1:71, 91
of water, 2005 V2:35, 167–168. *See also* water analysis; water purification
quantities. *See also* demand
clean gas agents, 2000 V3:23
in creativity checklist, 2004 V1:234
irrigation water, 2000 V3:99
water supplies, 2000 V3:3–8
quarter-circle rotary sprinkler heads, 2000 V3:102
quarts (qt, QT)
converting to SI units, 2004 V1:40
symbols for, 2004 V1:15
questions in value engineering presentations, 2004 V1:258
quick-coupling method of irrigation, 2000 V3:100, 101
quick-disconnect couplings, 2000 V3:210
quick-opening devices, 2000 V3:13
quick-response sprinklers, 2004 V1:29
quick valve closure, 2005 V2:80
quieting pipes, 2005 V2:14

R

R (hydraulic radii), 2004 V1:1
R, R- (refrigerants), 2004 V1:15, 151
°R, R (rankines), 2004 V1:15
R, R (thermal resistance), 2004 V1:16
R (radii), 2004 V1:15
R-13 and R-13A fire-protection systems, 2001 V4:58
R-595 gas, 2000 V3:22
ra, RA (return air), 2004 V1:15
Rack Storage of Materials (NFPA 231C), 2000 V3:2, 29
rad, RAD (radians). *See* radians
RAD (radiating or radiators), 2004 V1:15
RAD (radiation). *See* radiation
rad/s (radians per second), 2004 V1:33
rad/s^2 (radians per second squared), 2004 V1:33
radians (RAD)
measurement unit conversions, 2004 V1:33
radians per second, 2004 V1:33
radians per second squared, 2004 V1:33
symbols for, 2004 V1:15
radiant heating in swimming pools, 2000 V3:138, 146
radiating (RAD), 2004 V1:15
radiation (RADN, RAD)
heat loss and, 2000 V3:121
nature of, 2005 V2:246–247
radiation equivalent to man (rem), 2005 V2:247
rads (radioactive dosage), 2005 V2:247
symbols for, 2004 V1:15
treatment facilities, 2005 V2:248
radiators (RAD), 2004 V1:15, 2000 V3:178, 181, 184
radicals (ions), 2004 V1:144, 153, 2005 V2:239
radii (R), 2004 V1:15
radioactive waste drainage and vents
allowable radiation levels, 2005 V2:247
approval process and applications, 2005 V2:248
diluting radwaste, 2005 V2:250
introduction, 2005 V2:245
measuring radiation, 2005 V2:247
nature of radiation, 2005 V2:246–247
pipe selection, 2005 V2:249
radioactive materials, 2005 V2:248
shielding systems, 2005 V2:247–248
system design criteria, 2005 V2:248–250
radioactivity
defined, 2005 V2:245–246
radioactive half lives, 2005 V2:248
radioactive isotopes, 2005 V2:245–246, 248
radiological characteristics of drinking water, 2005 V2:200, 228
Radiological Safety Officers, 2005 V2:248
radium 226, 2005 V2:248

radius screwed ells, 2005 V2:101
RADN (radiation). *See* radiation
radon gas, 2005 V2:168, 200, 228
radwaste (waterborne radioactive waste), 2005 V2:245
Rainbird Company, 2000 V3:105
rainwater and precipitation
  capturing rainwater, 2004 V1:135, 264, 267
  cisterns, 2005 V2:170
  duration, 2000 V3:244
  flow rates, 2005 V2:56
  imperviousness factor, 2000 V3:242–243
  inlet times, 2000 V3:244
  intensity-duration-frequency curves, 2000 V3:242, 243
  precipitation, 2004 V1:27
  rainfall rates, 2005 V2:53–57, 2000 V3:242, 243
  rainwater drains (SD, ST). *See* storm-drainage systems
  return periods, 2000 V3:243–244
  storing in controlled flow systems, 2005 V2:52–53
  storm-drainage systems, 2005 V2:49–50
  swimming pools and, 2000 V3:139
raised-floor areas, 2000 V3:23
ramp-drain grates, 2005 V2:11
rankines (°R, R), 2004 V1:15
ranking functions in value engineering, 2004 V1:243
rapid sand/direct filtration package plants, 2005 V2:228
rate of corrosion
  acidity, 2004 V1:145
  Faraday's Law, 2004 V1:144
  film formation, 2004 V1:145
  homogeneity in, 2004 V1:145
  oxygen content, 2004 V1:145
  temperature, 2004 V1:145
  velocity in, 2004 V1:145
rate of flow. *See* flow rates
rate of temperature rise detection, 2000 V3:13
rated vacuum levels, 2005 V2:178–179
ratings for portable fire extinguishers, 2000 V3:27
Rational Method, 2004 V1:7, 2000 V3:242–244
raw sewage, 2004 V1:28
raw water, 2005 V2:197, 230
RCIR (recirculate), 2004 V1:15
RCP (reinforced concrete pipe), 2001 V4:32
RCRA (Resource Conservation and Recovery Act), 2005 V2:252, 2000 V3:87–88, 2000 V3:89–90, 154
rcvr, RCVR (receivers), 2004 V1:15, 199, 2005 V2:180–181, 182
re-evaporation, 2000 V3:197
re-flashing, 2000 V3:20
reaction forces in earthquakes, 2004 V1:186
reactive silencers, 2000 V3:202
reactive silica, 2005 V2:200
reagent grade water, 2005 V2:229–230
real costs, 2004 V1:223
rear wall grab bars, 2004 V1:114
reasoning against value engineering, 2004 V1:232
REC (receivers), 2004 V1:15, 199, 2005 V2:180–181, 182
receiver tanks
  medical air compressors, 2000 V3:66
  vacuum systems, 2000 V3:70
receivers (rcvr, RCVR, REC)
  receivers of noise, 2004 V1:199
  symbols for, 2004 V1:15
  in vacuum systems, 2005 V2:180–181, 182
receiving costs, 2004 V1:223
receptors, 2004 V1:28
recessed-box hose bibbs, 2004 V1:10
recessed sprinklers, 2004 V1:29
recharge basins, 2000 V3:247
rechargeable air chambers, 2005 V2:81
recharging aquifers, 2005 V2:163–164
rechlorination treatments, 2005 V2:122
reciprocating air compressors, 2000 V3:65, 66, 201, 205
reciprocating (rotary) piston pumps, 2005 V2:180
recirculate (recirc., RECIRC, RCIR, RECIR), 2004 V1:15
recirculating hot-water systems, 2004 V1:265, 2005 V2:118
recirculating sand filter sewage systems, 2005 V2:153
recirculation rates
  gutters and, 2000 V3:142
  swimming pools, 2000 V3:140
recirculation systems
  for high purity water, 2000 V3:47
  for hot water, 2005 V2:115
reclaimed water. *See* gray-water systems
Recommendation phase in value engineering, 2004 V1:213
  pre-recommendation questions, 2004 V1:254–257
Recommendations for a New ADAAG, 2004 V1:123
Recommended Minimum Requirements for Plumbing in Dwellings and Similar Buildings, 2005 V2:48
Recommended Practice for Handling Releases of Flammable and Combustible Liquids and Gases (NFPA 329), 2000 V3:154
recovered energy, 2004 V1:137
recovering heat from water heaters, 2005 V2:110
recovery in reverse osmosis, 2005 V2:221
recovery rooms
  fixtures, 2000 V3:36
  health-care facilities, 2000 V3:32
  medical gas stations, 2000 V3:52, 58
  medical vacuum, 2000 V3:54
recreational establishments
  estimating sewage quantities, 2005 V2:159
  septic tank/soil-absorption systems for, 2005 V2:156–157
recreational pools, 2000 V3:128
rectangles, calculating area, 2004 V1:3
rectangular bath seats, 2004 V1:122
rectangular gutters, 2005 V2:63
rectangular leaders, 2005 V2:63
rectangular solids, calculating volume, 2004 V1:4
rectifiers, 2004 V1:150, 151
recycled water in landscaping, 2004 V1:264
recycled water systems. *See* gray-water systems
red brass, 2004 V1:144
red brass piping, 2001 V4:27
red water in pools, 2000 V3:147
reduced noise transmission, 2005 V2:14
reduced pressure
  conditions in water storage tanks, 2005 V2:171
  in pressure-regulated valves, 2005 V2:67
  reduced-pressure backflow preventers, 2005 V2:68
  reduced pressure zones (RPZ), 2005 V2:68, 70, 2000 V3:223, 226
reduced-size venting

reduced size vents, defined, 2004 V1:28
sanitary drainage systems, 2005 V2:18–19
Reduced-size Venting Design, 2005 V2:47
reduced water-flow rates, 2004 V1:126–127
reduced zone backflow preventers (RZBP), 2004 V1:10
reducers, defined, 2004 V1:28
reducing bushings, 2005 V2:100
redundancy
fountain pumps, 2000 V3:115
hazardous waste systems, 2000 V3:90
reference standard specifications, 2004 V1:66–67
references
cold water systems, 2005 V2:104
compressed air systems, 2000 V3:214
conserving energy, 2004 V1:137
designing for people with disabilities, 2004 V1:123
fire-protection systems, 2000 V3:29
formulae, symbols, and terminology, 2004 V1:40
gasoline and diesel-oil systems, 2000 V3:173
gray-water systems, 2005 V2:35–36
health-care facilities, 2000 V3:86
irrigation systems, 2000 V3:105
reflecting pools and fountains, 2000 V3:125–126
sanitary drainage systems, 2005 V2:19
seismic protection, 2004 V1:191
special-waste drainage systems, 2005 V2:256
steam and condensate systems, 2000 V3:197
swimming pools, 2000 V3:151
vacuum systems, 2005 V2:196
vents, 2005 V2:47–48
water treatment and purification, 2005 V2:234
references section in specifications, 2004 V1:69, 88
reflecting pools
controls, 2000 V3:120–121
defined, 2004 V1:28
design, 2000 V3:107–111
discharge devices, 2000 V3:119–120
displays, 2000 V3:108–110, 111, 113–115
filtration systems, 2000 V3:112–113, 115–116
flow rates, 2000 V3:108–110
inlets, outlets, and devices, 2000 V3:110–111
lighting, 2000 V3:112, 121
makeup-water systems, 2000 V3:112, 124–125
multilevel pools, 2000 V3:108
overflow and drainage, 2000 V3:112, 125
overview, 2000 V3:107
piping and valves, 2000 V3:111–112, 116–119
pumps, 2000 V3:113–116
references, 2000 V3:125–126
systems and components, 2000 V3:111–112
valves, 2000 V3:118–119
water-heating system, 2000 V3:112, 121–122
water-treatment systems, 2000 V3:112, 122–124
reformatories, numbers of fixtures for, 2001 V4:20
refrigerant after-coolers, 2000 V3:203
refrigerants (R, R-), 2004 V1:15, 151
refrigerated air dryers, 2000 V3:204, 207
refrigeration mechanical rooms, 2004 V1:166
refrigeration piping, 2001 V4:34, 36
refrigeration systems
heat reclamation, 2004 V1:131
waste heat usage, 2004 V1:131, 132
refuse bins, 2004 V1:196
refuse disposal installations, soundproofing, 2004 V1:196
regenerable ion exchange, 2005 V2:215
regenerants, dealkalizing and, 2005 V2:209–210
regeneration cycle
in dealkalizing, 2005 V2:209–210
in deionizing, 2005 V2:216–219, 217
in demineralizers, 2000 V3:46
in ion exchange, 2005 V2:218–219
in water softeners, 2005 V2:220
regional authorities, 2005 V2:237
registers in fuel dispensers, 2000 V3:165
regulated substances, 2000 V3:153
regulations. *See* codes and standards
regulator relief vents, 2005 V2:129
regulators. *See specific types of regulators*
Rehabilitation Act of 1973 (93-112), 2004 V1:106
reinforced concrete pipe (RCP), 2001 V4:32
reinforcing ribs in tanks, 2000 V3:155
reject stream from reverse osmosis, 2005 V2:221
relative discharge curves, 2000 V3:220
relative humidity (rh, RH), 2004 V1:15, 2000 V3:200, 201
Relative Importance of Time and Surface Temperature in the Causation of Cutaneous Burns, 2005 V2:124
relay interface controls, 2000 V3:73
reliability of water supplies, 2000 V3:3, 8
relief valves
fire pumps, 2000 V3:25
gas regulators, 2000 V3:251
hot-water systems, 2005 V2:115–116
sizing, 2005 V2:116
relief vents
circuit and loop venting, 2005 V2:44
defined, 2004 V1:28
gas systems, 2005 V2:129
gas trains, 2000 V3:251
requirements, 2005 V2:40
soil and waste stacks, 2005 V2:44
remote-control fountain controls, 2000 V3:120
remote-control irrigation valves, 2000 V3:103
remote-control pool panels, 2000 V3:111
remote earth (remote electrodes), 2004 V1:153
remote electrodes, 2004 V1:153
remote fill ports, 2000 V3:156, 167
remote leakage from tanks, 2000 V3:162–163
remote portions of fire design areas, 2000 V3:16
remote-readout water meters, 2005 V2:69
remote secondary-containment enclosures, 2000 V3:167
Remove Organics by Activated Carbon Adsorption, 2005 V2:234
rems (radiation equivalent to man), 2005 V2:247
renovations, cost estimating and, 2004 V1:98
repetition in value engineering presentations, 2004 V1:258
replacements for Halon gases, 2000 V3:22
Report on Hydraulics and Pneumatics of Plumbing Drainage Systems, 2005 V2:19
required costs, 2004 V1:223
res, RES (resistance or resistors), 2004 V1:16
research facilities, radiation in, 2005 V2:248
reserves (connected standbys), 2000 V3:23
reservoirs
municipal, 2000 V3:8

storm drainage systems, 2005 V2:49
residential care facilities, numbers of fixtures for, 2001 V4:20
residential kitchen sinks
faucets, 2001 V4:13
types and requirements, 2001 V4:11–12
residential systems
cold-water systems. *See* cold-water systems
estimating sewage quantities, 2005 V2:158–160
firefighting demand flow rates, 2000 V3:232
fixture drainage loads, 2005 V2:3
hot-water systems. *See* hot-water systems
irrigation, 2000 V3:100
lavatory flow rates, 2001 V4:10
numbers of fixtures, 2001 V4:20
pool filters, 2000 V3:112
sewage-disposal systems. *See* private sewage-disposal systems
sprinklers, 2004 V1:30, 2000 V3:2
typical gray-water supply and demand, 2005 V2:29
water supply. *See* domestic water supply
residual pressure
defined, 2004 V1:28, 2005 V2:67
domestic water supply, 2000 V3:217–221
fire hydrants, 2000 V3:4, 8
sprinkler hydraulic calculations, 2000 V3:16
residual radiation, 2005 V2:249
resilient mounts
illustrated, 2004 V1:207
noise and vibration control, 2004 V1:199, 205
pipe run installations, 2004 V1:209
seismic danger and, 2004 V1:206
resilient pipe supports, 2004 V1:199, 206
resin beads, 2005 V2:217
resins, ion-exchange
continuous deionization, 2005 V2:219–220
defined, 2005 V2:215
in diluting compartments, 2005 V2:220
overview, 2005 V2:215–216
regenerating, 2005 V2:217
strong-acid and weak-acid, 2005 V2:216
volatile organic compounds in, 2005 V2:201
resistance ratings (fire loads), 2000 V3:2–3
resistance (res, RES, OHMS), 2004 V1:15
resistivity
defined, 2004 V1:154
soil, 2004 V1:150
resistors (res, RES, OHMS), 2004 V1:15
"resonant" air compression systems, 2000 V3:212
resource conservation, 2004 V1:124
Resource Conservation and Recovery Act, 2004 V1:124, 2005 V2:252, 2000 V3:87–90, 2000 V3:96, 154
resources
gasoline and diesel-oil systems, 2000 V3:173
health-care facilities, 2000 V3:86
industrial wastewater treatment, 2000 V3:97
irrigation systems, 2000 V3:105
respirators. *See* breathing apparatus
response in pressure-regulated valves, 2005 V2:67
response spectrum in earthquakes, 2004 V1:160–161, 186
restaurants, 2005 V2:156–157, 2001 V4:19, 22. *See also* food-processing areas and kitchens
restrained-spring mountings, 2004 V1:204
restraint systems
for earthquakes, 2004 V1:166, 189
for fire-protection joints, 2000 V3:229
restricted areas (facilities with radiation), 2005 V2:247
restrooms. *See* water-closet compartments; water closets
retail stores, numbers of fixtures for, 2001 V4:20
retard chambers, 2000 V3:9
retention basins, 2000 V3:247
retirement costs, in labor costs, 2004 V1:94
retractable ceiling medical gas columns, 2000 V3:58
return air (ra, RA), 2004 V1:15
return bends, 2005 V2:101
return circuits, 2004 V1:139
return offsets, 2004 V1:28
return periods in rainfall, 2005 V2:53–57, 2000 V3:243–244
returns
condensate returns, 2000 V3:186–189
fountain filtration, 2000 V3:115, 117
parallel flow piping designs, 2000 V3:178–179
return lines, 2000 V3:195, 196
returning water to pools, 2000 V3:119–120
swimming pools, 2000 V3:143–144
reusing water. *See* gray-water systems
rev, REV (revolutions), 2004 V1:15
revent pipes, 2004 V1:28. *See also* individual vents
reverse osmosis
cartridges, 2005 V2:204–205
continuous deionization and, 2005 V2:220
defined, 2005 V2:221–223
health-care facilities, 2000 V3:47
membrane configurations, 2005 V2:221–222
membrane selection, 2005 V2:223
polymer membranes, 2005 V2:223
silica and, 2005 V2:200
small drinking water systems, 2005 V2:228
VOCs in membranes, 2005 V2:201
water supply (RO), 2004 V1:8
Reverse Osmosis and Nanofiltration System Design, 2005 V2:234
reverse osmosis water supply (RO), 2004 V1:8
reverse-trap water closets, 2001 V4:3
reversible potential, defined, 2004 V1:153
revolutions (rev, REV)
revolutions per minute (rpm, RPM), 2004 V1:15
revolutions per second (rps, RPS), 2004 V1:16
Reynolds number for turbulence, 2005 V2:84, 85
Reynold's number for turbulence, 2004 V1:2
RFP (fiberglass reinforced plastic), 2005 V2:68, 92
rgh, RGH (roughness), 2004 V1:16. *See also* roughness
rh, RH (relative humidity). *See* relative humidity
RHO (density). *See* density
rhomboids, calculating area, 2004 V1:4
rhombuses, calculating area, 2004 V1:4
RI (Ryzner stability index), 2005 V2:207–208
Richardson, D.W., Sr., 2005 V2:234
right-angle triangles, calculating area, 2004 V1:4
rigid ceiling medical-gas columns, 2000 V3:58
rigid plastic piping, 2000 V3:169
rim top test, 2001 V4:6
rims

defined, 2004 V1:28
on urinals, 2004 V1:116–117
rim top test, 2001 V4:6
water closets, 2001 V4:4–5
ring-securing methods around drains, 2005 V2:16
rinsing in regeneration cycle, 2005 V2:217, 218
riser-mounted sprinkler heads, 2000 V3:102
risers
bracing, 2004 V1:171, 178
checklists, 2004 V1:102
defined, 2004 V1:28, 2000 V3:85
earthquake protection and joints, 2004 V1:168
low-pressure steam (lps, LPS), 2000 V3:187
natural gas piping, 2005 V2:137
riser down (elbows), 2004 V1:10
riser-mounted sprinkler heads, 2000 V3:102
riser up (elbows), 2004 V1:10
steam piping, 2000 V3:182, 185
symbols for, 2004 V1:12
rises or drops, 2004 V1:11
risk cabinets, 2005 V2:251
Risk Guides in value engineering, 2004 V1:254, 257
riveted steel piping, 2005 V2:83, 86
RO (reverse osmosis). *See* reverse osmosis
roadblocks to creativity, 2004 V1:231–232
roadway drainage pipes, 2001 V4:32
rock guards for lights, 2000 V3:121
rock salt, 2005 V2:220
Roentgens, 2005 V2:247
roll-in shower compartments, 2004 V1:119–120
roll-out gutters, 2000 V3:137
roof drainage, 2005 V2:49–52
avoiding septic tank disposal, 2005 V2:156
controlled flow systems, 2005 V2:52–53
green roof designs, 2004 V1:266
gutters and downspouts, 2005 V2:63
limited-discharge roof drains, 2000 V3:247
roof drain sizes, 2005 V2:62–64
roof drains, defined, 2004 V1:28
roofing
design considerations in seismic protection, 2004 V1:188
green roofs, 2004 V1:266–267
imperviousness factors, 2000 V3:243
roof penetrations, 2005 V2:42
rope anchors in pools, 2000 V3:145
rotary lobe compressors, 2000 V3:202
rotary lobe (roots) pumps, 2005 V2:180
rotary piston pumps, 2005 V2:180
rotary pop-up sprinkler heads, 2000 V3:102
rotary screw air compressors, 2000 V3:65, 66, 202
rotary vane, once-through-oil pumps, 2005 V2:180
rotating filters, 2000 V3:95
rotors
in gas boosters, 2005 V2:130
in pump engines, 2004 V1:197
rough-ins
checklist, 2004 V1:103
roughing in, defined, 2004 V1:28
water closets, 2001 V4:4
rough vacuum, 2005 V2:175
roughness (rgh, RGH, E), 2004 V1:16
roughness of pipes
fairly rough pipe, 2005 V2:89
fairly smooth pipe, 2005 V2:88
laminar flow and, 2005 V2:84
pipe sizing and, 2005 V2:87–90
pipe types and, 2005 V2:86
rough pipe, 2005 V2:90
smooth pipe, 2005 V2:87
types of pipes and, 2005 V2:83
round bowls on water closets, 2001 V4:4
round leaders, 2005 V2:63
rounded-edge weirs, 2000 V3:109
routing hot-water pipes, 2004 V1:265
RPBDs (reduced-pressure backflow preventers), 2005 V2:68
rpm, RPM (revolutions per minute), 2004 V1:15
rps, RPS (revolutions per second), 2004 V1:16
RPZ (reduced pressure zones), 2005 V2:68, 70, 71, 2000 V3:223, 226
RSOs (Radiological Safety Officers), 2005 V2:248
rubber compression gaskets, 2001 V4:27
rubber facing in dry-pipe clappers, 2000 V3:11
Rubber-Gasket Joints, 2001 V4:32
rubber gaskets, 2001 V4:32
rubber-in-shear isolators, 2004 V1:166
rubber isolation devices
concrete bases and, 2004 V1:204–205
defined, 2004 V1:204
dishwashers, 2004 V1:195
reducing water hammer, 2004 V1:198
vibration control, 2004 V1:203
rubble drains (french drains), 2004 V1:25
rules in Function Analysis, 2004 V1:225
running traps, 2000 V3:42
runoff
imperviousness factor, 2000 V3:242–243
rational method and, 2000 V3:242
Rational method for calculating, 2004 V1:7
runouts in steam piping, 2000 V3:182
rust
formation in iron pipes, 2004 V1:139
in pools, 2000 V3:147
rusting, defined, 2004 V1:154
RV (pressure-relief valves). *See* pressure-regulating or reducing valves
Ryzner stability index (RI), 2005 V2:207–208
RZBP (reduced zone backflow preventers), 2004 V1:10

S

S (entropy), 2004 V1:14, 33
s, SEC (seconds), 2004 V1:16, 33
S (siemens), 2004 V1:33
S (soil sewers), 2004 V1:8
S (surfaces), 2004 V1:16
s traps (unvented traps), 2000 V3:42
sa, SA (supply air), 2004 V1:16
sacrificial anodes, 2004 V1:147
saddles for tanks, 2000 V3:172
Safe Drinking Water Act of 1974, 2005 V2:163, 167, 197, 227
Safe Handling of Acids, 2005 V2:256
safety. *See also* hazards

condensation loads, 2000 V3:194
controlled substance spills, 2005 V2:195–196
flammable and volatile liquids, 2005 V2:254–256
gas boosters, 2005 V2:131
gases in septic tanks, 2005 V2:155
hot-water systems, 2005 V2:107, 122–124
life safety
in fire protection, 2000 V3:1
residential sprinkler systems, 2000 V3:2
radioactive waste-drainage systems, 2005 V2:248–249
Radiological Safety Officers, 2005 V2:248
reflecting pools and, 2000 V3:107
safety factors (sf, SF), 2004 V1:16
sanitary precautions for wells, 2005 V2:166–167
types of acids, 2005 V2:240–242
vacuum cleaning system issues, 2005 V2:195
safety cabinets, 2005 V2:251
safety shut-off devices, 2005 V2:144
sales tax, in plumbing cost estimation, 2004 V1:94
salesmanship in value engineering, 2004 V1:257
salt-air dryers, 2000 V3:207
salt splitting, 2005 V2:209
salts
disinfecting water with, 2000 V3:150
ions in reverse osmosis, 2005 V2:198
in irrigation water, 2000 V3:99
saltwater pools, 2000 V3:147
samples
acid wastes, 2000 V3:41–42
infectious waste systems, 2005 V2:252
radioactive waste effluent, 2005 V2:250
sampling manholes, 2000 V3:41–42, 44
San Diego Gas & Electric Company, 2004 V1:137
San Francisco Earthquake, 2004 V1:162
SAN (sanitary sewers), 2004 V1:8, 28. *See also* sanitary drainage systems
sand filtration
aluminum sulfate, 2000 V3:149–150
cleaning, 2000 V3:150
compared to diatomaceous earth, 2000 V3:135–137
drinking water, 2005 V2:167–168, 228
earthquake damage to filters, 2004 V1:162
fountains, 2000 V3:112
gravity and pressure systems, 2000 V3:132
high-rate pressure filters, 2000 V3:113
laboratory water, 2005 V2:211
pressure sand filters, 2000 V3:132–133, 134
pumps and, 2000 V3:140
pure water systems, 2005 V2:231
sand filters defined, 2004 V1:28
sewage treatment, 2005 V2:153
swimming pools, 2000 V3:130
tanks, 2000 V3:131
types of, 2000 V3:139
sand points, 2005 V2:165
sand traps, 2000 V3:113
sands
gray-water irrigation systems and, 2005 V2:29
imperviousness factors, 2000 V3:243
porous soils, 2000 V3:99–100, 105
in soil texture, 2005 V2:148
sanitary building drains. *See also* sanitary drainage systems
cast-iron soil pipe, 2001 V4:27
defined, 2004 V1:20
sanitary drainage fitting codes, 2004 V1:44
sanitary drainage systems, 2000 V3:232–240
alternative disposal methods, 2000 V3:240
alternative systems, 2005 V2:16–19
building sewers (house drains), 2005 V2:14–15, 2001 V4:27
codes and standards, 2005 V2:1
components, 2005 V2:8–13, 2000 V3:234–236
connections, 2000 V3:234, 236
defined, 2005 V2:1
drainage loads, 2005 V2:3
drainage structures, 2000 V3:234–236
fittings, 2004 V1:44
fixture discharge characteristics, 2005 V2:3
floor leveling around drains, 2005 V2:16
flow in, 2005 V2:1–2
force mains, 2000 V3:236–240
connections, 2000 V3:239
sizing, 2000 V3:236
sizing ejector pumps and pits, 2000 V3:236
gray-water systems and, 2005 V2:35
health-care facilities, 2000 V3:39–42
joining methods, 2005 V2:13–14
kitchen areas, 2005 V2:15
laboratories, 2000 V3:40–43
materials for, 2005 V2:13
overview, 2000 V3:232
pipes, 2004 V1:44
pneumatic pressures in, 2005 V2:2–3
preliminary information, 2000 V3:215–216
protection from damage, 2005 V2:16
public sewer availability, 2000 V3:234
reduced-size venting, 2005 V2:18–19
sample letters, 2000 V3:232
sanitary sewers (SAN, SS), 2004 V1:8, 28
sanitation and cleaning, 2005 V2:15
self-cleansing velocities, 2005 V2:7
single-stack systems, 2005 V2:18
sizing, 2000 V3:232–233
sloping drain capacities, 2005 V2:5–8
sovent systems, 2005 V2:17–18
stack capacities, 2005 V2:3–5
storm-drainage systems and, 2005 V2:49
supports, 2005 V2:12–13
thermal expansion, 2005 V2:16
trenching and bedding, 2000 V3:234, 235
vacuum drainage systems, 2005 V2:19
waterproofing, 2005 V2:15–16
sanitary joints, 2000 V3:48
sanitary sewer pipe codes, 2004 V1:44
sanitary sewer systems. *See* sanitary drainage systems
sanitary tees
flow capacity and, 2005 V2:4
water closet installation, 2001 V4:6–7
sanitaryware. *See* fixtures
sanitation. *See also* cleanouts
feed water, 2005 V2:205
fixture materials and, 2001 V4:1

floor drains, 2001 V4:17
precautions for wells, 2005 V2:166–167
sanitary seals on wells, 2005 V2:164
water softeners, 2005 V2:221
sanitizers, 2000 V3:38
Sansone, John T., 2005 V2:64
SARA Title III act (Superfund Amendment and Reauthorization Act of 1986), 2000 V3:154
sasol, 2005 V2:126
sat., SAT (saturation). *See* saturation
saturated steam, 2000 V3:175, 176
saturation (sat., SAT)
of soils, 2005 V2:149
symbols for, 2004 V1:16
of water with calcium carbonate, 2005 V2:206
SAVE. *See* Society of American Value Engineering
sawcutting trenches, labor productivity rates, 2004 V1:96
Saybolt Seconds Furol (ssf, SSF), 2004 V1:16, 2000 V3:154
Saybolt Seconds Universal (ssu, SSU), 2004 V1:16, 2000 V3:154
SAZ (solar azimuth), 2004 V1:14
SBCCI (Southern Building Code Congress International, Inc.), 2005 V2:64, 2000 V3:154
SC (shading coefficients), 2004 V1:16
scalars, defined, 2004 V1:93
scalding water, 2005 V2:107, 122–124
scale and scale formation
boilers, 2005 V2:225
chlorides and sulfates, 2005 V2:200
cooling towers, 2005 V2:227
hardness and, 2005 V2:200
heat transfer surfaces, 2000 V3:190
Langelier saturation index, 2005 V2:206–207
magnesium and, 2005 V2:200
pool water heaters and, 2000 V3:138
predicting water deposits and corrosion, 2005 V2:206–208
removing with water softening, 2005 V2:220
Ryzner stability index, 2005 V2:207–208
sequestering agents, 2000 V3:150
swimming pools, 2000 V3:147
total dissolved solids and, 2005 V2:204
water deposits and corrosion, 2005 V2:205–206
water piping systems, 2005 V2:168
scanning electron microscopy, 2005 V2:199. *See also* electron microscopes
scavenging adapters, 2000 V3:71
SCCC (Spill Containment Control and Countermeasures), 2000 V3:165
scfh (standard cfh), 2005 V2:131
scfm, SCFM (standard cubic feet per minute)
abbreviation, 2004 V1:14
ambient free air and, 2005 V2:176–178
compressed air pipe sizing, 2000 V3:210
compressed air tools, 2000 V3:208
defined, 2000 V3:85, 200
medical air compressors, 2000 V3:65, 66
medical vacuum systems, 2000 V3:69
scfs, SCFS (cubic feet per second), 2004 V1:33
Schedule 10 steel pipe, 2001 V4:48
Schedule 40 brass pipe, 2001 V4:27
Schedule 40 polyvinyl pipe, 2001 V4:62
Schedule 40 PVC plastic, 2000 V3:17, 116, 2001 V4:62
Schedule 40 steel pipe, 2001 V4:51–52
Schedule 80 brass pipe, 2001 V4:27
Schedule 80 polyvinyl pipe, 2001 V4:62
Schedule 80 PVC plastic, 2001 V4:62
Schedule 80 steel pipe, 2001 V4:53–54
schedules (project)
checklist, 2004 V1:102
section in specifications, 2004 V1:70, 90, 92
school laboratories. *See* laboratories
schools
hot water demand, 2005 V2:109
numbers of fixtures for, 2001 V4:19, 22
septic tank systems for, 2005 V2:156–157
shower room grates, 2005 V2:11
swimming pools and, 2000 V3:129
vacuum calculations for, 2005 V2:190
scope lines, 2004 V1:227
screening
in downspouts, 2005 V2:63
in gray-water treatment, 2005 V2:30
urinals, 2001 V4:10
vacuum exhaust piping, 2005 V2:194
screw compressors, 2000 V3:201, 205
screw pumps, 2005 V2:180
screw threads, 2004 V1:17
screwed ells, 2005 V2:101
screwed fittings, 2004 V1:162
screwed mechanical joints, 2005 V2:242
screwed tees, 2005 V2:101
scrub-up sinks, 2000 V3:32, 35–36, 38
“scuff-buff” grates, 2005 V2:11
scum
in septic tanks, 2005 V2:153
in swimming pools, 2000 V3:150
scuppers, 2005 V2:54, 56
SCW (soft cold water), 2004 V1:8
SD (storm or rainwater drains). *See* storm-drainage systems
SDI (silt density index), 2005 V2:204–205
SDR (standard dimension ratio)
HDPE pipe, 2001 V4:61
SDR21 PVC pipe, 2001 V4:62
SDR26 PVC pipe, 2001 V4:62
SE (sea level). *See* sea level
sea level (sl, SL, SE)
atmospheric pressure, 2000 V3:200
symbols for, 2004 V1:16
vacuum ratings, 2005 V2:178
sealed sprinklers, 2000 V3:9, 11
sealing grouts in wells, 2005 V2:166
seals
acoustic pipe-penetration seals, 2004 V1:201
flashing rings, 2005 V2:11
floor drains in infectious waste systems, 2005 V2:252
seal liquids in vacuum pumps, 2005 V2:181
sound insulation, 2004 V1:193
trap seals in floor drains, 2005 V2:10
water closets, 2001 V4:6
well fixtures, 2005 V2:166
seamless copper pipe, 2001 V4:34–36
seamless copper water tube, 2001 V4:34–44

seamless steel piping, 2001 V4:48
seats
accessible shower compartments, 2004 V1:120
bathtub and shower seats, 2004 V1:115, 117, 122–123
seat fouling tests, 2001 V4:6
water closets, 2001 V4:5
second-guessing designs, 2004 V1:213
secondary containment
of hazardous wastes, 2000 V3:90
of infectious wastes, 2005 V2:251
secondary containment tanks
aboveground types, 2000 V3:165, 167
interstitial monitoring, 2000 V3:160–161
interstitial spaces, 2000 V3:156
underground tanks, 2000 V3:155
secondary functions, 2004 V1:225, 227, 230
secondary pipe liquid monitoring, 2000 V3:162
secondary pipe vapor monitoring, 2000 V3:162
secondary storm-drainage systems
controlled-flow systems, 2005 V2:52–53
planning for in design, 2005 V2:55–56
scuppers, 2005 V2:56
Seconds Redwood, 2000 V3:154
seconds (s, SEC), 2004 V1:16, 33
Seconds Saybolt Furol (SSF), 2000 V3:154
Seconds Saybolt Universal (SSU), 2000 V3:154
Sectionformat, 2004 V1:65, 68–71
sections
in *Manual of Practice,* 2004 V1:88–92
of pump equipment, 2005 V2:169
in specifications, 2004 V1:63, 68–71
security of oxygen storage areas, 2000 V3:63
sediment
removing, 2005 V2:208–209
in water, 2005 V2:198
sediment buckets
kitchen drains, 2005 V2:15
materials, 2005 V2:13
in oil collectors, 2005 V2:12
in sanitary drainage systems, 2005 V2:11
sedimentation
in gray-water treatment, 2005 V2:30
in water treatment, 2005 V2:208–209
seepage beds. *See* soil absorption systems
seepage flanges, 2005 V2:15–16
seepage pits, 2004 V1:28, 2005 V2:30, 2000 V3:240
SEFF (surface efficiency), 2004 V1:14
seiches, 2004 V1:158
seismic, defined, 2004 V1:191
Seismic Design for Buildings, 2004 V1:183, 191
seismic joints, crossing, 2004 V1:162
seismic protection
air compressors and, 2000 V3:213
calculating seismic forces, 2004 V1:183–186
causes and effects of earthquakes, 2004 V1:156–158
codes and standards, 2004 V1:171–184
computer analysis of piping systems, 2004 V1:186
damage from earthquakes, 2004 V1:158
design considerations, 2004 V1:186–188
earthquake measurement and seismic design, 2004 V1:160–161
equipment protection, 2004 V1:163–171
glossary, 2004 V1:191
introduction, 2004 V1:155–156
learning from past earthquakes, 2004 V1:161–163
pipe restraints, 2004 V1:166–182, 2005 V2:13, 16, 2000 V3:15
potential problems, 2004 V1:188–191, 189
references, 2004 V1:191
seismic loads, defined, 2004 V1:155
seismic risk maps, 2004 V1:155–157
underground storage tanks and, 2000 V3:155
vibration isolation and, 2004 V1:206
Seismic Restraint Manual Guidelines for Mechanical Systems, 2004 V1:191
selective attack corrosion, 2004 V1:141
selectivity coefficients, 2005 V2:216
self-bracing problems in seismic protection, 2004 V1:190
self-cleansing velocities, 2005 V2:7
self-closing valves, 2000 V3:33
self-contained breathing units, 2005 V2:239, 241
self-contained fountains, 2000 V3:107
self-jetting well points, 2005 V2:165
self-metering faucets, 2001 V4:13
self-priming dry pumps, 2000 V3:113, 129–130, 142
self-regulating heat-trace systems, 2005 V2:115
self-scouring velocity in sewers, 2000 V3:232
self-siphonage, 2005 V2:2, 47
self-venting in sovent systems, 2005 V2:17–18
selling functions, 2004 V1:225
SEMI (Semiconductor Equipment Manufacturers Institute), 2005 V2:197, 228
semi-ambulatory individuals
semi-ambulatory disabilities, 2004 V1:107
water closet requirements, 2004 V1:116
semi-circular gutters, 2005 V2:63
semi-circular lavatories, 2001 V4:11
semi-instantaneous water heaters, 2005 V2:111
semi-permeable membranes, 2000 V3:47
Semiconductor Equipment Manufacturers Institute, 2005 V2:197, 228
Sendelbach, M.G., 2005 V2:234
seniors. *See* elderly
sensible heat (SH)
condensate drainage and, 2000 V3:189
defined, 2004 V1:137
sensible heat gain (SHG), 2004 V1:15, 16
sensible heat ratio (SHR), 2004 V1:16
symbols for, 2004 V1:16
sensitivity in pressure-regulated valves, 2005 V2:68
sensors
corrosive-waste systems, 2000 V3:40
electrical makeup water method, 2000 V3:124, 125
faucet controls, 2004 V1:135
hazardous material level sensors, 2000 V3:90
line-pressure sensors, 2000 V3:72
liquid fuel leakage, 2000 V3:163
pH sensors, 2000 V3:40
pressure sensors, 2005 V2:72
water-level sensors, 2000 V3:124
separating systems
for acid waste, 2005 V2:239, 244
for oil, 2005 V2:255–256
separator/filters in air compressors, 2000 V3:203

separators in vacuum cleaning systems
kinds of materials, 2005 V2:194
location, 2005 V2:190
pressure loss, 2005 V2:193
types of systems, 2005 V2:188
septic tanks
biological treatment of sewage in, 2005 V2:153
chemicals in, 2005 V2:155–156
cleaning, 2005 V2:155
clogging materials, 2005 V2:156
compartments, 2005 V2:154–155
defined, 2004 V1:28
estimating sewage quantities, 2005 V2:158–160
grease interceptors, 2005 V2:155
institutional and recreational establishments, 2005 V2:156–157
percolation rates and, 2005 V2:161
sanitary sewers and, 2000 V3:240
sizing, 2005 V2:153
solids removal, 2005 V2:153
specifications, 2005 V2:153–155
venting, 2005 V2:156
septum filters, 2005 V2:228, 2000 V3:134, 135
sequence
of project phases, cost estimates and, 2004 V1:98
section in specifications, 2004 V1:70, 90
sequential functions in FAST approach, 2004 V1:230
sequential functions in FAST approach, 2004 V1:230
sequestering agents, 2000 V3:150
service cocks, 2005 V2:103
service deionization, 2005 V2:219
service sinks, 2005 V2:94, 109, 2001 V4:12–13, 18–22
Service Station Tankage Guide (API 1611), 2000 V3:173
service stations, 2000 V3:166, 2001 V4:20
"Service Water Heating," 2005 V2:104
service-weight cast-iron soil pipe, 2001 V4:27, 30–31
services
costs, 2004 V1:222
ongoing and one-time costs, 2004 V1:223
set pressure in pressure-regulated valves, 2005 V2:68, 116
settlement. *See* bedding and settlement; creep
settling tanks, 2000 V3:93
severe backflow hazard, 2000 V3:222
sewage, defined, 2004 V1:28. *See also* effluent
sewage effluent. *See* effluent
sewage ejectors, 2004 V1:28
sewage systems. *See* sewer systems
sewage treatment plants, 2005 V2:35
sewer gas, 2005 V2:126
sewer mains
asbestos concrete piping, 2001 V4:26
nonreinforced concrete pipe, 2001 V4:32
sewer systems. *See also* building sewers; private sewage-disposal systems; public sewers; *specific types of sewers*
combined systems, 2000 V3:247
discharge from laboratories, 2000 V3:40
preliminary information, 2000 V3:215–216
sample sewer services letter, 2000 V3:257
sanitary sewer systems, 2000 V3:232–240. *See also* sanitary drainage systems
alternative disposal methods, 2000 V3:240
components and design, 2000 V3:234–236
force mains, 2000 V3:234–236
overview, 2000 V3:232
sample letters, 2000 V3:232
sizing, 2000 V3:232–233
sewer video equipment, 2005 V2:9
storm sewers, 2000 V3:240–248
calculations, 2000 V3:244–245
codes and standards, 2000 V3:240
disposal methods, 2000 V3:245–247
overview, 2000 V3:240
rational method and design glow, 2000 V3:242–244
sizing ditches, 2000 V3:247–248
swimming pool water and, 2000 V3:131, 140
sf, SF (safety factors), 2004 V1:16
sft hp, SFT HP (shaft horsepower), 2004 V1:16
sfu (supply fixture units), 2004 V1:24
SGPH (standard gallons per hour), 2004 V1:15
SH (sensible heat), 2004 V1:15, 16, 137
shading coefficients (SC), 2004 V1:16
shaft horsepower (sft hp, SFT HP, SHP), 2004 V1:16
shafts, piping and acoustic design for, 2004 V1:196
shaking vacuum filter bags, 2005 V2:188
shallow-end depth of swimming pools, 2000 V3:128
shallow fill, building sewers and, 2005 V2:14
shallow manholes, 2000 V3:234, 238
shallow wells, 2005 V2:163, 164, 170
shapes of swimming pools, 2000 V3:129
shear motions, preventing, 2004 V1:163, 189, 190
sheet copper, 2001 V4:15
sheet flow, 2005 V2:47
sheet flows, 2000 V3:244
sheet lead, 2001 V4:15
Sheet Metal and Air Conditioning Contractors' National Association (SMACNA), 2004 V1:170, 191
Sheet Metal Industry Fund of Los Angeles, 2004 V1:191
shell-and-tube heat exchangers, 2004 V1:131
shelving
accessibility in toilet and bathing rooms, 2004 V1:113
ambulatory accessible toilet compartments, 2004 V1:115–116
Sherlin, G.C., 2005 V2:48
SHG (sensible heat gain), 2004 V1:15, 16
shielding on radioactive drainage systems, 2005 V2:247–248
shine. *See* radiation
shipping costs, 2004 V1:98, 223
shock absorbers. *See* water hammer arresters
shock intensity of water hammer, 2005 V2:80
shock treatments in pools and fountains, 2000 V3:123
Sholes, Christopher, 2004 V1:231
shopping centers, 2005 V2:28–29, 2001 V4:20
shops, numbers of fixtures for, 2001 V4:20
short-circuiting installations, 2004 V1:151
short cycling in boilers, 2000 V3:180
shot-in concrete anchors, 2004 V1:163, 190
shower pans, 2001 V4:15
shower valves
flow rates, 2001 V4:16
installation, 2001 V4:16
types, 2001 V4:15–16
showerheads

Energy Policy Act requirements, 2004 V1:264
low flow, 2004 V1:136
scaling, 2005 V2:122
wasted water, 2004 V1:136
showers
acoustic ratings of, 2004 V1:194–195
body sprays, 2001 V4:16
emergency showers, 2005 V2:239, 241, 251, 2001 V4:17–18
enclosures, 2004 V1:120
fixture pipe sizes and demand, 2005 V2:94
fixture-unit loads, 2005 V2:3
flow rates, 2001 V4:15
grab bars, 2004 V1:121–122
grates in school shower rooms, 2005 V2:11
gray-water supply and demand, 2005 V2:29
gray-water systems, 2004 V1:135
health-care facilities, 2000 V3:32, 38
heat recovery systems, 2004 V1:266
hot water demand, 2005 V2:109
hydrotherapy, 2000 V3:35
labor rooms, 2000 V3:36
minimum numbers of, 2001 V4:18–22
patient rooms, 2000 V3:34
pressure reducing balancing valves and, 2005 V2:71–72
public areas in health-care facilities, 2000 V3:33
rates of sewage flows, 2005 V2:160
reduced water usage, 2004 V1:126
reducing flow rates, 2004 V1:135
requirements, 2001 V4:14–15
resilient-mounting design, 2004 V1:206
seats, 2004 V1:122–123
shower compartment accessibility, 2004 V1:119–122
showerhead acoustic ratings, 2004 V1:195
spray units, 2004 V1:118, 120
standards, 2001 V4:2
stop levers, 2004 V1:136
swimming pool bathhouses, 2000 V3:130
temperatures, 2000 V3:45
thresholds, 2004 V1:120
water fixture unit values, 2000 V3:217
SHP (shaft horsepower), 2004 V1:16
SHR (sensible heat ratio), 2004 V1:16
Shreir, L.L., 2004 V1:154
shrinkage of ceramic fixtures, 2001 V4:1
shrub sprinkler heads, 2000 V3:103
Shumann, Eugene R., 2005 V2:64
shut-off devices
defined, 2005 V2:144
fuel dispensers, 2000 V3:165
shut-off valves
earthquake-sensitive valves, 2004 V1:162
fountains, 2000 V3:118
medical gases, 2000 V3:71, 72
shutdown pump features, 2005 V2:73
shutdown relays, 2000 V3:24
Shweitzer, 2000 V3:97
SI units. *See* International System of Units
siamese fire-department connections, 2004 V1:12, 28, 2000 V3:11. *See also* fire-protection systems
side reach for wheelchairs, 2004 V1:109, 112
side spray accessories, 2001 V4:12, 14
side vents, 2004 V1:28, 2005 V2:41
sidesway prevention, 2004 V1:189
sidewalk fire-department connections, 2004 V1:12
sidewall grab bars, 2004 V1:114
sidewall heat loss in pools, 2000 V3:144
sidewall sprinklers, 2004 V1:13, 30
Siegrist, R., 2005 V2:36
siemens, 2004 V1:33
sight disabilities, 2004 V1:107
signals for fire alarms, 2000 V3:9
significant digits, 2004 V1:32
silencers
on air compressors, 2000 V3:202, 212
on vacuum systems, 2005 V2:189
silica, 2005 V2:200
silica gel, 2000 V3:204
silicates, 2005 V2:199, 2000 V3:147
silicon, 2005 V2:199
silicon iron piping, 2005 V2:14
silt
content of water, 2000 V3:99
loams, 2000 V3:100
removing, 2005 V2:208–209
silt density index, 2005 V2:204–205
in soil texture, 2005 V2:148
in water, 2005 V2:198
silt density index (SDI), 2005 V2:204–205
silver, 2004 V1:139, 141, 144
Silver-level LEED certification, 2004 V1:263
silver salt, 2000 V3:150
silver solder, 2004 V1:141
A Simple Method for Retention Basin Design, 2005 V2:64
simplex air compressors, 2000 V3:213
simplex gas booster systems, 2005 V2:132
simultaneous operators of vacuum systems, 2005 V2:190, 191
simultaneous-use factors. *See* diversity factor
single-acting altitude valves, 2005 V2:172
single-acting cylinders in compressors, 2000 V3:201
single-compartment septic tanks, 2005 V2:154
single-compartment sinks, 2001 V4:11
single-degree-of-freedom systems, 2004 V1:160, 161
single-family dwellings, 2001 V4:20, 21
single-occupant toilet rooms, 2001 V4:18, 23
single-seated pressure-regulated valves, 2005 V2:78
single-stack systems, 2005 V2:18
single-stage distillation, 2005 V2:210
single-step deionization (mixed bed), 2005 V2:216, 218
single-tank residential filters, 2000 V3:134
single-wall tanks, 2000 V3:156
sinistans, 2000 V3:38
sink-disposal units. *See* food waste grinders
sinks and wash basins. *See also* lavatories
accessibility, 2004 V1:117
faucets, 2001 V4:13
fixture pipe sizes and demand, 2005 V2:94
fixture-unit loads, 2005 V2:3
food-preparation, 2000 V3:36
general category of, 2001 V4:13
gray-water supply and demand, 2005 V2:28–29
health-care facilities, 2000 V3:32, 38
hot water demand, 2005 V2:109

infectious waste drainage, 2005 V2:251
kitchen sinks, 2001 V4:11–12
laboratory rooms, 2000 V3:37
laboratory sink drainage rates, 2005 V2:245
laundry sinks, 2001 V4:13
neutralizing acid from, 2005 V2:245
pharmacies and drug rooms, 2000 V3:35
public areas in health-care facilities, 2000 V3:33
rates of sewage flows, 2005 V2:161
service sinks, 2001 V4:12–13
sound-damping materials, 2004 V1:196
standards, 2001 V4:2
suds problems, 2005 V2:45–46
surgical scrub-up areas, 2000 V3:35–36
traps and acid wastes, 2000 V3:42
water fixture unit values, 2000 V3:217
siphon jet urinals, 2001 V4:9
siphon jet water closets, 2001 V4:3
siphonage
factors in trap seal loss, 2005 V2:47
induced siphonage, 2005 V2:47
siphons in secondary containment areas, 2000 V3:90
site storm drainage
Rational Method formulas, 2004 V1:7
site utilities
domestic water supply
codes and standards, 2000 V3:216
overview, 2000 V3:216
sample water service letter, 2000 V3:256
service components and design, 2000 V3:217–224
system requirements, 2000 V3:216–217
water mains and pressure, 2000 V3:216
water utility letters, 2000 V3:216
fire-protection water supply, 2000 V3:224–232
ancillary devices, 2000 V3:226–229
building water supply, 2000 V3:225–226
codes and standards, 2000 V3:225
overview, 2000 V3:224–225
sizing system, 2000 V3:229–232
natural gas services, 2000 V3:248–254
codes and standards, 2000 V3:248
overview, 2000 V3:248
sample gas utility letter, 2000 V3:258–259
site distribution, 2000 V3:252
sizing methods, 2000 V3:252–254
system components, 2000 V3:250–252
testing and purging, 2000 V3:252
types of services, 2000 V3:249
off-peak power savings, 2004 V1:128–129
overview, 2000 V3:215
preliminary information, 2000 V3:215–216
sample general notes, 2000 V3:255
sanitary sewer services, 2000 V3:232–240
alternative disposal methods, 2000 V3:240
components and design, 2000 V3:234–236
force mains, 2000 V3:236–240
overview, 2000 V3:232
sample letters, 2000 V3:232
sample sewer services letter, 2000 V3:257
sizing, 2000 V3:232–233
storm sewers, 2000 V3:240–248
calculations, 2000 V3:244–245
codes and standards, 2000 V3:240
disposal methods, 2000 V3:245–247
overview, 2000 V3:240
rational method and design glow, 2000 V3:242–244
sample sewer services letter, 2000 V3:257
sizing ditches, 2000 V3:247–248
swimming pool locations and, 2000 V3:128
sites
geological stability of, 2005 V2:29
irrigation system plans, 2000 V3:104
obtaining plans, 2000 V3:215
sitz baths, 2005 V2:109, 2000 V3:32, 38
Six Sticks exercise, 2004 V1:232, 261
sizing
acid-neutralization tanks, 2000 V3:40, 42
acid-waste drainage system pipes, 2005 V2:244
air compressors, 2000 V3:68, 210–213
air receivers, 2000 V3:205–206
clean agent gas pipes, 2000 V3:24
cleanouts, 2005 V2:9
cold-water system pipes, 2005 V2:82–103, 87–90
condensate traps, 2000 V3:193–195, 197
cryogenic tanks, 2000 V3:62
domestic water heaters, 2005 V2:108–109
elevated water tanks, 2005 V2:75–76
fire extinguishers, 2000 V3:27, 28
floor drains, 2005 V2:10
force mains, 2000 V3:236
fountain display pumps, 2000 V3:115
fountain drains, 2000 V3:110, 125
fountain filtration systems, 2000 V3:110, 112, 113, 115–116
fountain nozzles, 2000 V3:117–118
fountain return inlets, 2000 V3:117–118
gas boosters, 2005 V2:133–134
gas line filters, 2000 V3:250
gas meters, 2000 V3:250
gas piping, 2004 V1:7
gas regulators, 2000 V3:251–252
grab bars, 2004 V1:121
gutters, 2000 V3:142
hot-water circulation systems, 2005 V2:115
hydropneumatic tanks, 2005 V2:73–74
hypochlorinators, 2000 V3:151
irrigation, 2000 V3:100
liquefied petroleum gas systems, 2005 V2:142
liquid fuel piping, 2000 V3:169, 2000 V3:169–170
medical air compressors, 2000 V3:68
medical air piping, 2000 V3:210
medical gas systems, 2000 V3:49–50, 73–74, 75, 76–77
medical vacuum systems, 2000 V3:69, 75
multilevel pools, 2000 V3:108
natural gas piping, 2005 V2:134–137, 138–141, 2000 V3:252–254
nitrogen gas systems, 2000 V3:68, 75
nitrous oxide systems, 2000 V3:65, 75, 76
nominal pipe size, 2005 V2:175
oxygen systems, 2000 V3:63, 75, 76
pipe examples for cold-water systems, 2005 V2:97–99
pressure and, 2005 V2:92–96
pressure and temperature relief valves, 2005 V2:116
pressure-regulated valves, 2005 V2:78–79

pressurized fuel product piping, 2000 V3:170
project size and cost estimates, 2004 V1:98
propane systems, 2005 V2:143
review of pipe procedures, 2005 V2:97
roof drainage systems, 2005 V2:49–59, 53, 56–64
sanitary sewer systems, 2000 V3:232–233
septic tanks, 2005 V2:153
skimmers, 2000 V3:110, 142
soil absorption systems, 2005 V2:151
special-waste system pipes, 2005 V2:238, 239, 240, 241
sprinkler system pipes, 2000 V3:16, 18
standpipe systems, 2000 V3:19
steam systems, 2000 V3:177, 186–187, 191
steam traps, 2000 V3:191, 193–195, 196
storm drainage systems, 2005 V2:56–60, 62–64
storm sewers, 2000 V3:244–245, 246
storm water ditches, 2000 V3:247–248
submersible pumps, 2000 V3:164, 2000 V3:170, 2000 V3:170
sump pits for LSDS systems, 2005 V2:252
surge chambers, 2000 V3:143
in sustainable designs, 2004 V1:264
swimming pool return systems, 2000 V3:143
swimming pool water heaters, 2000 V3:144–145
swimming pools, 2000 V3:127–128
toilet compartments, 2004 V1:113–114
vacuum system receivers, 2005 V2:180
vacuum systems, 2005 V2:184–187, 2000 V3:79
exhaust, 2000 V3:70
pumps, 2000 V3:70
vacuum cleaning inlets, tools, and tubing, 2005 V2:190
vacuum cleaning piping network, 2005 V2:190–193, 194
vacuum cleaning system separators, 2005 V2:194–196
vacuum exhaust pipes, 2005 V2:186
vacuum piping, 2005 V2:184–186
vacuum producers (exhausters), 2005 V2:193–194
vacuum pumps, 2005 V2:186
velocity and, 2005 V2:92
vents, 2005 V2:39, 43–44
vertical stacks, 2005 V2:5
water hammer arresters, 2005 V2:81–82
water mains, 2000 V3:8
water meters, 2005 V2:69
water storage tanks, 2005 V2:170–171
wells, 2005 V2:164
skating rinks, numbers of fixtures for, 2001 V4:19
sketches. *See also* plumbing drawings
costs analysis phase, 2004 V1:241
function evaluation, 2004 V1:239–240
functional development, 2004 V1:254, 255
skimmers
dissolving tablets in, 2000 V3:149
head loss and, 2000 V3:115
pools and fountains, 2000 V3:110
swimming pools, 2000 V3:137, 142
skimming oils, 2000 V3:93
sl, SL (sea level), 2004 V1:16, 2005 V2:178
slabs, in radioactive waste systems, 2005 V2:250
slack cables in earthquake protection, 2004 V1:166
slaughterhouses, 2005 V2:15
sliding motions
preventing for pipes or equipment, 2004 V1:163
of seismic plates, 2004 V1:158
sliding vane compressors, 2000 V3:201, 205
sliding vane pumps, 2005 V2:183
slime, 2005 V2:205
slime bacteria, 2005 V2:199
slip-resistant bases in baths, 2001 V4:16
slope
of ditches, 2000 V3:248
of floors, 2000 V3:130
of sewers, 2000 V3:233
of sites, 2005 V2:50, 2000 V3:105, 244
sloping drains
fixture loads, 2005 V2:6, 8
Manning formula, 2004 V1:1
minimum slope of piping, 2005 V2:6
sanitary drainage systems, 2005 V2:5–8
self-cleansing velocities, 2005 V2:7
steady flow in, 2005 V2:6
ultra-low-flow fixtures and pipes, 2004 V1:264
slow sand filtration, 2005 V2:228
sludge
activated sludge systems, 2000 V3:95
defined, 2004 V1:28, 2005 V2:205
from water softeners, 2005 V2:168
removal, 2000 V3:93
in septic tanks, 2005 V2:153
slugs of water, 2005 V2:2, 4, 37
slurry feeding in filtration, 2000 V3:134–135
SMACNA (Sheet Metal and Air Conditioning Contractors' National Association), 2004 V1:170, 191
small bore pipes, 2005 V2:249
small-diameter gravity sewers, 2005 V2:152
Small Welded Petroleum Tanks (API 12F), 2000 V3:95
smoke detectors, 2004 V1:22, 2000 V3:24
smoke, vacuum systems and, 2000 V3:69
smooth piping, 2005 V2:87
smothering fires, 2000 V3:19
snow melting piping, 2001 V4:35
snubbing devices for earthquake protection, 2004 V1:164–166, 165, 186
soaking combustibles in inerting atmosphere, 2000 V3:20
soap dispensers, 2001 V4:12
soaps. *See also* suds
in gray water, 2005 V2:35
in septic tanks, 2005 V2:156
soapstone fixtures, 2001 V4:2, 13
Social Security taxes, in labor costs, 2004 V1:94
Society of American Value Engineering (SAVE), 2004 V1:211, 213
socket-type joints, 2000 V3:254
socket welding
defined, 2005 V2:249
socket-weld end connections, 2004 V1:23
soda ash (sodium carbonate), 2000 V3:148, 149
sodium, 2005 V2:199, 200
sodium aluminate, 2005 V2:209
sodium azide, 2005 V2:13
sodium bicarbonate, 2005 V2:200
sodium bisulfate, 2005 V2:168, 2000 V3:93, 148, 149, 150

sodium carbonate (soda ash), 2005 V2:200, 2000 V3:148, 149
sodium chloride, 2005 V2:200
sodium cycle ion exchange, 2005 V2:220
sodium hexametaphosphate, 2004 V1:151, 2005 V2:168
sodium hydroxide (lye), 2005 V2:155, 218, 2000 V3:93, 149, 150
sodium hypochlorite, 2005 V2:168, 2000 V3:93, 149, 150–151
sodium silicate, 2004 V1:151
sodium sulfate, 2005 V2:199
sodium thiosulfate, 2005 V2:168
soft cold water (SCW), 2004 V1:8
soft conversions, 2004 V1:32
soft water (SW). *See* water softeners
softening water. *See* water softeners
softness of vibration control materials, 2004 V1:202
software. *See* computer programs
soil-absorption sewage systems
  allowable rates of sewage application, 2005 V2:161
  alternative components, 2005 V2:152
  choosing absorption systems, 2005 V2:150
  construction considerations, 2005 V2:151–152
  drain fields defined, 2004 V1:23
  estimating sewage quantities, 2005 V2:158–160
  estimating soil absorption potential, 2005 V2:147–150
  individual wastewater treatment plants, 2005 V2:157
  inspection, 2005 V2:160–161
  institutional and recreational establishments, 2005 V2:156–157
  mound systems, 2005 V2:152
  percolation rates for soils, 2005 V2:149–150
  selecting systems, 2005 V2:150
  setbacks, 2005 V2:150
  sizing, 2005 V2:151
Soil Conservation Service, 2005 V2:64
soil-moisture monitors, 2000 V3:104
soil pipes, 2004 V1:28
soil sewers (S, SS), 2004 V1:8
soil stacks, 2005 V2:1
soil vents. *See* stack vents
soils
  color, 2005 V2:148
  depth, 2005 V2:149
  gray-water irrigation systems and, 2005 V2:29
  irrigation and, 2000 V3:99–100, 104–105
  maps of, 2005 V2:148
  percolation tests, 2005 V2:149–150
  profiles, 2000 V3:99–100, 216
  resistivity, 2004 V1:150
  in seismic force calculations, 2004 V1:183
  structure, 2005 V2:148
  swelling characteristics, 2005 V2:149
  swimming pool locations and, 2000 V3:128
  texture, 2005 V2:148–149
  underground tanks and, 2000 V3:155
SOL (solar), 2004 V1:16
solar (SOL), defined, 2004 V1:16
solar azimuth (SAZ), 2004 V1:14
solar energy
  copper pipe, 2001 V4:35, 36
  heating for swimming pools, 2000 V3:138
  solar (SOL), defined, 2004 V1:16
  solar energy sources, defined, 2004 V1:137
  water heaters, 2004 V1:130, 265
soldering
  clearance for, 2001 V4:25
  copper water tube, 2001 V4:37
  corrosion and, 2004 V1:146
  reducing, 2004 V1:266
  soldered joints and earthquake protection, 2004 V1:167
solenoid valves
  makeup water systems, 2000 V3:124
  symbols for, 2004 V1:9
solid angles, 2004 V1:33
solid chlorine, 2000 V3:123
solid expansion traps, 2000 V3:182
solid toilet seats, 2001 V4:5
solid waste disposal
  as energy source, 2004 V1:130–131
  solid waste incineration systems, 2004 V1:130–131
  solids removal in septic tanks, 2005 V2:153
solids
  loading in filtration beds, 2000 V3:132
  rectangular, 2004 V1:4
  solids interceptors, 2000 V3:41, 43
  in water, 2005 V2:204, 2000 V3:132
soluble silica, 2005 V2:200
solute. *See* treated water
solution sinks, 2000 V3:35
solutions to puzzles, 2004 V1:261
solvents
  PEX piping and, 2001 V4:61
  in pure-water systems, 2000 V3:48
sonic cleaners, 2000 V3:38
sound power
  defined, 2004 V1:208
  levels, 2004 V1:194, 208
sound pressure, 2004 V1:209
sounds. *See* acoustics in plumbing systems
sour gas, 2000 V3:250
source shut-off valves, 2000 V3:71
source water
  defined, 2005 V2:197
  pure-water systems, 2005 V2:230
sources of acoustic problems, 2004 V1:199
sources of information in value engineering, 2004 V1:214, 221
sources, vacuum, 2005 V2:179–182, 182–183, 186
Southern Building Code Congress International, Inc. (SBCCI), 2005 V2:64, 2000 V3:154
sovent single-stack plumbing systems, 2005 V2:17–18
sp, SP (static pressure), 2004 V1:15, 16
sp ht, SP HT (specific heat)
  measurements, 2004 V1:33
  sp ht at constant pressure (c_p, c_p, CP), 2004 V1:16
  sp ht at constant volume (c_v, c_v, CV), 2004 V1:16
  symbols for, 2004 V1:16
sp vol, SP VOL (specific volume). *See* specific volume
spacing
  around water closets, 2001 V4:6–7
  drinking fountains, 2001 V4:14
  grab bars for accessibility, 2004 V1:121–122
  lavatories, 2001 V4:11

manholes, 2000 V3:236, 240
swimming pool inlets, 2000 V3:143
urinals, 2001 V4:9–10
of vacuum inlets, 2005 V2:189
spas, 2005 V2:122, 2000 V3:107
spec, SPEC (specifications). *See* specifications
special sprinklers, 2004 V1:30
special-waste drainage systems
acid-waste systems, 2005 V2:239–245
chemical-waste systems, 2005 V2:253
codes and standards, 2005 V2:237
fire-suppression water drainage, 2005 V2:253–254
flammable and volatile liquids, 2005 V2:254–256
future growth of systems, 2005 V2:239
general design considerations, 2005 V2:239
infectious and biological waste systems, 2005 V2:250–252
introduction, 2005 V2:237
pH values in waste, 2005 V2:239
piping and joint selection, 2005 V2:238
planning for larger systems, 2005 V2:239
radioactive waste drainage and vents, 2005 V2:248–250
references, 2005 V2:256
separating systems, 2005 V2:239
sizing piping, 2005 V2:238, 239–241, 240, 241
special wastes defined, 2004 V1:28
system approval requirements, 2005 V2:237–238
specialty water closets, 2004 V1:136
specific conductance, 2005 V2:203
specific energy, converting to SI units, 2004 V1:39
specific functionality, defined, 2004 V1:225
specific gravity (SG)
defined, 2005 V2:144, 2000 V3:154
natural gas, 2005 V2:137, 141
plastic pipe, 2001 V4:60
plastic pipe and, 2001 V4:61
PVC pipe, 2001 V4:62
symbols for, 2004 V1:16
specific heat (sp ht, SP HT, C)
measurements, 2004 V1:33
sp ht at constant pressure (c_p, c_p, CP), 2004 V1:16
sp ht at constant volume (c_v, c_v, CV), 2004 V1:16
symbols for, 2004 V1:16
specific resistance in water, 2005 V2:203, 2000 V3:46
specific volume (sp vol, SP VOL, V, CVOL)
measurements, 2004 V1:33
symbols for, 2004 V1:16
Specification for Copper Drainage Tube (DWV), 2001 V4:35
Specification for Seamless Copper Tube for Medical Gas Systems, 2001 V4:35
Specification for Seamless Copper Water Tube, 2001 V4:35
specifications (spec, SPEC). *See also* construction contract documents; project manuals; *names of specific listing agencies; titles of specific documents*
checklist, 2004 V1:102
computer production of, 2004 V1:71–72
contents of sections, 2004 V1:68–71
costs associated with, 2004 V1:223
in FAST approach, 2004 V1:230
formats, 2004 V1:63–64
introduction, 2004 V1:61
MasterFormat, 2004 V1:64
MasterFormat 2004, 2004 V1:77–88
MasterFormat Level Four (1995), 2004 V1:76
MasterFormat Level One (1995), 2004 V1:73
MasterFormat Level Three (1995), 2004 V1:76
MasterFormat Level Two (1995), 2004 V1:73–75
methods for creating, 2004 V1:66–68
problems with reuse, 2004 V1:63
in project manuals, 2004 V1:62
questioning in value engineering, 2004 V1:212
"specifications" as incorrect term, 2004 V1:61
symbols for, 2004 V1:16
Uniformat, 2004 V1:64, 73
Specifications for Making Buildings and Facilities Usable by the Physically Handicapped, 2004 V1:105
Specifications Group, 2004 V1:65, 77–88
specimen-type water closets, 2000 V3:35
Spectext, 2004 V1:71
speculation in creativity, 2004 V1:232
speed of pumps, 2004 V1:6
Speller, Frank N., 2004 V1:154
Spencer Turbine Co., 2005 V2:196
spherical soil structure, 2005 V2:148
spigot outlets, 2005 V2:13
Spill Containment Control and Countermeasure (40 CFR 112) (SCCC), 2000 V3:154, 165
spill lips on weirs, 2000 V3:109
spills
aboveground tank systems, 2000 V3:167
acids, 2005 V2:239
controlled substances, 2005 V2:195–196
industrial waste, 2000 V3:90
oil, 2005 V2:254–256
underground liquid fuel tanks, 2000 V3:157
spiral wound modules
in cross-flow filtration, 2005 V2:223
in reverse osmosis (SWRO), 2005 V2:205, 221–222
Spitzglass formula, 2004 V1:7
natural gas piping, 2005 V2:137
split-case horizontal end-suction pumps, 2000 V3:25, 115
split rim toilet seats, 2001 V4:5
sply., SPLY (supplies), 2004 V1:16
sponge rubber isolators, 2004 V1:204
sports facilities, numbers of fixtures for, 2001 V4:19
spout location on water fountains, 2004 V1:109
spray effects in fountains, 2000 V3:108–109, 119–120
spray heads on irrigation sprinklers, 2000 V3:101–102
spray nozzle waterfall aerators, 2005 V2:208
spray units
in bathtubs, 2004 V1:118
in showers, 2004 V1:120
spring isolators
concrete bases and, 2004 V1:205
problems in seismic protection, 2004 V1:188, 189
pump isolation and, 2004 V1:205
stored energy in, 2004 V1:166
spring-loaded check valves, 2000 V3:118
spring supports, 2004 V1:186
springing pipes, 2001 V4:25
Sprinkler Irrigation, 2000 V3:105
Sprinkler Irrigation Systems, 2000 V3:105
sprinkler systems (fire protection)

automatic sprinkler system types, 2004 V1:29
combined dry-pipe and pre-action, 2000 V3:15
concealed sprinklers, 2004 V1:29
corrosion-resistant sprinklers, 2004 V1:29
defined, 2004 V1:28–37
deluge systems, 2000 V3:13–15
design density, 2000 V3:15
drop nipples on pendent sprinklers, 2004 V1:13
dry upright sprinklers, 2004 V1:29
earthquake damage to, 2004 V1:162
effectiveness statistics, 2000 V3:2
in elevator shafts, 2000 V3:25
extended-coverage sidewall sprinklers, 2004 V1:29
fire hazard evaluation, 2000 V3:2–3
fire pumps for, 2000 V3:25
firefighting water drainage, 2005 V2:253–254
flush sprinklers, 2004 V1:29
foam extinguishers, 2000 V3:21
fully-sprinklered spaces, 2004 V1:12
gaseous fire-suppression systems and, 2000 V3:22
heads, 2004 V1:13
history of, 2000 V3:1–2
hydraulic design, 2000 V3:15–18
intermediate-level sprinklers, 2004 V1:29
large-drop sprinklers, 2004 V1:29
nippled-up sprinklers, 2004 V1:13
non-sprinklered spaces, 2004 V1:12
numbers of sprinklers in operation, 2000 V3:16
occupancy classification, 2004 V1:29
open sprinklers, 2004 V1:29
ornamental sprinklers, 2004 V1:29
partially-sprinklered spaces, 2004 V1:12
pendent sprinklers, 2004 V1:13, 29
pipe materials, 2000 V3:12
pre-action systems, 2000 V3:13
quick-response sprinklers, 2004 V1:29
recessed sprinklers, 2004 V1:29
residential sprinklers, 2004 V1:30
sediment buckets in drains, 2005 V2:11
seismic protection and, 2004 V1:183–184
sidewall sprinklers, 2004 V1:13, 30
special sprinklers, 2004 V1:30
sprinkler types, 2004 V1:29, 2000 V3:8–15
supports and hangers, 2000 V3:15
system design, 2000 V3:2–18
water demands, 2005 V2:167, 2000 V3:3–8
sprinkler systems (irrigation)
concepts, 2000 V3:100–101
impact heads, 2000 V3:102–103
lawn sprinklers, 2004 V1:8
sample information sheet, 2000 V3:106
shrub heads, 2000 V3:103
spray heads, 2000 V3:101–102
trickle irrigation, 2000 V3:103
spurs, 2000 V3:234
sq., SQ (squares). *See* squares
square-edged inlets, 2005 V2:101
square feet, 2000 V3:29
square feet EDR, 2000 V3:178
square foot [m^2] method, defined, 2004 V1:97–98
squares (sq., SQ)
calculating area, 2004 V1:3
converting to SI units, 2004 V1:40
symbols for, 2004 V1:16
sr (steradians), 2004 V1:33
SS (sanitary sewers), 2004 V1:8, 28. *See also* sanitary drainage systems
SSD (subsoil or footing drains), 2004 V1:8, 30
ssf, SSF (Saybolt Seconds Furol), 2004 V1:16, 2000 V3:154
ssu, SSU (Saybolt Seconds Universal), 2004 V1:16, 2000 V3:154
ST (storm or rainwater drains). *See* storm-drainage systems
stability index (Ryzner), 2005 V2:207–208
stabilization ponds, 2005 V2:157
stack groups, 2004 V1:30
stack vents
air in, 2005 V2:2
defined, 2004 V1:30, 2005 V2:41
sizing, 2005 V2:43–44
stack venting defined, 2004 V1:30
stacks. *See* vertical stacks
stadiums, numbers of fixtures for, 2001 V4:19
staff areas (health-care facilities), 2000 V3:33–34
staff lounges, 2000 V3:32
staged evaporation, 2005 V2:210–211
stages in pump equipment, 2005 V2:169
stagnant water, 2005 V2:81
stain-resistance testing, 2001 V4:2
stainless steel
commercial sinks, 2001 V4:12
electromotive force series, 2004 V1:144
filtration tanks, 2000 V3:131
fixtures, 2000 V3:33, 2001 V4:2
fountains and, 2000 V3:116
glass pipe couplings, 2001 V4:48
nickel content, 2001 V4:2
passivation, 2004 V1:146–147
pump shafts, 2000 V3:145
stainless-steel drains, 2005 V2:250, 2000 V3:143
stainless-steel grates, 2005 V2:15
stainless-steel piping
compressed air systems, 2000 V3:210
exposed piping on storage tanks, 2000 V3:165
fountains and, 2000 V3:119
industrial waste pipe, 2005 V2:249
pure-water system, 2000 V3:47–48
soil and waste pipe, 2005 V2:13
USP water, 2005 V2:233
vacuum systems, 2005 V2:183
stainless-steel storage tanks, 2005 V2:233, 2000 V3:91
stairs and stairwells
aboveground storage tanks, 2000 V3:165, 166–167
standpipe systems, 2000 V3:19
stale sewage, 2004 V1:30
stall urinals, 2001 V4:9, 10
standard (std, STD), 2004 V1:16
standard air, 2004 V1:18, 2000 V3:200
standard atmospheric pressure
defined, 2000 V3:200
in vacuums, 2005 V2:175
standard cartridge depth filtration, 2005 V2:211
standard cfh (scfh), 2005 V2:131

standard cubic feet per minute (scfm). *See* scfm, SCFM (standard cubic feet per minute)
standard dimension ratio (SDR), 2001 V4:61
standard fire-protection symbols, 2004 V1:12–13
standard fire tests, 2000 V3:3
Standard for Bulk Oxygen Systems at Consumer Sites (NFPA 50), 2000 V3:61, 86
Standard for Color-marking of Compressed Gas Cylinders Intended for Medical Use (CGA C-9), 2000 V3:86
Standard for Health-care Facilities (NFPA 99), 2005 V2:182, 2000 V3:86, 2001 V4:45
Standard for Hypochlorites, 2005 V2:104
Standard for Liquid Chlorine, 2005 V2:104
Standard for Parking Structures, 2005 V2:127
Standard for Portable Fire Extinguishers (NFPA 10), 2000 V3:27, 29
Standard for Public Swimming Pools (ANSI/NSPI-1), 2000 V3:125, 151
Standard for Residential, In-ground Swimming Pools (ANSI/NSPI-5), 2000 V3:151
Standard for Tank Vehicles for Flammable and Combustible Liquids (NFPA 385), 2000 V3:154
Standard for the Installation of Nitrous Oxide Systems at Consumer Sites (CGA G-8.1), 2000 V3:86
Standard for the Installation of Sprinkler Systems, 2004 V1:191
Standard for the Machining and Finishing of Aluminum and the Production and Handling Aluminum Products (NFPA 651), 2000 V3:20
Standard for the Processing and Finishing of Aluminum (NFPA 65), 2000 V3:20
Standard for the Production, Processing, Handling and Storage of Titanium (NFPA 481), 2000 V3:20
Standard for the Production, Processing, Handling and Storage of Zirconium (NFPA 482), 2000 V3:20
Standard for the Storage, Handling and Processing of Magnesium Solids and Powders (NFPA 480), 2000 V3:20
standard free air
  at atmospheric pressure (scfm). *See* scfm, SCFM (standard cubic feet per minute)
  in vacuum sizing calculations, 2005 V2:185
standard gallons per hour, 2004 V1:15
Standard Handbook for Mechanical Engineers, 2004 V1:1
Standard Method of Test of Surface Burning Characteristics of Building Materials (NFPA 255), 2000 V3:77
Standard on Flow Testing and Marking of Fire Hydrants (NFPA 291), 2000 V3:3
standard plumbing and piping symbols, 2004 V1:7–13
Standard Plumbing Code, 2005 V2:64
Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings, 2001 V4:37
standard reference points (compressed air), 2000 V3:200
Standard Specification for Concrete Sewer, Storm Drain, and Culvert Pipe for Non-reinforced Concrete, 2001 V4:32
Standard Specification for Copper Drainage Tube (DWV), 2001 V4:45
Standard Specification for Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber Gaskets, 2001 V4:32
Standard Specification for Liquid and Paste Fluxes for Soldering Applications of Copper and Copper Alloy Tube, 2001 V4:37
Standard Specification for Reinforced Concrete Culverts, Storm Drain, and Sewer Pipe, 2001 V4:32
Standard Specification for Reinforced Concrete D-Load Culvert Storm Drain and Sewer Pipe for Reinforced Concrete Pipe, 2001 V4:32
Standard Specification for Seamless Copper Pipe, Standard Sizes, 2001 V4:34
Standard Specification for Seamless Copper Tube for Medical Gas Systems, 2001 V4:45
Standard Specification for Seamless Red Brass Standard Sizes, 2001 V4:27
standard time meridian (STM), 2004 V1:16
standard water closets, 2001 V4:4
standard-weight brass pipe (Schedule 40), 2001 V4:27
standard-weight steel pipe, 2001 V4:48
standards. *See* codes and standards
standby losses
  in circulating systems, 2004 V1:127
  water heaters, 2004 V1:265
standpipe systems
  classifications and characteristics, 2000 V3:18–19
  defined, 2004 V1:24, 30
  fire pumps for, 2000 V3:25
  flat land storage tanks, 2005 V2:170
  overflow standpipes, 2000 V3:125
  standpipe air chambers, 2005 V2:80–81, 81
  swimming pools and, 2000 V3:139
  symbols for, 2004 V1:13
  system classes of service, 2004 V1:30
  system types, 2004 V1:30
starting unloaders, 2000 V3:205
state agencies, 2005 V2:237, 248, 2000 V3:88
state frost lines, 2000 V3:226
state rainfall rate tables, 2005 V2:53–57
states in creativity checklist, 2004 V1:234
static deflection for pump vibration, 2004 V1:205
static fountain displays, 2000 V3:111, 119
static head
  calculating, 2004 V1:2
  gallons per minute and, 2005 V2:83, 84
  swimming pool gutters and, 2000 V3:142
  velocity head and, 2004 V1:5
  well pumps, 2005 V2:170
static pressure (SP)
  defined, 2005 V2:68
  domestic water supply, 2000 V3:217–221
  elevation and, 2005 V2:96
  fire hydrants, 2000 V3:4–5
  irrigation flow, 2000 V3:105
  sprinkler hydraulic calculations, 2000 V3:16
  symbols, 2004 V1:15, 16
  water mains, 2000 V3:216
static wells, 2005 V2:165–166
stations (medical gas and vacuum)
  ceiling outlets, 2000 V3:57
  estimating number, 2000 V3:50, 51–52

inlets, 2000 V3:85
medical gas diversity factors, 2000 V3:75
medical vacuum, 2000 V3:54
order of gas outlets, 2000 V3:56
outlets, 2000 V3:85
patient headwall gas systems, 2000 V3:56–57
surgical ceiling columns, 2000 V3:57–58
terminals, 2000 V3:54–56
types of, 2000 V3:58
std, STD (standard), 2004 V1:16
std gph (standard gallons per hour), 2004 V1:15
steady flow in horizontal drains, 2005 V2:6, 8
steady-state heat balance equations, 2005 V2:109–110
steam and condensate systems
condensate drainage, 2000 V3:189–197
flashing flow and high-pressure piping, 2000 V3:196–197
problems, 2000 V3:189–191
proper drainage, 2000 V3:191–196
distilling water from steam, 2005 V2:210–211
geothermal, 2004 V1:131
high-pressure steam, 2004 V1:9
low-pressure steam, 2004 V1:9, 15
medium-pressure steam, 2004 V1:9, 15
overview, 2000 V3:175
references, 2000 V3:197
sizing pipes, 2000 V3:177
steam atmospheric vents, 2004 V1:9
steam tables, 2000 V3:176
steam traps. *See* steam traps
system classifications, 2000 V3:175–189
condensate return methods, 2000 V3:186–189
operating pressure range, 2000 V3:175–178
piping arrangement classifications, 2000 V3:178–186
waste heat usage of condensate, 2004 V1:131–134
steam deaerators, 2005 V2:209
steam-fired water heaters, 2004 V1:130
steam heat exchangers, 2000 V3:121
steam traps, 2000 V3:182–186
collection legs and, 2000 V3:191
oversizing, 2000 V3:191, 196
parallel trapping, 2000 V3:196
pressure differentials, 2000 V3:191
seat pressure ratings, 2000 V3:193
strainers, 2000 V3:195
symbol, 2004 V1:11
steam vaporizers, 2000 V3:61
steatite fixtures, 2001 V4:2
steel. *See also* stainless steel; steel piping
beam connections in pipe bracing, 2004 V1:175, 176
in electromotive force series, 2004 V1:144
fixtures, 2001 V4:2
floor decks in earthquakes, 2004 V1:167
in galvanic series, 2004 V1:141
roofing drains, 2005 V2:63
springs, 2004 V1:204, 208
steel substrate roofing drains, 2005 V2:63
storage tanks, 2000 V3:155
underground tanks, 2000 V3:172
water tanks, 2005 V2:170
Steel Above Ground Tanks for Flammable and Combustible Liquids (UL 142), 2000 V3:95, 154, 165
steel fixtures, 2001 V4:2
steel piping. *See also* galvanized-steel piping; stainless-steel piping
dimensions, 2001 V4:51–55
fittings, 2001 V4:48
fuel-product dispensing, 2000 V3:169
Manning formula and, 2000 V3:245
natural gas, 2000 V3:254
radioactive wastes, 2005 V2:249
roughness, 2005 V2:86
surface roughness, 2005 V2:83
types, 2001 V4:48, 51–55
velocity and, 2005 V2:92
Steel Tank Institute (STI), 2000 V3:154
Steel Tanks for Oil Storage (API 250), 2000 V3:95
Steel Underground Tanks for Flammable and Combustible Liquids (UL 58), 2000 V3:95
Steele, Alfred, 2004 V1:40, 2005 V2:64, 104
Stenzel, Mark H., 2005 V2:234
step heaters, 2000 V3:144
steradians, 2004 V1:33
sterilization
feed water, 2005 V2:205
infectious waste systems, 2005 V2:252
pure water systems, 2005 V2:233
ultraviolet, 2000 V3:47
sterilizers, 2000 V3:36, 38, 39
Stevens Building Technology Research Laboratory, 2005 V2:19
Stevens Institute of Technology, 2005 V2:48
STI (Steel Tank Institute), 2000 V3:154
sticking (manual tank gauging), 2000 V3:159
stilling wells, 2000 V3:124
stills, 2005 V2:210–211, 2000 V3:39, 46
STM (standard time meridian), 2004 V1:16
stop levers in showers, 2004 V1:136
stop valves, 2004 V1:30, 2000 V3:33
storage
costs, 2004 V1:223
fire hazard evaluation, 2000 V3:2
of gray water, 2005 V2:28, 35
of medical gases
medical compressed air, 2000 V3:65–68
nitrogen, 2000 V3:68
nitrous oxide, 2000 V3:64–65
oxygen, 2000 V3:59–63
of pure water, 2005 V2:233
of rainwater, 2005 V2:52–53
section in specifications, 2004 V1:70, 89–90
of sewage in septic tanks, 2005 V2:154
storage plants, 2001 V4:20
storage reservoirs, 2000 V3:90
storage rooms, 2000 V3:73
storage tanks. *See* tanks
stores, numbers of fixtures for, 2001 V4:20
storm building drains. *See* storm-drainage systems
Storm Drainage Design and Detention using the Rational Method, 2005 V2:64
storm drainage pipe codes, 2004 V1:42

storm-drainage systems, 2000 V3:240–248. *See also* rainwater and precipitation
building drainage systems, 2005 V2:50–52
calculations, 2005 V2:56–64, 2000 V3:244–245
cast-iron soil-pipe building drains, 2001 V4:27
codes, 2004 V1:42–44, 2000 V3:240
codes and standards, 2005 V2:50
controlled-flow systems, 2005 V2:52–53
design criteria, 2005 V2:50–52
design storms, 2000 V3:242
disposal methods, 2000 V3:245–247
drywells, 2000 V3:247
existing flow paths, 2000 V3:247
limited-discharge roof drains, 2000 V3:247
public sewers, 2000 V3:245–247
recharge basins, 2000 V3:247
retention basins, 2000 V3:247
green roof designs, 2004 V1:266
green uses of, 2004 V1:264
introduction, 2005 V2:49–50
materials, 2005 V2:50
overview, 2000 V3:240
pipe sizing and layout, 2005 V2:49–59, 61
preliminary information, 2000 V3:215–216
Rational method, 2004 V1:7, 2000 V3:242–244
reinforced concrete pipe building drains, 2001 V4:32
roof drainage, 2005 V2:53–56
sample utility letters, 2000 V3:240
secondary drainage systems, 2005 V2:55–56
sizing, 2000 V3:244–245, 246
sizing ditches, 2000 V3:247–248
sizing sheet, 2005 V2:66
storm drains (SD, ST), 2004 V1:8
storm sewers defined, 2004 V1:30
storm water in pools and fountains, 2000 V3:110
swimming pool water and, 2000 V3:131, 139
Storm Water Retention Methods, 2005 V2:64
STPs (sewage treatment plants), 2005 V2:27, 35
straight lobe compressors, 2000 V3:202
strain, defined, 2004 V1:30
strainers
basket strainers. *See* basket strainers
cold water systems, 2005 V2:70
downspouts, 2005 V2:63
fountain pumps, 2000 V3:116
pressure losses, 2000 V3:224
roof drains, 2005 V2:53, 63
sanitary drainage systems, 2005 V2:10–11
sediment buckets, 2005 V2:11
steam traps, 2000 V3:195
symbols for, 2004 V1:10
stratification in water heaters, 2005 V2:114
stray current corrosion, 2004 V1:141, 154
stream-spray irrigation sprinklers, 2000 V3:103
streamline fittings (avoiding suds formation), 2005 V2:45
streams, irrigation systems and, 2005 V2:30
stress
conversion factors, 2004 V1:36
measurements, 2004 V1:33
stress-accelerated corrosion, 2004 V1:154
stress corrosion, 2004 V1:154
stress-corrosion cracking, 2004 V1:141, 154, 2005 V2:206
strip-chart recorder water meters, 2005 V2:69
strip methods in pipe manufacturing, 2001 V4:32
strong-base regeneration, 2005 V2:216, 218
strongbacks, 2004 V1:163
strontium 90, 2005 V2:248
structural angle bracing, 2004 V1:171
structural channel bracing, 2004 V1:171
structural strength
bath and shower seats, 2004 V1:122–123
grab bars, 2004 V1:122
structure-borne sound, 2004 V1:196, 199
strut bracing, 2004 V1:173, 175
styrofoam blocking on glass pipe, 2001 V4:47
sub-micron cartridge filtration, 2005 V2:211
sub-sterilizing rooms, 2000 V3:32, 36
subdrains, building, 2004 V1:20
submain sewers, 2004 V1:30
submersible pumps
fountain display pumps, 2000 V3:113
protection of wells, 2005 V2:166
shallow wells, 2005 V2:170
sizing, 2000 V3:170
underground storage tanks, 2000 V3:164
well pumps, 2005 V2:168
submittals section in specifications, 2004 V1:69, 88–89
subsoil drainage pipe, 2004 V1:44
subsoil drains (SSD), 2004 V1:8, 30
substances, amount (moles), 2004 V1:33
substituting products
in proprietary specifications, 2004 V1:68
value engineering process and, 2004 V1:211
subsurface drip irrigation systems, 2005 V2:30
subsurface obstructions, swimming pool locations and, 2000 V3:128
subsurface waste-disposal systems. *See* soil-absorption sewage systems
subsurface water. *See* ground water
SUC (suction), 2004 V1:16
suct., SUCT (suction), 2004 V1:16
suction (suct., SUCT, SUC), 2004 V1:16
suction basket strainers, 2000 V3:115
suction diffusers, 2000 V3:116
suction fuel-delivery systems, 2000 V3:162–163
suction inlets
in fountains, 2000 V3:117
in storage tanks, 2005 V2:171
suction piping, 2004 V1:202, 2005 V2:171, 2000 V3:117
suction sand filters, 2000 V3:134
suction screens, 2000 V3:116
suction-type pumps, 2005 V2:165
sudden enlargements, 2005 V2:100
suds
pressure zones, 2005 V2:45–46
venting, 2005 V2:45–46
sulfate-reducing bacteria, 2005 V2:199
sulfates, 2005 V2:199, 200, 216
sulfides, 2004 V1:146
sulfites, 2005 V2:199, 226, 2000 V3:147
sulfur, 2005 V2:199
sulfur dioxide, 2000 V3:93
sulfuric acid
pool chemicals, 2000 V3:150

in regeneration, 2005 V2:218
special wastes, 2005 V2:240–242
storage tanks, 2000 V3:91–92
in water chemistry, 2005 V2:199
sulfurous acid, 2005 V2:199
SUM (summary, summation), 2004 V1:16
summary section in specifications, 2004 V1:69, 88
summary, summation (SUM), 2004 V1:16
sumps and sump pumps
acoustic problems, 2004 V1:197
containment sumps, 2000 V3:156
duplex sump pump systems, 2005 V2:8
fixture-unit values, 2005 V2:8
flexible pipe connectors, 2000 V3:169
floor drains and, 2005 V2:10
liquid-waste decontamination systems, 2005 V2:251–252
pool mechanical spaces, 2000 V3:111
roof drainage and, 2005 V2:54
sanitary drainage systems, 2005 V2:8, 9
sump pits, 2005 V2:252, 2000 V3:111
sump pumps defined, 2004 V1:30
sumps defined, 2004 V1:30
vibration isolation, 2004 V1:208
Sun, T.Y., 2004 V1:191
sunlight
protecting against, 2005 V2:16, 2000 V3:116, 165
solar energy. *See* solar energy
SUP (supplies), 2004 V1:16
superchlorination, 2000 V3:147, 148, 149
supercritical flow, 2005 V2:49. *See also* hydraulic jumps in flow
Superfund Amendment and Reauthorization Act of 1986 (SARA Title III), 2000 V3:88, 2000 V3:154
superstrut bracing, 2004 V1:170
supervised heat-up, 2000 V3:191, 194
supervisory (tamper) switches, 2004 V1:30
supplementary conditions, 2004 V1:62
supplementary units of measurement, 2004 V1:33
supplies (sply., SPLY, SUP)
abbreviations, 2004 V1:16
ongoing and one-time costs, 2004 V1:223
supply air (sa, SA), 2004 V1:16
supply fixture units, 2004 V1:24
supply valves, 2000 V3:179
support mats in filtration, 2000 V3:134
supports and hangers
alternate attachment to hangers, 2004 V1:174
clean agent gas pipes, 2000 V3:24
codes, 2004 V1:43
defined, 2004 V1:30
hanger rod connections in bracing, 2004 V1:171
hanger rod gravity forces in earthquakes, 2004 V1:186
installation productivity rates, 2004 V1:96
isolation hangers, 2004 V1:203
materials, 2004 V1:43
medical gas piping, 2000 V3:73
resilient pipe hangers, 2004 V1:199
sanitary drainage systems, 2005 V2:12–13
in sanitary drainage systems, 2005 V2:12–13
sprinkler systems, 2000 V3:15
symbols for, 2004 V1:13
vacuum cleaning tubing, 2005 V2:189
SUR (surfaces), 2004 V1:16
SURD (surfaces, dry), 2004 V1:16
surface abrasions
corrosion and, 2004 V1:146
grab bars, 2004 V1:122
surface efficiency (SEFF), 2004 V1:14
surface evaporation, 2000 V3:121
surface fault slips, 2004 V1:158
surface fires, 2000 V3:19
surface-mounted pumps, 2005 V2:168
surface runoff. *See* runoff
surface skimmers. *See* skimmers
surface-type sprinkler spray heads, 2000 V3:101
surface water
as feed water for pure water systems, 2005 V2:230
defined, 2005 V2:198
discharge permits for, 2000 V3:89
Surface Water Treatment Rule, 2005 V2:227
surfaces (SUR, S)
dry (SURD), 2004 V1:16
fixture materials, 2001 V4:1
symbols for, 2004 V1:16
wet (SURW), 2004 V1:16
surge chambers, 2000 V3:142, 143, 212
surge pits, 2000 V3:108, 109
surge pressure. *See* water hammer
surge tanks, 2005 V2:30, 2000 V3:137, 140
surges
in horizontal drains, 2005 V2:5
swimming pool pumps, 2000 V3:139
surgical ceiling columns, 2000 V3:57–58
surgical clean-up areas, 2000 V3:32
surgical gas track systems, 2000 V3:58–59
surgical instruments, 2000 V3:59, 68
surgical scrub areas, 2000 V3:32
surgical supply areas, 2000 V3:32
surgical vacuum (SV), 2004 V1:9
surveys in plumbing cost estimation, 2004 V1:93
SURW (surfaces, wet), 2004 V1:16
suspended equipment
fixed suspended equipment, 2004 V1:164
vibration-isolated, suspended equipment, 2004 V1:166
suspended metals in wastes, 2000 V3:93
suspended piping, earthquake recommendations, 2004 V1:162
suspended solids
defined, 2005 V2:198
filtration, 2005 V2:211
removing, 2005 V2:209
total suspended solids, 2005 V2:203–204
turbidity, 2005 V2:198
suspended tanks, 2004 V1:162
suspension, defined, 2005 V2:198
sustainable design, 2004 V1:263–267
Sustainable Sites design (LEED), 2004 V1:263
SV (service) cast-iron soil pipe, 2001 V4:27, 30–31
SV (surgical vacuum), 2004 V1:9
swamp gas, 2005 V2:201
sway bracing
acceptable types, 2004 V1:187
horizontal loads for, 2004 V1:185–186

lateral and longitudinal, 2004 V1:181–182, 185–186
longitudinal and transverse, 2004 V1:179, 180
potential problems, illustrated, 2004 V1:189
sway in piping, 2004 V1:162
swelling characteristics of soils, 2005 V2:149
swimming pools
applying standards to reflecting pools, 2000 V3:107
components and materials
backwash pits, 2000 V3:143
cleaning equipment, 2000 V3:146
filtration systems, 2000 V3:131–137, 139–140, 143–144
fittings, 2000 V3:137, 144, 145
flow indicators, 2000 V3:142
gutters, 2000 V3:142
heaters, 2000 V3:144–145
ladders, 2000 V3:145
main drains, 2000 V3:143
piping, 2000 V3:145
pumps, 2000 V3:140–142
skimmers, 2000 V3:142, 146
surge chambers, 2000 V3:143
underwater lights, 2000 V3:145
vacuum cleaning lines, 2000 V3:144
valves and pumps, 2000 V3:145–146
water heaters, 2000 V3:138–139, 146
water supply and drainage, 2000 V3:131
defined, 2004 V1:30
design parameters, 2000 V3:127–130
bathhouses, toilets, and showers, 2000 V3:130
location, 2000 V3:128
physical characteristics, 2000 V3:128–130
size and capacity, 2000 V3:127–128
disinfection, 2000 V3:148–151
algaecides, 2000 V3:150
aluminum sulfate, 2000 V3:149–150
breakdown chlorination, 2000 V3:149
calcium hypochlorite, 2000 V3:148–149
chemical feeding equipment, 2000 V3:150–151
chlorine gas, 2000 V3:148
cleaning filters, 2000 V3:150
cyanurates, 2000 V3:149
filtration turnover rates, 2000 V3:140
sodium hypochlorite, 2000 V3:149
sulfuric acid, 2000 V3:150
superchlorination, 2000 V3:149
grate materials, 2005 V2:13
heat loss retardants, 2000 V3:150
indoor and outdoor pools, 2000 V3:139
numbers of fixtures for, 2001 V4:19
numbers of swimmers, 2000 V3:127–128
overview, 2000 V3:127
references, 2000 V3:151
resources, 2000 V3:151
sequestering agents, 2000 V3:150
water chemistry, 2000 V3:146–148
mineral deposits, 2000 V3:147–148
pH values, 2000 V3:147
water supply, 2000 V3:131
Swimming Pools: A Guide to their Design and Operations, 2000 V3:151
swing check valves, 2005 V2:100, 172, 2000 V3:118
switch-gear rooms, 2000 V3:73
SWRO (spiral wound modules), 2005 V2:205, 221–222
SYGEF piping, 2000 V3:48
symbols
fire protection, 2004 V1:12–13
references, 2004 V1:40
standardized plumbing and piping symbols, 2004 V1:7–13
Synthesis phase in value engineering, 2004 V1:213
synthetic fiber gas filters, 2000 V3:250
synthetic resins, 2005 V2:215
SYS (systems), 2004 V1:16, 137
system descriptions in specifications, 2004 V1:69, 88
system performance criteria in specifications, 2004 V1:69, 88
Systeme International and d'Unites, 2004 V1:32
systems (SYS)
defined, 2004 V1:137
diagramming, 2004 V1:231
symbols for, 2004 V1:16
value engineering questions, 2004 V1:213–214

T

t (metric tons), 2004 V1:34
T STAT (thermostats), 2004 V1:16
)t, TD (temperature differences), 2004 V1:16, 136
T (temperature). *See* temperature
T (tera) prefix, 2004 V1:34
T (teslas), 2004 V1:33
T (time). *See* time
T&P valves (temperature and pressure relief), 2005 V2:115–116
tab, TAB (tabulation), 2004 V1:16
table salt, 2000 V3:150
tablespoons, converting to SI units, 2004 V1:40
tabular take-off sheets, in cost estimations, 2004 V1:94
tabulation (tab, TAB), 2004 V1:16
take-off estimating method, cost estimating, 2004 V1:94–95
Take the Guesswork out of Demineralizer Design, 2005 V2:234
tamper switches, 2004 V1:30
tamping fill, 2005 V2:15
Tanaka, T., 2005 V2:234
tangential-flow filtration, 2005 V2:211, 221
tank-mounted product dispensers, 2000 V3:168
tank-refilling acoustics, 2004 V1:194
tank-type water closets, 2004 V1:135–136
tank-type water heaters, 2004 V1:129
tankless water heaters, 2004 V1:129–130
tanks. *See also* septic tanks
aboveground tanks, 2000 V3:90–91, 165–169
connections and access, 2000 V3:166
construction, 2000 V3:165
corrosion protection, 2000 V3:165
filling and spills, 2000 V3:166–167
leak prevention and monitoring, 2000 V3:167–168
materials, 2000 V3:165
overfill prevention, 2000 V3:167
product dispensing systems, 2000 V3:168
tank protection, 2000 V3:169
vapor recovery, 2000 V3:168

venting, 2000 V3:167
calculating volume, 2005 V2:73–74
carbon dioxide extinguishing systems, 2000 V3:20, 21
cryogenic, 2000 V3:62
distilled water systems, 2000 V3:46
drinking water storage, 2005 V2:170–171
earthquake damage, 2004 V1:161, 162
earthquake protection, 2004 V1:163–164, 188, 189
expansion tanks, 2005 V2:76–77
fire-protection supplies, 2000 V3:226
firefighting drainage, 2005 V2:254
gauges, 2000 V3:166
gravity tank systems, 2005 V2:74–76
hazardous waste incompatibilities, 2000 V3:90, 91
hydropneumatic-tank systems, 2005 V2:72, 73–74
kill tanks, 2005 V2:252
Legionella growth in, 2005 V2:118, 120
liquefied petroleum gas, 2005 V2:142
liquid fuel tanks
connections and access, 2000 V3:156–157
construction, 2000 V3:156
filling and spills, 2000 V3:156–157
installation, 2000 V3:172
materials, 2000 V3:155–156
overfill prevention, 2000 V3:158
venting, 2000 V3:157–158
natural gas systems, 2005 V2:142
protection, 2000 V3:169
radioactive wastes, 2005 V2:250
settling tanks, 2000 V3:93
storage tanks defined, 2000 V3:153
suspended, 2004 V1:164
tank end deflection, 2000 V3:172
tank farms, 2004 V1:150
thermal expansion tanks, 2005 V2:116
tightness testing, 2000 V3:161–162, 171, 2000 V3:172, 2000 V3:172
underground tanks, 2000 V3:90–91
illustrated, 2000 V3:164
liquid fuel tanks, 2000 V3:155–158
venting, 2000 V3:157–158, 166, 2000 V3:167
vibration isolation, 2004 V1:205
water storage tanks, 2005 V2:233, 2000 V3:44
tannin in water, 2000 V3:147
tapping illegally into water lines, 2005 V2:68
tappings for cast iron radiators, 2000 V3:179
taps
large wet tap excavations, 2000 V3:222
pressure loss and, 2000 V3:221
target areas in water closets, 2001 V4:4
taste of drinking water, 2005 V2:168, 227
TAU (transmissivity), 2004 V1:16
taverns and bars, numbers of fixtures for, 2001 V4:19, 22
taxes
in labor costs, 2004 V1:94
in plumbing cost estimation, 2004 V1:94
tc, TC (thermocouple), 2004 V1:16
Tchobanoglous, George, 2000 V3:125
TCPL (thermocouple), 2004 V1:16
TD (temperature differences), 2004 V1:16, 136
TD (turndown ratio), 2005 V2:133
TDIF (temperature differences), 2004 V1:16
TDS (total dissolved solids), 2005 V2:204, 227
TE (temperature entering), 2004 V1:16
teaspoons, converting to SI units, 2004 V1:40
technetium 99, 2005 V2:248
technology advances, value engineering and, 2004 V1:212
Technology for the Storage of Hazardous Liquids, 2000 V3:96
tectonic plates, 2004 V1:156–158
tee-wyes, flow capacity and, 2005 V2:4
tees (TEE), 2004 V1:10, 16
Teflon, 2005 V2:249, 2000 V3:42
temp., TEMP (temperatures). *See* temperature
TEMP. HW (tempered hot water), 2004 V1:8
TEMP. HWR (tempered hot water recirculating), 2004 V1:8
temperature (temp., TEMP, T)
acid wastes, 2000 V3:40
bathtub water notes, 2004 V1:119
cast iron radiators, 2000 V3:180
compressed air systems and, 2000 V3:211
conversion factors, 2004 V1:37, 38
cooling air compressors, 2000 V3:202
corrosion rates and, 2004 V1:145
CPVC *vs.* PVC piping, 2001 V4:62
deaeration water temperatures, 2005 V2:209
dew points, 2000 V3:201
elevated temperatures for removing Legionella, 2005 V2:120
feed water temperature and deposits, 2005 V2:207, 224, 231
hot-water properties, 2005 V2:117
hot-water relief valves, 2005 V2:115–116
hot-water temperatures, 2005 V2:111, 112–114, 114, 2000 V3:36, 45
Legionella growth and, 2005 V2:118–120
maintenance hot-water temperatures, 2005 V2:115
measurements, 2004 V1:33
microbial control in water, 2005 V2:224
mixed-water temperatures, 2005 V2:111
natural gas, 2005 V2:131
non-SI units, 2004 V1:34
pipe expansion and contraction, 2004 V1:3
PVC pipe and, 2001 V4:62
rate of rise detection, 2000 V3:13
scalding water, 2005 V2:122–124
shower compartments, 2004 V1:120, 2001 V4:15
special-waste effluent, 2005 V2:238
specific resistance and, 2005 V2:203
sprinkler head ratings, 2000 V3:17
storage tanks and piping, 2000 V3:172
stratification, 2000 V3:172
swimming pools, 2000 V3:139
symbols for, 2004 V1:16
temperature differences (TD, Δt, TDIF), 2004 V1:16, 136
temperature differentials, 2004 V1:125–126
temperature entering (TE, TENT), 2004 V1:16
temperature leaving (TL, TLEA), 2004 V1:16
temperature stratification, 2000 V3:172
thermal support systems and earthquakes, 2004 V1:168
water heaters, 2005 V2:107, 111

water vapor in air and, 2000 V3:200–201
water volume and, 2005 V2:77
Temperature Limits in Service Hot Water Systems, 2005 V2:124
temperature-pressure-relief valves (TPV), 2004 V1:10, 2005 V2:115–116
temperature stratification, 2000 V3:172
tempered water
defined, 2004 V1:30
tempered hot water (TEMP. HW, TW), 2004 V1:8
tempered hot water recirculating (TEMP. HWR, TWR), 2004 V1:8
tennis courts, numbers of fixtures for, 2001 V4:19
tensile strength
plastic pipe, 2001 V4:60
PVC pipe and, 2001 V4:62
Tension 360 bracing, 2004 V1:169
tension problems in seismic protection, 2004 V1:190
TENT (temperature entering), 2004 V1:16
Tentative Provisions for the Development of Seismic Regulations for Buildings, 2004 V1:183, 191
"tera" prefix, 2004 V1:34
terminal elements, defined, 2004 V1:137
terminal length, defined, 2005 V2:1
terminal velocity
defined, 2005 V2:1
stack capacities and, 2005 V2:4
stack terminal velocity, 2004 V1:3
terminal vents. *See* vent stack terminals
terminals, passenger, 2001 V4:19
termites, 2000 V3:116
tertiary treatment of gray water, 2005 V2:31, 35
teslas, 2004 V1:33
test block conditions in gas boosters, 2005 V2:134
test fittings, 2000 V3:195
test headers, 2004 V1:12
test-method standards, 2004 V1:66
test station cathodic protection, 2004 V1:151
testing
acoustic ratings of fixtures and appliances, 2004 V1:194–195
cold-water systems, 2005 V2:103
fountain piping systems, 2000 V3:117
gaseous fire-suppression systems, 2000 V3:24–25
hot-water relief valves, 2005 V2:116
hydrants, 2000 V3:4
hydraulic soil conditions, 2005 V2:147–150
liquid fuel systems, 2000 V3:170–172
medical-gas alarms, 2000 V3:81
medical-gas systems, 2000 V3:77–83
natural gas services, 2000 V3:252, 253
percolation rates for soils, 2005 V2:149–150
pipes for radioactive waste systems, 2005 V2:249
plastic fixtures, 2001 V4:2
swimming pools, 2000 V3:131
tank tightness testing, 2000 V3:161–162, 171, 2000 V3:172, 2000 V3:172
urinal tests, 2001 V4:9
water closet flushing, 2001 V4:5–6
welders for radioactive pipe systems, 2005 V2:249
wells, 2005 V2:166
tetrafluoroethylene (TFE), 2001 V4:48
text, abbreviations in, 2004 V1:14–16
texture of soils, 2005 V2:148–149
theaters
numbers of fixtures for, 2001 V4:19, 21
vacuum calculations for, 2005 V2:190
theoretical barometric pressure, 2000 V3:200
theoretical standard atmospheric pressure, 2000 V3:200
therapy pools, 2000 V3:128
therm, converting to SI units, 2004 V1:40
thermal conductivity (*k,* K)
measurements, 2004 V1:33
plastic pipe, 2001 V4:60
symbols for, 2004 V1:16
thermal efficiency
defined, 2004 V1:30, 136
water heaters and, 2005 V2:116–117
thermal expansion
backflow prevention and, 2005 V2:70
converting to SI units, 2004 V1:39
hot-water systems and, 2005 V2:116
sanitary drainage systems, 2005 V2:16
thermal expansion coefficients (TXPC), 2004 V1:16
thermal expansion tanks, 2005 V2:116
thermal expansion loops, 2004 V1:162
thermal-hydraulic irrigation valves, 2000 V3:103
thermal insulation thickness, 2004 V1:127
thermal movement, sound insulation and, 2004 V1:193
thermal resistance (*R,* R, RES), 2004 V1:16
thermal-shock protection, 2004 V1:120
thermal shock treatments, 2005 V2:118
thermal-support systems, earthquakes and, 2004 V1:168
thermocompression distillation, 2005 V2:210
thermocouple (tc, TC, TCPL), 2004 V1:16
thermodisc traps, 2000 V3:182, 186
thermodynamic steam traps, 2000 V3:182, 194
thermometers, 2004 V1:10
thermoplastic pipes, 2001 V4:58
thermoset plastic, 2000 V3:155, 2001 V4:58
thermostatic bellows, 2000 V3:182
thermostatic-mixing shower valves, 2001 V4:15, 18
thermostatic-mixing tub valves, 2001 V4:16
thermostatic radiator vents, 2000 V3:179
thermostatic steam traps, 2000 V3:182, 186, 194, 196
thermostats (T STAT), 2004 V1:16
thickness (thkns, THKNS, THK)
of soils, 2005 V2:149
symbols for, 2004 V1:16
Thickness Design, 2001 V4:32
thinking outside the box, 2004 V1:232
THK (thickness), 2004 V1:16
thkns, THKNS (thickness), 2004 V1:16
thousand circular mils (Mcm, MCM), 2004 V1:16
thousand cubic feet (Mcf, MCF), 2004 V1:16
thousand foot-pounds (kip ft, KIP FT, KIPFT), 2004 V1:16
thousand pounds (kip, KIP), 2004 V1:16
threaded end connections, 2004 V1:23
threaded joints, 2004 V1:167
threaded outlets, 2005 V2:14
three-compartment sinks, 2001 V4:11, 12
thresholds in shower compartments, 2004 V1:120
throttling damper devices, 2000 V3:144
throttling valves, 2000 V3:118, 140, 144

thrust bearings, 2004 V1:196
thrust blocks, 2000 V3:231
tie-in tests, 2000 V3:82
tie rods, 2000 V3:229
"tight" piping systems, 2004 V1:168
tightness testing, 2000 V3:161–162, 171, 172
tiles in absorption systems, 2005 V2:151
time (T)
  clean agent gas fire suppression, 2000 V3:23
  of concentration in runoff, 2000 V3:244
  in creativity checklist, 2004 V1:234
  intervals in hydraulic shock, 2004 V1:6
  in measurements, 2004 V1:33
  non-SI units, 2004 V1:34
  symbols for, 2004 V1:16
  time in pipes, 2000 V3:244
  time-temperature curves in fire tests, 2000 V3:3
time delays
  clean gas extinguishing systems, 2000 V3:24
  fountain relays, 2000 V3:120–121
time history
  computer analysis, 2004 V1:186
  earthquakes, 2004 V1:159, 160
time switches for fountains, 2000 V3:121
timers for pumps, 2005 V2:73
tin
  corrosion, 2004 V1:139
  galvanic series, 2004 V1:141
  piping, 2005 V2:83
tin-lined copper pipes, 2000 V3:47
tipping prevention, 2004 V1:189
tissue-culture rooms, 2000 V3:45
titanium, 2004 V1:141, 144, 2000 V3:20
TL (temperature leaving), 2004 V1:16
TLEA (temperature leaving), 2004 V1:16
TOC (total organic carbon), 2005 V2:204
toe clearance in toilet compartments, 2004 V1:113, 114
toilet compartments. *See* water-closet compartments
toilet paper
  dispensers, 2004 V1:114
  in septic tanks, 2005 V2:156
toilets. *See also* water closets
  composting, 2004 V1:265
  incinerating, 2004 V1:265
  vacuum toilets, 2005 V2:19
tolerance, 2004 V1:32
tons (TON)
  converting to SI units, 2004 V1:40
  symbols for, 2004 V1:16
  tons of refrigeration (tons, TONS), 2004 V1:16
tools
  tool access in cleanouts, 2005 V2:9
  for vacuum cleaning systems, 2005 V2:190
top coats, 2004 V1:147
top-spud water closets, 2001 V4:3, 8
torch testing, 2001 V4:2
Toro Company, 2000 V3:105
torque
  conversion factors, 2004 V1:35
  converting to SI units, 2004 V1:39
  measurements, 2004 V1:33
torrs, 2005 V2:176
TOT HT (total heat), 2004 V1:16
total (TOT), 2004 V1:16
total alkalinity, 2005 V2:199
total connected loads, 2000 V3:50, 249, 253
total costs
  defined, 2004 V1:222
  generalized, 2004 V1:223
total dissolved solids (TDS), 2005 V2:204, 227, 2000 V3:123
total dynamic head, 2005 V2:169
total flooding systems
  carbon dioxide systems, 2000 V3:20
  defined, 2004 V1:26
  dry-chemical extinguishing systems, 2000 V3:19
total head, 2005 V2:169
total heat (tot ht, TOT HT), 2004 V1:16
total organic carbon (TOC), 2005 V2:204
total pressure loss method, 2005 V2:68, 97, 98
total pumping head, 2005 V2:169
total suspended solids, 2005 V2:203–204
total trihalomethanes (TTHM), 2005 V2:120
total work force in vacuum systems, 2005 V2:179
towers in standpipe systems, 2000 V3:19
TPV (temperature-pressure-relief valves), 2004 V1:10, 2005 V2:115–116
trace elements in water, 2005 V2:200
Trace Level Analysis of High Purity Water, 2005 V2:234
tractor-type grates, 2005 V2:11
traffic loads
  automotive traffic and grates, 2005 V2:11
  cleanouts and, 2005 V2:9
  grates and strainers, 2005 V2:10
trailer parks
  septic tank systems for, 2005 V2:156–157
  sewers, 2004 V1:30
transfer-type showers, 2004 V1:121
transferring hazardous wastes, 2000 V3:90
transition fittings, 2000 V3:252
transmission loss (sound), 2004 V1:209
transmission of noise, 2004 V1:199
transmissivity (TAU), 2004 V1:16
transport trucks, 2000 V3:61
Transportation Department. *See* U.S. Department of Transportation
transportation gas service, 2005 V2:126
transportation gas services, 2000 V3:249
transverse bracing, 2004 V1:167, 171, 191
transverse sway bracing, 2004 V1:179
trap arms
  defined, 2005 V2:41
  length of, 2005 V2:47
trap seals
  controlling induced siphonage, 2005 V2:47
  defined, 2004 V1:31
  factors in trap seal loss, 2005 V2:46–47
  floor drains, 2005 V2:10, 2001 V4:17
  introduction, 2005 V2:46–47
  primer devices, 2001 V4:17
  reducing trap seal losses, 2005 V2:46–47
  tests, 2001 V4:5
  vents and, 2005 V2:47
trapeze

bracing pipes on trapeze, 2004 V1:175, 178
potential problems in bracing, 2004 V1:189
trapeziums, calculating area, 2004 V1:4
trapezoids, calculating area, 2004 V1:4
traps. *See also* trap seals
building traps, defined, 2004 V1:19
condensate traps, 2000 V3:193–195, 195, 196
defined, 2004 V1:31
eliminating siphonage with vents, 2005 V2:47
fixture traps and vents, 2005 V2:47
introduction, 2005 V2:46–47
piping arrangement steam classifications, 2000 V3:182–186
roof drains, 2005 V2:64
sink traps, 2000 V3:42
special-waste drainage systems, 2005 V2:238
steam traps, 2000 V3:180–182
urinals, 2001 V4:9
TRC (tubular modules in reverse osmosis), 2005 V2:221, 222
treated water. *See also* water treatment
defined, 2005 V2:197
from reverse osmosis, 2005 V2:221
systems. *See* gray-water systems
Treating Cooling Water, 2005 V2:234
treatment of black water, 2005 V2:31
treatment of gray water, 2005 V2:30–32, 31, 35
treatment of oil in water, 2005 V2:254–256
Treatment of Organic Chemical Manufacturing Wastewater for Reuse (EPA 600), 2000 V3:96
treatment rooms
fixtures, 2000 V3:35
health-care facilities, 2000 V3:32
medical gas stations, 2000 V3:51
medical vacuum, 2000 V3:54
water demand, 2000 V3:45
tree piping systems, 2000 V3:16
trench drains
in chemical plants, 2005 V2:253
defined, 2001 V4:17
trenches
absorption trenches. *See* soil absorption systems
labor productivity rates, 2004 V1:95–97
sanitary sewer services, 2000 V3:234, 235
storage tank piping, 2000 V3:172
Tri-Services Manual, 2004 V1:183
triage rooms, 2000 V3:35
triangles
calculating area, 2004 V1:4–5
exercise, 2004 V1:232, 261
rule for sink location, 2001 V4:12
trichloroethylene, 2000 V3:70
trickle irrigation, 2000 V3:103
trickling filters, 2000 V3:95
triggering clean agent gas fire suppression, 2000 V3:24
trihalomethanes, 2005 V2:223
triplex air compressors, 2000 V3:213
triplex vacuum pump arrangements, 2005 V2:186
trisodium phosphate, 2005 V2:12
TROs (tubular modules in reverse osmosis), 2005 V2:221, 222
troughs for waterfalls, 2000 V3:109
truss-type bracing, 2004 V1:190
tsunamis, 2004 V1:158
TTHM (total trihalomethanes), 2005 V2:120
tub fillers, 2001 V4:16
tube ozone units, 2005 V2:224
tube washers, 2000 V3:37
tuberculation, 2004 V1:154
tubing
vacuum cleaning hose capacity, 2005 V2:190
vacuum cleaning systems, 2005 V2:190
tubular-bag separators, 2005 V2:188
tubular modules in reverse osmosis, 2005 V2:221, 222
tunnel chases for swimming pool piping, 2000 V3:144
turbidity
clarification of, 2005 V2:208–209
defined, 2005 V2:198
drinking water, 2005 V2:227
measuring, 2005 V2:203–204
removing, 2005 V2:168
turbine meters, 2005 V2:95
turbine pumps, 2005 V2:168–169, 170
turbine water meters, 2005 V2:68, 69
turbo pumps, 2005 V2:180
turbo-surgical instruments, 2000 V3:59
turbulence
defined, 2004 V1:31
determining friction, 2005 V2:84
in rate of corrosion, 2004 V1:145
turbulent flow in pipes, 2004 V1:2
turf imperviousness factors, 2000 V3:243
turndown ratio (TD), 2005 V2:134
turnover rates
gutters and, 2000 V3:142
swimming pools, 2000 V3:140
TW (tempered hot water), 2004 V1:8
twin-agent dry-chemical systems, 2000 V3:20
twin-tower air dryers, 2000 V3:207
two. *See also entries beginning with* double-, dual-, *or* multiple-
two-bed deionizing units, 2000 V3:46
two-compartment septic tanks, 2005 V2:154–155
two-compartment sinks, 2001 V4:11, 12
two-family dwellings, numbers of fixtures for, 2001 V4:20
two-pipe steam systems, 2000 V3:178, 180–182, 185, 186–187
two-pipe venturi suction pumps, 2005 V2:165
two-point vapor recovery, 2000 V3:163
two-stage reduction, 2005 V2:78
two-step deionization (dual-bed), 2005 V2:216, 217
two-valve parallel pressure-regulated valves, 2005 V2:78
two-word expressions of functions, 2004 V1:225, 231
TWR (tempered hot water recirculating), 2004 V1:8
TXPC (thermal expansion coefficients), 2004 V1:16
Type 1 air compressors, 2000 V3:65, 67
Type 2 air compressors, 2000 V3:65
Type A gray-water systems, 2005 V2:32–34
Type ACR/MED pipes, 2001 V4:36
Type ACR pipes, 2001 V4:36
Type B gas vents, 2005 V2:144
Type B gray-water systems, 2005 V2:32–34
Type B vent codes, 2004 V1:43
Type B-W gas vents, 2005 V2:144

Type DWV pipes, 2001 V4:36, 45
Type G copper, 2001 V4:36
Type K copper
copper water tube, 2001 V4:37
dimensions and capacity, 2001 V4:39–40
lengths, standards, and applications, 2001 V4:35
medical gas tube, 2000 V3:77, 2001 V4:45
Type L copper
copper water tube, 2001 V4:37
dimensions and capacity, 2001 V4:41–42
fountains, 2000 V3:119
lengths, standards, and applications, 2001 V4:35
medical gas tube, 2000 V3:77, 2001 V4:45
natural gas, 2000 V3:254
pool water heating and, 2000 V3:122
Type L gas vents, 2005 V2:144
Type L vent codes, 2004 V1:43
Type M copper
copper water tube, 2001 V4:37
dimensions and capacity, 2001 V4:43–44
lengths, standards, and applications, 2001 V4:35
Type OXY/ACR pipes, 2001 V4:36
Type OXY, MED pipes, 2001 V4:36
Type OXY/MED pipes, 2001 V4:36

U

U-factor (U), 2004 V1:16
U, U (heat transfer coefficients), 2004 V1:15
UF membranes, 2005 V2:201
UFAS (Uniform Federal Accessibility Standard), 2004 V1:105–106
UFC (Uniform Fire Code), 2000 V3:154
Uhlig, Herbert H., 2004 V1:154
UL listings
address, 2004 V1:59
gas booster components, 2005 V2:131
hot-water components, 2005 V2:115, 124
list of standards, 2004 V1:57
pipe hangers, 2000 V3:15
ULF. *See* ultra-low-flow water closets
ultra-high vacuum, 2005 V2:175
ultra-low-flow fixture green building credits, 2004 V1:264
ultra-low-flow water closets
operation, 2004 V1:135–136
water usage rates, 2004 V1:134–135
ultra-pure water systems, 2005 V2:228
ultrafilters and ultrafiltration
cross-flow filtration, 2005 V2:211, 223
membrane filters, 2005 V2:221–223
oil spills, 2005 V2:255
Ultraviolet Disinfection in Biotechnology: Myth vs. Practice, 2005 V2:234
ultraviolet radiation treatment of water, 2005 V2:120–122, 168, 223–224, 228, 232, 233
ultraviolet rays
chlorine and, 2000 V3:149
PVC pipes, 2000 V3:116
sterilization, 2000 V3:47
swimming pool disinfection, 2000 V3:150
unassisted creativity, 2004 V1:232
unbalanced motors in pumps, 2004 V1:196
unconsolidated aquifers, 2005 V2:165
undamped mechanical systems, 2004 V1:160
under-counter mounted lavatories, 2001 V4:11
under-counter mounted sinks, 2001 V4:12
under-film corrosion, 2004 V1:154
under-floor areas, 2000 V3:23
under-table waste and vent piping, 2000 V3:42
underdrain systems in sand filters, 2000 V3:132
underground building sanitary pipe codes, 2004 V1:44
underground inspections, 2004 V1:102–103
underground piping
acid-waste piping, 2005 V2:242–244
cast-iron soil pipe, 2001 V4:27
coatings, 2004 V1:147
defined, 2004 V1:31
fountains, 2000 V3:116
glass pipe, 2001 V4:47
materials for, 2005 V2:13
medical gas piping, 2000 V3:73
storm-drainage systems, 2005 V2:50
underground building sanitary pipe codes, 2004 V1:44
underground pressurized fuel delivery systems, 2000 V3:162
underground sprinklers, 2000 V3:101
underground storage tanks (USTs)
codes and standards, 2000 V3:154
defined, 2000 V3:153
hazardous wastes, 2000 V3:90
illustrated, 2000 V3:164
liquid fuel storage tanks, 2000 V3:155–158
connections and access, 2000 V3:156–157
construction, 2000 V3:156
filling and spills, 2000 V3:156–157
leak detection and system monitoring, 2000 V3:158–163
materials, 2000 V3:155–156
overfill prevention, 2000 V3:158
venting, 2000 V3:157–158
product dispensing systems, 2000 V3:163–165
dispenser pans, 2000 V3:165
pressure dispensing, 2000 V3:164
product dispensers, 2000 V3:164–165
testing, 2000 V3:171
vapor recovery systems, 2000 V3:163
underground suction fuel delivery systems, 2000 V3:162–163
underwater lights, 2000 V3:112, 121, 145
underwriters. *See* insurance carriers
Underwriters Laboratories, Inc. (UL)
address, 2004 V1:59, 2000 V3:97
gas booster components, 2005 V2:131
hot-water components, 2005 V2:115, 124
list of standards, 2004 V1:57
pipe hangers, 2000 V3:15
UL 58: Steel Underground Tanks for Flammable and Combustible Liquids, 2000 V3:95
UL 142: Steel Above Ground Tanks for Flammable and Combustible Liquids, 2000 V3:95, 154, 165
UL 2085: Fire Resistance, 2000 V3:154
unemployment taxes, in labor costs, 2004 V1:94
ungridded piping systems, 2000 V3:16
uniform attack corrosion, 2004 V1:142
Uniform Building Code (UBC), 2004 V1:183, 191

Uniform Federal Accessibility Standard (UFAS), 2004 V1:105–106
Uniform Fire Code (UFC), 2000 V3:154
uniform flow
in horizontal drains, 2005 V2:6
Manning formula, 2004 V1:1
Uniform Plumbing Code, 2005 V2:44, 2001 V4:18
uniform pressure loss method, 2005 V2:68, 97, 98
Uniformat specification system, 2004 V1:64, 73
uninterrupted water supplies, 2000 V3:43
uninterruptible gas services, 2000 V3:249
unions (joins)
flanged, 2004 V1:10
screwed, 2004 V1:10
unions (labor), cost estimates and, 2004 V1:98
unisex toilet rooms, 2001 V4:18, 23
unit costs, in plumbing cost estimation, 2004 V1:93
United States agencies and departments. *See* U.S. agencies and departments
United States Pharmacopoeia. *See* U.S. Pharmacopoeia (USP)
units (UNIT)
symbols for, 2004 V1:16
units of measurement. *See* measurement units
universities. *See also* laboratories
diversity factor calculations for vacuums, 2005 V2:184
unknowns in value engineering presentations, 2004 V1:258
unlined piping, 2001 V4:26
unloading in air compressors, 2000 V3:205
unobstructed reach for wheelchairs, 2004 V1:111, 112
unoccupied buildings, conserving energy in, 2004 V1:127
unrestricted areas (facilities with radiation), 2005 V2:247
untreated sewage, 2004 V1:28
upfeed risers, 2000 V3:185
upright sprinklers, 2004 V1:13, 29, 30
upstream, defined, 2004 V1:31
upward-tapered weirs, 2000 V3:109
Urban Hydrology for Small Watersheds, 2005 V2:64
urinals. *See also* water closets
accessibility design, 2004 V1:116–117
acoustic ratings of, 2004 V1:194
Energy Policy Act requirements, 2004 V1:264
exclusion from gray-water systems, 2005 V2:25
female, 2001 V4:9
fixture pipe sizes and demand, 2005 V2:94
flushing requirements, 2001 V4:10
gray water use, 2004 V1:267, 2005 V2:28
health-care facilities, 2000 V3:32, 33
installation requirements, 2001 V4:9–10
minimum number for buildings, 2001 V4:21–22
reducing flow rates, 2004 V1:134–135
screening, 2001 V4:10
specialty urinals, 2004 V1:136
standards, 2001 V4:2
testing, 2001 V4:9
traps, 2001 V4:9
types, 2001 V4:8–9
typical use, 2005 V2:28
ultra low flow, 2004 V1:135–136
water fixture unit values, 2000 V3:217
waterless, 2004 V1:265, 2001 V4:10
U.S. Architectural and Transportation Barriers Compliance Board (ATBCB), 2004 V1:106, 107
U.S. Army Corps of Engineers
specifications, 2004 V1:63
U.S. Army Corps of Engineers Manual, 2005 V2:144
value engineering, 2004 V1:211
U.S. Centers for Disease Control and Prevention, 2005 V2:118
U.S. competitive swimming meets, 2000 V3:128
U.S. Department of Commerce, National Information Services, 2005 V2:36
U.S. Department of Defense, 2004 V1:161, 185, 191, 212–213
U.S. Department of Energy *Greening Federal Facilities,* 2004 V1:134, 137
U.S. Department of Health and Environmental Control, 2005 V2:124
U.S. Department of Health and Human Services, 2000 V3:33
U.S. Department of Housing and Urban Development, 2004 V1:105, 106
U.S. Department of the Army, 2005 V2:64
U.S. Department of Transportation (DOTn), 2004 V1:54, 58, 2005 V2:142, 2000 V3:88
U.S. Environmental Protection Agency
address, 2000 V3:173
aggressiveness index, 2005 V2:208
brass pipe standards, 2001 V4:27
chemical waste system codes and, 2005 V2:252
Effluent Guideline program, 2000 V3:88–89
industrial waste water defined, 2000 V3:87
potable water treatment technologies, 2005 V2:197
private water wells, 2005 V2:163
publications, 2005 V2:161, 162
EPA 440: The EPA Effluent Guidelines Series, 2000 V3:96
EPA 600/2-79-130: Activated Carbon Process for Treatment of Wastewater Containing Hexavalent Chromium, 2000 V3:96
EPA 600: Treatment of Organic Chemical Manufacturing Wastewater for Reuse, 2000 V3:96
regulations, 2000 V3:88
Safe Drinking Water Act and, 2005 V2:167
special waste drainage codes and, 2005 V2:237
storage tank regulations, 2000 V3:154
tank leak detection regulations, 2000 V3:158
water consumption statistics, 2004 V1:135
U.S. Federal Housing Administration, 2004 V1:199
U.S. Federal Specifications (FS), 2004 V1:25, 58
U.S. Food and Drug Administration, 2005 V2:197, 231, 234, 237
U.S. General Services Administration, 2004 V1:191, 199, 263, 2005 V2:36
U.S. Government Printing Office
address, 2000 V3:97
Clean Water Act, 2000 V3:96
Code of Federal Regulations, 2000 V3:96
Comprehensive Environmental Response, Compensation and Liability Act, 2000 V3:96
Resource Conservation and Recovery Act, 2000 V3:96
U.S. Green Building Council, 2004 V1:263

U.S. Occupational Safety and Health Administration, 2005 V2:242
U.S. Pharmacopoeia (USP)
USP nomographs, 2005 V2:229
USP purified water, 2005 V2:229–230, 231
water treatment standards, 2005 V2:197
U.S. Public Health Service (USPHS), 2005 V2:161, 2000 V3:151
U.S. Veterans Administration, 2004 V1:191
U.S. War Department, 2005 V2:64
USACOE. *See* U.S. Army Corps of Engineers
usages in swimming pools, 2000 V3:128
use factors
air compressors, 2000 V3:206
compressed air systems, 2000 V3:209
users in cost equation, 2004 V1:223
USGBC (U.S. Green Building Council), 2004 V1:263
USP. *See* U.S. Pharmacopoeia (USP)
USPHS. *See* U.S. Public Health Service (USPHS)
USTs. *See* underground storage tanks (USTs)
utilities. *See* site utilities
utility costs, lowering, 2004 V1:128
utility gas. *See* fuel-gas piping systems
utility sinks, 2000 V3:32
utility water treatment, 2005 V2:225
UV (ultraviolet rays)
chlorine and, 2000 V3:149
Legionella control, 2005 V2:120–122
PVC pipes and, 2000 V3:116
sterilization, 2000 V3:47
swimming pool disinfection, 2000 V3:150
UV treatment of water, 2005 V2:168, 223–224, 228, 232, 233

V

v, V (valves). *See* valves
V (specific volume). *See* specific volume
V (velocity of uniform flow), 2004 V1:1
V (velocity). *See* velocity
V (vents). *See* vents and venting systems
V (volts). *See* volts
v/v (volume to volume), 2005 V2:201
VA (volt amperes), 2004 V1:16
vac, VAC (vacuum). *See* vacuum
vacation pay, in labor costs, 2004 V1:94
vacuum (vac, VAC)
defined, 2004 V1:31, 2005 V2:175
perfect vacuum, 2000 V3:200
surgical use, 2000 V3:57
symbols for, 2004 V1:8, 16
vacuum breakers. *See* backflow preventers
vacuum cleaning systems, 2005 V2:188–196. *See also* vacuum systems
cleanouts, 2005 V2:195
codes and standards, 2005 V2:188
components, 2005 V2:188–189
friction losses, 2005 V2:191–193, 193–194
inlet locations and spacing, 2005 V2:189
piping, 2005 V2:189
separators, 2005 V2:194–196
simultaneous operators, 2005 V2:190
sizing exhausters, 2005 V2:193–194
swimming pools, 2000 V3:145, 146
types, 2005 V2:188
Vacuum Cleaning Systems, 2005 V2:196
vacuum condensate pumps, 2000 V3:189
vacuum deaerators, 2005 V2:209
vacuum diatomaceous earth filtration, 2000 V3:132, 135, 136, 139
vacuum drainage systems, 2005 V2:19
vacuum levels
defined, 2005 V2:175
in exhauster sizing, 2005 V2:193
vacuum producers (exhausters), 2005 V2:188, 190, 193–194
vacuum product dispensers, 2000 V3:163, 168
vacuum pumps, 2005 V2:180, 186, 2000 V3:49, 70, 71
vacuum relief valves, 2004 V1:31
Vacuum Sewage Collection, 2005 V2:161
vacuum sewers, 2005 V2:152
vacuum sources, 2005 V2:179–182, 182–183, 184, 186
Vacuum Sources, 2005 V2:196
vacuum steam units, 2000 V3:188, 189
vacuum systems, 2005 V2:188–196. *See also* vacuum cleaning systems
altitude adjustments, 2005 V2:178
cast iron radiators, 2000 V3:180
codes and standards, 2005 V2:182
color coding, 2000 V3:56
fundamentals, 2005 V2:175
general layout, 2005 V2:183–184
introduction, 2005 V2:175
laboratory systems, 2005 V2:182–187, 2000 V3:37–39
leakage, 2005 V2:186, 187
Level 1 defined, 2000 V3:85
Level 3 defined, 2000 V3:86
medical gas system switches, 2000 V3:72
medical vacuum
design checklist, 2000 V3:49–50
diversity factors, 2000 V3:75
laboratory outlets, 2000 V3:37–39
number of stations, 2000 V3:50, 51–52
oral surgery equipment, 2000 V3:39
patient vacuum, 2000 V3:85
peak demand, 2000 V3:55
piping systems, 2000 V3:54, 68–70
operating pressure steam classification, 2000 V3:178
operating pressures, 2000 V3:175
piping, 2005 V2:183, 2000 V3:74, 79
pressure drop, 2005 V2:179
pressure measurement, 2005 V2:176–178
pump curves, 2005 V2:179
purchasing, 2005 V2:180
references, 2005 V2:196
sizing, 2005 V2:184–187, 2000 V3:74, 79
swimming pools, 2000 V3:144
time to reach rated vacuum, 2005 V2:178–179
vacuum-pressure gauges, 2005 V2:181
vacuum sources, 2005 V2:179–182, 182–183, 186
velocity calculations, 2005 V2:179
work forces, 2005 V2:179
valence, 2005 V2:198, 199, 216
value, defined, 2004 V1:213–214

Value Engineering Change Proposals (VECP), 2004 V1:260
Value Engineering Job Plan (VEJP), 2004 V1:214
value engineering (VE)
arguments against, 2004 V1:232
checklists
creativity worksheets, 2004 V1:233–234
detail/product/material specification checklists, 2004 V1:220
evaluation checklists, 2004 V1:237–238
function definitions forms, 2004 V1:225–227, 228
functional evaluation worksheets, 2004 V1:243–251
idea development and estimated cost forms, 2004 V1:241–242
idea evaluation worksheets, 2004 V1:243, 253
project information checklists, 2004 V1:215–220
project information sources checklists, 2004 V1:221
questions checklists, 2004 V1:213–214
recommendation worksheets, 2004 V1:258, 259
compared to cost fitting, 2004 V1:258
contract document clauses, 2004 V1:258, 260
cost information, 2004 V1:222–225
creativity process, 2004 V1:231–235
defined, 2004 V1:211
elements of, 2004 V1:214–225
Evaluation phase, 2004 V1:235–243
Function Analysis phase, 2004 V1:224–243
Functional Development sketches, 2004 V1:237, 239–240
Gut Feel Index, 2004 V1:254
Information phase, 2004 V1:214–222
job plan phases, 2004 V1:213
overview, 2004 V1:211–212
pre-recommendation questions, 2004 V1:254–257
purpose, 2004 V1:211–212
qualitative results, 2004 V1:212
Recommendation/presentation phase, 2004 V1:257–258
results of, 2004 V1:261
Risk Guides, 2004 V1:254, 257
salesmanship in, 2004 V1:257
science of, 2004 V1:258–260
second creativity, cost, and evaluation analysis, 2004 V1:254
teams, 2004 V1:212
value changes, 2004 V1:212–213
“value” defined, 2004 V1:213–214
valve-in-head irrigation, 2000 V3:101
valve-per-sprinkler method of irrigation, 2000 V3:100, 101
valved zones in irrigation systems, 2005 V2:30
valves (v, V, VLV). *See also specific types of valves*
acoustic problems, 2004 V1:197
acoustic ratings, 2004 V1:194
automatic shutdown, 2000 V3:90
battery-controlled, 2004 V1:135
closing quickly, 2005 V2:80
codes and standards, 2004 V1:43
compressed air systems, 2000 V3:210
domestic pressure drops and, 2000 V3:221
equivalent lengths for natural gas, 2005 V2:135
fountains, 2000 V3:116–119, 118–119
friction loss in, 2005 V2:99–102
head loss and, 2000 V3:115
infectious waste systems, 2005 V2:252
irrigation systems, 2000 V3:103–104
medical air compressors, 2000 V3:66
medical gas control valves, 2000 V3:71–72
pure water systems, 2005 V2:233
in risers, 2004 V1:10
sulfuric acid and, 2005 V2:240
swimming pools, 2000 V3:145–146
symbols for, 2004 V1:16
testing in medical gas systems, 2000 V3:81
vacuum systems, 2000 V3:70
valve flow coefficients, 2004 V1:14
in yard boxes (YB), 2004 V1:10
vandal-proof grates and strainers, 2005 V2:10
vandalism
dressing rooms, 2000 V3:130
fasteners on grates and strainers, 2005 V2:10
protecting against, 2005 V2:16
vane-type water-flow indicators, 2000 V3:9, 10
VAP (vapor pressure), 2004 V1:15
vap pr, VAP PR (vapor pressure), 2004 V1:15
vap prf, VAP PRF (vaporproof), 2004 V1:16
vapor-compression distillation, 2005 V2:210
vapor operating pressure, 2000 V3:175
vapor pressure, 2004 V1:15
vapor recovery systems
aboveground tank systems, 2000 V3:168
classifications, 2000 V3:154
hazardous wastes, 2000 V3:90
testing, 2000 V3:171
underground tank systems, 2000 V3:163
vapor system pressure, 2000 V3:175–178
vaporizers, 2000 V3:61
vaporproof (vap prf, VAP PRF), 2004 V1:16
vapors, hazardous
acid wastes and, 2005 V2:239, 241
atmospheric tank venting and, 2000 V3:157–158
contamination in compressed air, 2000 V3:201
hydrocarbons, 2000 V3:154
monitoring, 2000 V3:160, 162
vapor pockets, 2000 V3:172
VOCs, 2005 V2:201
var, VAR (variables), 2004 V1:16
variable air volume (VAV), 2004 V1:16
variable-speed drivers, 2000 V3:25
variable-speed pumps, 2005 V2:72
variables (var, VAR), 2004 V1:16
varnishes in septic tanks, 2005 V2:156
vaults
dry pumps in, 2000 V3:115
pools and fountains, 2000 V3:111
VAV (variable air volume), 2004 V1:16
VECP (Value Engineering Change Proposals), 2004 V1:260
vegetable oil, 2005 V2:9
vehicular traffic, 2005 V2:11
VEJP (Value Engineering Job Plan), 2004 V1:214
vel., VEL (velocity). *See* velocity
velocity (vel., VEL, V). *See also* dynamic pressure
acoustic pump problems, 2004 V1:197

air in vents and, 2005 V2:37
cold-water systems, 2005 V2:86, 92
conversion factors, 2004 V1:37
counterflow piping designs, 2000 V3:178
defined, 2004 V1:31
earthquakes, 2004 V1:159
flow from outlets, 2004 V1:6
hydraulic shock, 2004 V1:6
intake air in compression systems, 2000 V3:212
Legionella growth in systems and, 2005 V2:120
liquid fuel piping, 2000 V3:170
measurements, 2004 V1:33
non-SI units, 2004 V1:34
open-channel flow, 2004 V1:1
in rate of corrosion, 2004 V1:145
self-scouring velocity in sewers, 2000 V3:232
sizing method for pipes, 2005 V2:80
steam systems, 2000 V3:175
storm water in ditches, 2000 V3:248
symbols for, 2004 V1:16
terminal velocity, defined, 2005 V2:1
types of piping and, 2005 V2:92
vacuum cleaning systems, 2005 V2:190–191
vacuum systems, 2005 V2:179
water hammer and, 2004 V1:198, 2005 V2:80, 81, 92
wind (w vel., W VEL), 2004 V1:16
velocity head (h), 2004 V1:5
velocity pipe sizing method, 2005 V2:99
vent connectors, defined, 2005 V2:144
vent gases, defined, 2005 V2:144
vent headers, 2005 V2:41–42
vent pipes
cast-iron soil pipe, 2001 V4:27
glass pipe, 2001 V4:47
vent stack terminals, 2005 V2:42
vent stacks
air in, 2005 V2:2
defined, 2004 V1:31, 2005 V2:42
sizing, 2005 V2:42
vent systems codes, 2004 V1:43
ventilation
oxygen storage areas, 2000 V3:63
swimming pools, 2000 V3:129
ventilators, 2000 V3:74
vents and venting systems (V, vent, VENT). *See also* vent stack terminals; vent stacks
1-pipe steam systems, 2000 V3:179–180
aboveground tank systems, 2000 V3:167
acid-waste systems, 2005 V2:239, 244, 2000 V3:39
air admittance valves, 2005 V2:46
atmospheric tank venting, 2000 V3:167
chemical-waste systems, 2005 V2:253
definitions, 2005 V2:38–43
duct seismic protection, 2004 V1:155
ducts in clean agent gas fire suppression, 2000 V3:23
factors in trap seal loss, 2005 V2:46–47, 47
fire-suppression drainage and, 2005 V2:254
flash tanks, 2000 V3:195
force mains, 2000 V3:241
gas appliances, 2005 V2:128
infectious waste systems, 2005 V2:252
introduction, 2005 V2:37
laboratory waste and vent piping, 2000 V3:42
loop venting, 2004 V1:31
main vents, 2000 V3:184
manholes, 2000 V3:236, 239
oil separators, 2005 V2:256
purposes, 2005 V2:37
radiators, 2000 V3:178, 184
reduced-size venting
sanitary drainage systems, 2005 V2:18–19
references, 2005 V2:47–48
septic tank vents, 2005 V2:156
sizes and lengths, 2004 V1:3, 2005 V2:43–44
sizing, 2005 V2:46
special-waste drainage systems, 2005 V2:238
storm-drainage stacks, 2005 V2:52
suds venting, 2005 V2:45–46
symbols for, 2004 V1:8, 16
testing, 2000 V3:171
traps and trap seals, 2005 V2:46–47
underground liquid fuel tanks, 2000 V3:157–158
vent extensions, 2005 V2:47
vented inlet tees in septic tanks, 2005 V2:154
waste anesthetic gas management, 2000 V3:71
venturi action in pools, 2000 V3:108
venturi-meters, 2004 V1:197
venturi suction pumps, 2005 V2:165
verbs in function analysis, 2004 V1:224, 225, 231
vert., VERT (vertical). *See* vertical
vertical (vert., VERT), 2004 V1:16
vertical filters, 2000 V3:131
vertical forces, 2004 V1:189
vertical leaders, 2005 V2:51–52
vertical pipes, 2004 V1:31
vertical pressure media filters, 2005 V2:211
vertical risers for vacuum systems, 2005 V2:189
vertical seismic load, 2004 V1:184
vertical shaft turbine pumps, 2004 V1:24
vertical stacks
calculating terminal velocity and length, 2004 V1:3
defined, 2004 V1:31, 2005 V2:1
fittings, 2005 V2:1
flow in, 2005 V2:1–2
hydraulic jumps and, 2005 V2:2
loading tables, 2005 V2:4
maximum fixture-unit values, 2005 V2:4
multistory stacks, 2005 V2:5
pneumatic pressure in, 2005 V2:2–3
sizing, 2005 V2:5
stack capacities, 2005 V2:3–5
storm-drainage stacks, 2005 V2:52
weight of, 2005 V2:2
vertical turbine pumps
fire pumps, 2000 V3:25
illustrated, 2005 V2:169
private water systems, 2005 V2:168–169
shallow wells, 2005 V2:170
swimming pool pumps, 2000 V3:140, 142
VFR (volumetric flow rates), 2004 V1:16
viable-count essays, 2005 V2:199
vibrating fill above sewers, 2005 V2:15
vibration and vibration isolation
defined, 2004 V1:209

earthquakes
earthquake vibration periods, 2004 V1:160
floor-mounted equipment, 2004 V1:164–166
isolators and, 2004 V1:206
piping and, 2004 V1:168
suspended equipment, 2004 V1:166
equipment vibration criteria, 2004 V1:202
fixtures, isolating, 2004 V1:205, 207
natural or free vibration, 2004 V1:160
noise and vibration control, 2004 V1:199–200
piping, 2004 V1:168. *See also* water hammer
pumps, 2004 V1:205, 208
static deflection for pump vibration, 2004 V1:205
types of vibration control devices, 2004 V1:203–206
vibration isolation mounts, 2004 V1:162, 163
vibration isolators, 2004 V1:199
video equipment, 2005 V2:9
vinyl coatings, 2004 V1:147
viruses in feed water, 2005 V2:199, 223–225
viscosity, kinematic, 2005 V2:83, 85
viscosity (visc, VISC, MU)
calculating values of, 2004 V1:2
defined, 2000 V3:154
measurements, 2004 V1:33
symbols for, 2004 V1:16
visitors' facilities, numbers of fixtures for, 2001 V4:20, 21
visualization in function analysis, 2004 V1:227
vitreous china fixtures, 2000 V3:33, 2001 V4:1, 2
vitrified clay piping, 2005 V2:83, 253, 2000 V3:245, 2001 V4:49, 56–57
vitrified sewer pipes, 2004 V1:31
VLV (valves). *See* valves
VOCs (volatile organic compounds), 2005 V2:201, 208, 2000 V3:154, 163
vol., VOL (volume). *See* volume
volatile liquids, 2005 V2:12, 254–256
volatile organic compounds (VOCs), 2005 V2:201, 208, 2000 V3:154, 163
volcanoes, 2004 V1:156
volts (V, E, VOLTS)
decomposition potential defined, 2004 V1:152
measurement conversions, 2004 V1:33
symbols for, 2004 V1:16
volt amperes (VA), 2004 V1:16
volume
water calculations, 2005 V2:77
volume (vol., VOL)
calculating, 2004 V1:3–5
conversion factors, 2004 V1:37
flow rate measurements, 2004 V1:33, 2005 V2:176–177
gas particles, 2000 V3:199
non-SI units, 2004 V1:34
symbols for, 2004 V1:16
volume to volume (v/v), 2005 V2:201
volumetric flow rates (VFR), 2004 V1:16
vortexes
anti-vortex grating, 2000 V3:110
from pumps, 2004 V1:197
from sumps, 2004 V1:197
vp, VP (dynamic pressure or velocity), 2004 V1:15

W

W, W (humidity ratios), 2004 V1:15
W (walls). *See* walls
W (waste sewers), 2004 V1:8
W (watts). *See* watts
W/m K (watts per meter per kelvin), 2004 V1:33
w vel., W VEL (velocity, wind), 2004 V1:16
w/w (weight to weight), 2005 V2:201
wading areas, 2000 V3:128
wafer butterfly valves, 2005 V2:189
WAG (waste anesthetic gases), 2000 V3:70–71
WAGD (waste anesthetic-gas disposal), 2000 V3:57, 70–71, 86
wages, in labor costs, 2004 V1:94
waiting rooms, 2000 V3:32
WAL (walls). *See* walls
wall azimuth (WAZ), 2004 V1:14
wall carriers, 2001 V4:6
wall cleanouts (WCO), 2004 V1:11
wall-hung lavatories, 2001 V4:11
wall-hung urinals, 2001 V4:10
wall-hung water closets, 2001 V4:4, 6
wall hydrants (WH), 2004 V1:10, 12, 2005 V2:94
wall-mounted medical gas stations, 2000 V3:58
walls (W, WAL)
piping and acoustic design, 2004 V1:195–196
symbols for, 2004 V1:16
wall penetrations of pipes, 2004 V1:201
wander, 2004 V1:22, 190
ward rooms, 2000 V3:34
warehouses, numbers of fixtures for, 2001 V4:20, 21
warm-up loads
automatic heat-up systems, 2000 V3:196
equations, 2000 V3:195
steam piping, 2000 V3:187, 191, 192
warning systems (medical gas), 2000 V3:72–73
area alarms, 2000 V3:72
master alarms, 2000 V3:72
testing, 2000 V3:81
warranty section in specifications, 2004 V1:70, 90
Warren, Alan W., 2005 V2:64
wash basins. *See* sinks and wash basins
wash-down urinals, 2001 V4:9
wash-down water closets, 2001 V4:3
washing floors with gray water, 2005 V2:25
washing machines. *See* laundry systems and washers
washout urinals, 2001 V4:9
washout water closets, 2001 V4:3
waste, defined, 2004 V1:31
waste anesthetic-gas disposal, 2000 V3:57, 70–71, 86
waste brines, 2005 V2:156, 220
waste-disposal units. *See* food waste grinders
waste fitting standards, 2001 V4:2
waste grinders, 2000 V3:32
waste-heat usage, 2004 V1:131–134, 266
waste-heat vaporizers, 2000 V3:61
waste oil (WO), 2004 V1:8, 2000 V3:154
waste oil vents (WOV), 2004 V1:8
waste or soil vents. *See* stack vents
waste pipes, 2004 V1:31, 2001 V4:27
waste sewers (W), 2004 V1:8
waste stacks, 2005 V2:1

waste streams
evaluation, 2000 V3:90
segregating, 2000 V3:94
wastewater. *See also* private onsite wastewater treatment systems (POWTS)
Wastewater Engineering: Treatment, Disposal, and Reuse, 2000 V3:125
Wastewater Engineering: Treatment/Disposal/Reuse, 2005 V2:161
wastewater heat recovery, 2004 V1:133
wastewater management. *See also* gray-water systems; private sewage-disposal systems
green building technologies, 2004 V1:264
individual aerobic wastewater treatment, 2005 V2:157–158
industrial wastewater treatment. *See* industrial wastewater treatment
reclaimed and gray water systems, 2004 V1:135, 2005 V2:30–32
swimming pools, 2000 V3:131
WAT (watts). *See* watts
water (WTR). *See also* water analysis; water chemistry
as seal liquid in liquid ring pumps, 2005 V2:181
asbestos concrete piping, 2001 V4:26
clarity, 2000 V3:135
contamination in compressed air, 2000 V3:201
kinematic viscosity, 2005 V2:83, 85
mass and volume calculations, 2005 V2:77
oil-water separation, 2000 V3:93
portable fire extinguishers, 2000 V3:27
potable amounts present, 2004 V1:263
samples of, 2005 V2:104
water absorption, plastic pipe and, 2001 V4:60
water analysis
aggressiveness index, 2005 V2:208
codes and standards, 2005 V2:197
example report, 2005 V2:202
introduction, 2005 V2:201–202
pH, 2005 V2:202–203, 207
predicting water deposits and corrosion, 2005 V2:206–208
references, 2005 V2:234
Ryzner stability index, 2005 V2:207–208
silt density index, 2005 V2:204–205
specific conductance, 2005 V2:203
total dissolved solids, 2005 V2:204
total organic carbon, 2005 V2:204
total suspended solids, 2005 V2:203–204
water chemistry
elements, acids, and radicals in water, 2005 V2:199
heat loss retardants, 2000 V3:150
introduction, 2005 V2:197–198
mineral deposits, 2000 V3:147–148
pH values, 2000 V3:147
pools and fountains, 2000 V3:123
sequestering agents, 2000 V3:150
swimming pools, 2000 V3:146–148
water impurities, 2005 V2:198–201
water-closet compartments
accessibility, 2004 V1:113–116
ambulatory-accessible toilet compartments, 2004 V1:114
kitchen areas, 2000 V3:36
patient rooms, 2000 V3:34
single-occupant unisex toilet rooms, 2001 V4:18, 23
spacing, 2001 V4:6–7
swimming pool bathhouses, 2000 V3:130
water-closet flanges, 2001 V4:6
water closets (WC). *See also* urinals
accessibility design, 2004 V1:113–116
acoustic design, 2004 V1:200
acoustic ratings of, 2004 V1:194
bolts, 2001 V4:6
composting toilets, 2004 V1:265
conserving water in, 2005 V2:157
dual flush, 2004 V1:265
Energy Policy Act requirements, 2004 V1:264
exclusion from gray-water systems, 2005 V2:25
fixture pipe sizes and demand, 2005 V2:94
fixture-unit loads, 2005 V2:3
flushing performance testing, 2001 V4:5–6
flushing systems, 2001 V4:6–8
gray water usage, 2004 V1:267, 2005 V2:28–29
in health-care facilities, 2000 V3:32, 33, 34
incinerators, 2004 V1:265
installation requirements, 2001 V4:6–7
minimum numbers of, 2001 V4:18–22
mounting, 2001 V4:4
rates of sewage flows, 2005 V2:161
reducing flow rates, 2004 V1:134–135
seats, 2001 V4:5
shapes and sizes, 2001 V4:4–5
specimen-type, 2000 V3:35
standards, 2001 V4:2, 6
types of, 2004 V1:135–136, 2001 V4:3–4
typical use, 2005 V2:28–29
ultra-low-flow, 2004 V1:135–136
water conservation, 2004 V1:135–136
water fixture unit values, 2000 V3:217
water column (wc), 2001 V4:5
Water Conditional Manual, 2005 V2:234
water conditioning. *See also* water purification; water softeners; water treatment
defined, 2005 V2:197
water-conditioning or treating devices, 2004 V1:31
water conservation. *See* conserving water
water consumption tests, 2001 V4:5, 9
water-cooled after-coolers, 2000 V3:202
water coolers
access to, 2004 V1:109–112
health-care facilities, 2000 V3:32
public areas in health-care facilities, 2000 V3:33
standards, 2001 V4:2
types, 2001 V4:14
wheelchair space around, 2004 V1:112
water damage
sprinkler systems, 2000 V3:2
swimming pool bathhouses, 2000 V3:130
water deposits, 2005 V2:205, 206–208
Water Distributing Systems for Buildings, 2005 V2:104
water-distribution pipes and systems. *See also* cold-water systems; hot-water systems
acoustic design, 2004 V1:195–196
codes, 2004 V1:45

defined, 2004 V1:31
pipe codes, 2004 V1:45
water supply and distribution symbols, 2004 V1:12
water supply systems, 2004 V1:31
weight of water-filled pipes, 2004 V1:184
Water Efficiency design (LEED), 2004 V1:263–264
water-flow indicators, 2000 V3:9, 10
water flow tests, 2005 V2:95
water for injection (WFI), 2005 V2:229, 230, 231, 233
water gas, 2005 V2:126
water glass, 2004 V1:151
water hammer
acoustic control of, 2004 V1:201
air locks, 2004 V1:201
controlling water hammer, 2005 V2:80–82, 81
counterflow piping designs, 2000 V3:178
defined, 2004 V1:31, 2005 V2:79–82
flow velocity and, 2004 V1:198
fountains and, 2000 V3:116
fuel dispensers, 2000 V3:170
shock intensity, 2005 V2:80
sizing of arresters, 2005 V2:81–82
steam systems, 2000 V3:189, 190, 191
swimming pool pumps, 2000 V3:139
symbols on arresters, 2005 V2:82
system protection and control, 2005 V2:80–82
velocity and, 2005 V2:92
water hammer arresters (WHA)
acoustic design in water pipes, 2004 V1:195
as protection and control, 2005 V2:81–82
codes, 2004 V1:43
defined, 2004 V1:31
flow velocity and, 2004 V1:198
shock absorbers, 2004 V1:198, 201
sizing, 2005 V2:80–82
symbols, 2004 V1:10, 2005 V2:82
water heaters. *See also* hot-water systems
avoiding standby losses, 2004 V1:127
booster water heaters, 2004 V1:126, 129, 2005 V2:111
codes, 2004 V1:43
condensation use, 2004 V1:267
conserving energy, 2004 V1:124–125, 127
copper-fin heaters, 2005 V2:111–114
earthquake damage, 2004 V1:162
earthquake protection, 2004 V1:162, 163
efficiency, 2005 V2:107
expansion tanks, 2005 V2:76–77
explosions, 2005 V2:107
gas efficiency, 2005 V2:127
gas water heaters, 2004 V1:129
heat recovery, 2005 V2:110
high-efficiency, 2004 V1:265
instantaneous, 2004 V1:265
locations of, 2004 V1:129
mineral deposits and, 2000 V3:147
overview, 2005 V2:111–114
point-of-use booster heaters, 2000 V3:45
reflecting pools and fountains, 2000 V3:112, 121–122
sizing, 2005 V2:108–109
step heaters, 2000 V3:144
stratification in water heaters, 2005 V2:114
swimming pools, 2000 V3:138–139, 144–145, 146
temperature, 2005 V2:107, 111
thermal efficiency, 2005 V2:116–117
types of systems, 2004 V1:129–134
water impurities
alkalinity, 2005 V2:199
analysis and measurement, 2005 V2:201–205
biological fouling, 2005 V2:205, 227
dissolved gases, 2005 V2:200
hardness, 2005 V2:199–200
microorganisms, 2005 V2:198–199
specific resistance, 2005 V2:203
suspended solids, 2005 V2:198
treatment methods, 2005 V2:208–225
volatile organic compounds, 2005 V2:201
water levels
in pools, 2000 V3:112
sensors, 2000 V3:124
water-level dependent spray jets, 2000 V3:119
water-level independent spray jets, 2000 V3:119
water mains
age and size, 2000 V3:8
copper pipe, 2001 V4:34, 35
defined, 2004 V1:31
fire-protection connections, 2000 V3:225, 227
inspection checklist, 2004 V1:103
pressure and, 2000 V3:216
sprinkler systems, 2000 V3:3
water makeup. *See* makeup water systems
Water Management: A Comprehensive Approach for Facility Managers, 2005 V2:36
water management plans, 2004 V1:134–135
water meters
domestic water meters, 2005 V2:68–69
flow-pressure loss averages, 2005 V2:69
irrigation, 2000 V3:105
locations for, 2000 V3:217
loss of pressure, 2005 V2:95
pressure losses, 2000 V3:224
water motor gongs, 2000 V3:9, 10
water, oil, and gas (WOG) pressure rating, 2000 V3:210
water pipes. *See* cold-water systems; hot-water systems; water-distribution pipes and systems
water pressure
excess water pressure, 2005 V2:77–79
gravity-tank systems, 2005 V2:74–76
hydropneumatic-tank systems, 2005 V2:72, 73–74
water hammer and, 2005 V2:81
water purification
central purification equipment, 2005 V2:233–234
codes and standards, 2005 V2:197, 229
feed water, 2005 V2:230
high-purity water, 2000 V3:46
methods, 2000 V3:46–47
pharmaceutical systems, 2005 V2:229–230
polishers and, 2005 V2:221
pure-water systems defined, 2005 V2:197
references, 2005 V2:234
specific resistance of pure water, 2005 V2:203
system design, 2005 V2:231–233
water impurities, 2005 V2:198–201
water quality
Clean Water Act, 2000 V3:88

grades of laboratory water, 2005 V2:229
gray-water systems, 2005 V2:35
introduction, 2005 V2:167
references, 2005 V2:234
water-resistivity meters, 2005 V2:203
water-reuse systems. *See* gray-water systems
water rise tests, 2001 V4:5
water risers, 2004 V1:31
water-service pipes, defined, 2004 V1:31
water shock absorbers. *See* water hammer arresters (WHA)
water slides, 2000 V3:128
water softeners
earthquake damage, 2004 V1:162
hardness of water, 2005 V2:199–200
ion-exchange, 2005 V2:215
leakage, 2005 V2:220–221
pure water systems, 2005 V2:232
types of, 2005 V2:168, 220
utility water, 2005 V2:225
waste brines, 2005 V2:156
water sports, 2000 V3:128
Water Spray Fixed Systems for Fire Protection (NFPA 15), 2000 V3:2, 29
water-spray systems, 2000 V3:13
water-storage tanks
earthquake damage, 2004 V1:162
fire-protection water supply, 2000 V3:232
pressure regulators, 2005 V2:171–172
types of, 2005 V2:170–171
water levels in, 2005 V2:170–171
water supply fixture units (WSFU), 2005 V2:39, 92
water-supply systems. *See* cold-water systems; domestic water supply; fire-protection systems; hot-water systems; private water systems; water-distribution pipes and systems; wells
Water Systems for Pharmaceutical Facilities, 2005 V2:234
water tables
underground storage tanks and, 2000 V3:155
wells, 2005 V2:165–166
Water Tanks for Fire Protection, 2005 V2:170
water temperature
bathtub water notes, 2004 V1:119
deaeration water temperatures, 2005 V2:209
feed water temperature and deposits, 2005 V2:207, 224, 231
hot-water properties, 2005 V2:117
hot-water relief valves, 2005 V2:115–116
hot-water temperatures, 2005 V2:111, 112–114, 114, 2000 V3:36, 45
maintenance hot-water temperatures, 2005 V2:115
mixed-water temperatures, 2005 V2:111
reflecting pools and fountains, 2000 V3:108
scalding water, 2005 V2:122–124
shower compartments, 2004 V1:120, 2001 V4:15
swimming pools, 2000 V3:129, 139
water heaters, 2005 V2:107, 111
water toys, 2000 V3:128
water treatment
aeration, 2005 V2:208
aluminum sulfate, 2000 V3:149–150
boiler feed water, 2005 V2:226
clarification, 2005 V2:208–209
codes and standards, 2005 V2:197
cooling towers, 2005 V2:227
corrosion inhibitors, 2004 V1:151
deaeration, 2005 V2:209
dealkalizing, 2005 V2:209–210
decarbonation, 2005 V2:210
defined, 2005 V2:197
distillation, 2005 V2:210–211
drinking water, 2005 V2:228
filtration, 2005 V2:211–215
fountains and pools, 2000 V3:107, 112, 122–124
ion-exchange and removal, 2005 V2:215–221
membrane filtration and separation, 2005 V2:211, 221–223
microbial control, 2005 V2:223–225
references, 2005 V2:234
swimming pools, 2000 V3:130, 140, 146
utility water treatment, 2005 V2:225
water impurities, 2005 V2:198–201
water purification, 2005 V2:228–234
water softening, 2005 V2:220
Water Treatment for HVAC and Potable Water Systems, 2005 V2:234
Water Use in Office Buildings, 2005 V2:36
Water: Use of Treated Sewage on Rise in State, 2005 V2:36
Water-Use Reduction Credit, 2004 V1:264
Water Uses Study, 2005 V2:35
water utility letters, 2000 V3:216
water vapor in air, 2000 V3:200–201, 201
water wells. *See* wells
waterborne radioactive waste (radwaste), 2005 V2:245
waterfall aerators, 2005 V2:208
waterfalls, 2000 V3:108, 109
waterless urinals, 2004 V1:136, 265, 2001 V4:10
waterproof manholes, 2000 V3:236, 239
waterproofing drains, 2005 V2:15–16, 53
watertight joints, 2001 V4:26
watt-hours (Wh, WH), 2004 V1:16
watts (W, WAT)
converting to SI units, 2004 V1:40
measurement conversions, 2004 V1:33
symbols for, 2004 V1:16
W/m K (watts per meter per kelvin), 2004 V1:33
wave actions in water (tsunamis), 2004 V1:158
wave pools, 2000 V3:128
wax ring seals, 2001 V4:6
WAZ (wall azimuth), 2004 V1:14
wb, WB (wet bulbs), 2004 V1:16
Wb (webers), 2004 V1:33
wbt, WBT (wet-bulb temperature), 2004 V1:16
wc (water column), 2001 V4:5
WCO (wall cleanouts), 2004 V1:11
WD (wind). *See* wind
wdir, WDIR (wind direction), 2004 V1:16
weak-base regeneration, 2005 V2:216, 218
weather conditions, 2004 V1:98, 2000 V3:100, 105, 165, 219
webers, 2004 V1:33
weep holes, 2005 V2:16, 2000 V3:144, 2001 V4:15
weight (wt, WT)
clean agent gas fire containers, 2000 V3:23

horizontal loads of piping, 2004 V1:184
piping, earthquake protection and, 2004 V1:167
in seismic force calculations, 2004 V1:183
swimming pool filtration equipment, 2000 V3:140
symbols for, 2004 V1:16
weight loss in corrosion, 2004 V1:144
weight to weight (w/w), 2005 V2:201
weighted evaluations in value engineering, 2004 V1:243
weirs
flow rates, 2000 V3:109
materials, 2000 V3:146
swimming pools, 2000 V3:142
water return in, 2000 V3:119–120
waterfall rates and, 2000 V3:108
welded steel piping, 2001 V4:48
welding
clearance for, 2001 V4:25
corrosion and, 2004 V1:146
earthquake protection techniques, 2004 V1:167
problems in seismic protection, 2004 V1:190
weld decay defined, 2004 V1:154
welded fittings, 2004 V1:24
welded joints in radioactive waste systems, 2005 V2:249
well screens, 2000 V3:119–120
wells
bored wells, 2005 V2:164–165
driven wells, 2005 V2:165
dug and augered wells, 2005 V2:164
equilibrium equations for wells, 2005 V2:165–166
fire-protection connections, 2000 V3:225
gray-water irrigation systems and, 2005 V2:29
hydraulics of, 2005 V2:165–166
initial operation and maintenance, 2005 V2:172
introduction, 2005 V2:164
irrigation usage, 2000 V3:105
jetted wells, 2005 V2:165
matching water storage to pump flow, 2005 V2:170–171
monitoring fumes, 2000 V3:162
monitoring groundwater, 2000 V3:162
performance specifications, 2005 V2:172
protection of, 2005 V2:166–167
pumps, 2005 V2:168–170
swimming pool supplies, 2000 V3:131
system equipment, 2005 V2:168–172
types of, 2005 V2:163
water demand and, 2005 V2:167
water quality, 2005 V2:167–168
Westaway, C. R., 2005 V2:104
wet-alarm valve risers, 2000 V3:9, 10
wet-bulb temperature (wbt, WBT), 2004 V1:16
wet bulbs (wb, WB), 2004 V1:16
wet-cast pipe, 2001 V4:32
wet floors in chemical plants, 2005 V2:253
wet gas, 2000 V3:250
wet-niche pool lighting, 2000 V3:145
wet-pipe systems, 2004 V1:29, 2000 V3:9
wet pits, 2000 V3:142
wet returns, 2000 V3:179
wet standpipes, 2004 V1:30
wet surfaces, 2004 V1:16
wet-tap excavations, 2000 V3:222
wet vacuum-cleaning systems (WVC)
defined, 2005 V2:188
illustrated, 2005 V2:195
pitch, 2005 V2:195–196
separators, 2005 V2:188
symbols for, 2004 V1:9
wet venting
bathroom groups, 2005 V2:42
defined, 2004 V1:31, 2005 V2:42
Weymouth formula, 2004 V1:7, 2005 V2:137
WFI (water for injection), 2005 V2:229, 230, 231, 233
WH (wall hydrants), 2004 V1:10, 12
Wh, WH (watt-hours), 2004 V1:16
WHA (water hammer arresters). *See* water hammer arresters
What Future Role for Pressure Sewers?, 2005 V2:161
wheel loads in pipe selection, 2001 V4:26
wheelchairs
adult-sized, dimensions, 2004 V1:108
anthropometrics for wheelchairs, 2004 V1:109
approaches and reaches, 2004 V1:110
clear space for, 2004 V1:109
toilet and bathing rooms, 2004 V1:112–113
wheeled fire extinguishers, 2000 V3:19, 27
WHEN relationship, 2004 V1:230
whirlpool bathtubs, 2005 V2:122, 2001 V4:16
White, George Clifford, 2005 V2:104
Whitney, Eli, 2004 V1:231
WHY logic path, 2004 V1:230, 231, 258
WI (width), 2004 V1:16
width (WI), 2004 V1:16
wind (WD)
direction (wdir, WDIR), 2004 V1:16
effect on irrigation sprinklers, 2000 V3:102
fountains and, 2000 V3:115, 120–121
reflecting pools and, 2000 V3:108
speed and heat loss, 2000 V3:121
symbols for, 2004 V1:16
velocity, 2004 V1:16
vent stack terminals and, 2005 V2:44
wind pressure (wpr, WPR, WP, WPRES), 2004 V1:16
WO (waste oil), 2004 V1:8
WOG (water, oil, and gas pressure rating), 2000 V3:210
wood shrinkage, protecting against, 2005 V2:16
wood stave piping, 2005 V2:83, 86
Woodcock, J.J., 2005 V2:31
word processing of specifications, 2004 V1:71–72
work
conversion factors, 2004 V1:35
converting to SI units, 2004 V1:39
defined, 2004 V1:61
measurements, 2004 V1:33
work change directives, 2004 V1:63
work functions in value engineering, 2004 V1:225, 243
working deionizers, 2005 V2:215, 216
working hours, in cost estimation, 2004 V1:98
working occupants, 2005 V2:109
working pressure
in pipe selection, 2001 V4:26
vacuum systems, 2005 V2:179
workmanship standards, 2004 V1:66
workmen's compensation, in labor costs, 2004 V1:94

worksheets. *See* checklists and forms
worst case possibilities, radiation and, 2005 V2:249
worth, defined, 2004 V1:213
WOV (waste oil vents), 2004 V1:8
WP (wind pressure), 2004 V1:16
wpr, WPR (wind pressure), 2004 V1:16
WPRES (wind pressure), 2004 V1:16
wrapped piping
  sound damping, 2004 V1:196, 201–202
  wrapped storm piping, 2005 V2:50
wrist blades on faucets, 2000 V3:33
written amendments, 2004 V1:63
Wrought Copper and Copper Alloy Solder-Joint Pressure Fittings, 2001 V4:37
Wrought Copper and Wrought Copper Alloy Solder-Joint Drainage Fittings, 2001 V4:45
Wrought Copper Braze Fittings, 2001 V4:45
wrought iron piping, 2005 V2:83, 86
WSFU (water supply fixture units), 2005 V2:39, 92
wt, WT (weight). *See* weight
WVC (wet vacuum cleaning). *See* wet vacuum-cleaning systems
wyes
  water closet installation, 2001 V4:6–7
Wyly, R.S., 2005 V2:4, 19, 48

X

x-ray areas, 2000 V3:39, 51
x-rays, 2005 V2:246
X#A (compressed air). *See* compressed air (A, X#, X#A)
XH (extra heavy) cast iron soil pipe, 2001 V4:29–30
XH (extra heavy) cast-iron soil pipe, 2001 V4:27
XP explosion-proof construction, 2005 V2:130
XP junction boxes, 2005 V2:130
XPAN (expansion. *See* expansion

Y

y (years), 2004 V1:16, 34
y-type strainers, 2000 V3:116
yards (yd, YD)
  converting to SI units, 2004 V1:40
  symbols for, 2004 V1:16
yards and lawns
  lawn imperviousness factors, 2000 V3:243
  lawn sprinkler supply (LS), 2004 V1:8
  storm-drainage systems and, 2005 V2:49
  yard cleanouts (CO), 2004 V1:11
YB (valves in yard boxes), 2004 V1:10
yd, YD (yards), 2004 V1:16, 40
year-round pools, 2000 V3:129
years (yr, YR), 2004 V1:16, 34
Yeh, K.L., 2005 V2:234
yellow brass, 2004 V1:144
YMCAs, 2005 V2:109
yoke vents, 2004 V1:31, 2005 V2:43
Young, Virgil E., 2000 V3:105
yr, YR (years), 2004 V1:16, 34
Yrjanainen, Glen, 2005 V2:64

Z

z, Z (zones), 2004 V1:16, 183
Zelmanovich, Y., 2005 V2:234
zeolite process, 2005 V2:168
zeolites, 2005 V2:215
zero-flow potential, 2004 V1:153
zero governors, 2000 V3:251
zeta potential, 2005 V2:209
zinc
  anodes, 2004 V1:150
  corrosion, 2004 V1:139
  electromotive force series, 2004 V1:144
  galvanic series, 2004 V1:141
zirconium, 2000 V3:20
ZN (zones), 2004 V1:16, 183
zone valves, 2000 V3:49, 71
zones (z, Z, ZN)
  in seismic force calculations, 2004 V1:183
  symbols for, 2004 V1:16