Practical Plumbing Engineering

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Editor in Chief

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PREFACE

This book brings together in a single volume the various aspects of the field of plumbing engineering, including the planning, design, and installation of plumbing systems. The methods employed are based on standard engineering practices and the application of principles of engineering design that follow standard code regulations. Each chapter is written by an expert in the subject.

The design and installation of plumbing systems has a long history, generally accepted *practice* and code requirements have changed considerably over the years—particularly during the past few decades. For example, Chapter 9 describes one such recent development in some geographic areas, notably California, where new regulations provide greater seismic protection in plumbing systems for buildings. Another recent change is the increased use of "master specifications" employing an interactive computer system, described in Chapter 10. Using such a system, specifications can be prepared quickly, more economically, and with fewer errors and/or omissions than in the past. In other chapters, new materials and installation techniques are described. Although new developments are emphasized, proven traditional approaches are presented.

Practical Plumbing Engineering is a working guide and reference for engineers, plumbing designers and engineers, plumbing officials, architects, plant engineers, inspectors, journeymen, students, contractors, builders, and all others associated with the construction industry. Because the text presents technical information in an easy to understand language, nonspecialists will find the contents of this book especially useful. Lucid explanations and simple charts often replace derivations and complicated technical formulas.

Both the U.S. Customary System (I.P.) units and the International System (S.I.) units are used throughout.

I appreciate the resourcefulness and diligent labors of the contributing staff of this book toward the objective of presenting practical design information usefully and clearly, and I thank them all. Special mention should be given to Louis S. Nielsen, whose major contributions were largely based on his book *Standard Plumbing Engineering Design.* I also appreciate the help provided by the American Society of Plumbing Engineers.

Cyril M. Harris

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PART 1

WATER SUPPLY SERVICES

CHAPTER 1

WATER QUALITY AND TREATMENT

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INTRODUCTION

Any undesirable physical, chemical, or microbiological substance in a water supply can be considered a *contaminant.** All water supplies contain some contaminants in various concentrations, and no two supplies are identical in the kinds and concentrations of contaminants they contain.[1]

If a contaminant is considered dangerous to human health, it may be called a *pollutant.** Many contaminants, natural and artificial, fall into this category. The requirement to remove or reduce contaminants in water supplies is dictated by the intended use of the water. The specific treatment technology is determined by the kind of contaminant present, the total volume to be treated, and the degree of removal or reduction that is required.

This chapter defines waterborne contaminants and details the various technologies available today for contaminant removal or reduction. Various water quality standards are discussed along with considerations relating to the monitoring of water quality.

WATERBORNE CONTAMINANTS

Because virtually no water supply can be rendered completely free from measurable levels of contamination, the term *contaminated water* is use-defined. Water quality of sufficient purity for one application may be completely unacceptable for another. Contaminants found in water supplies can be classified as:

- *Suspended solids*, i.e., particulate materials which (for any of several reasons) are in an insoluble form. This may occur because the contaminant will not dissolve in water, or because its concentration is higher than its solubility limits,

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* There are no standard definitions for these terms. In the field of cross-connection control, they have different meanings. See Chap. 13.

so that it has precipitated out of solution. The term *suspended solids* includes both inorganic and organic solids as well as immiscible liquids, such as oil and grease.

- *Dissolved solids (also known as solutes)*, i.e., solid materials that are an intimate part of a liquid system, having a mean diameter of less than 0.000001 mm. Dissolved solids can be subdivided into (*a*) dissolved salts and (*b*) dissolved organic material.
- *Dissolved salts*, i.e., solids that form ionic components when in solution. Typically, they are inorganic and form charged ions, known as *cations* (positively charged) and *anions* (negatively charged). These are also commonly called *minerals*.
- *Dissolved organic materials*, materials that generally do not dissociate into ions but form covalent bonds with water molecules and become nonionic solute.
- *Microorganisms*, i.e., living water contaminants that are capable of reproduction and propagation throughout the water system. These include bacteria, viruses, and such plantlike organisms as algae.
- *Dissolved gases*, i.e., gases such as oxygen, carbon dioxide, and hydrogen sulfide. All these gases dissolve in water and are released on heating or on reduction of pressure in the water supply.

A water supply may contain any one or all of the above contaminants in various concentrations.

METHODS OF WATER TREATMENT

A number of methods are available for the removal of waterborne contaminants. No single method is optimum for removal of all the different types of contaminants, and it is virtually impossible to remove 100 percent of any contaminant. The best treatment method is always a compromise between cost and practical application.

Table 1.1 lists water treatment processes appropriate for removal of various contaminants. Table 1.2 indicates types of technologies commonly applied to process water for an entire building and to provide drinking water at a faucet. Figure 1.1 identifies various contaminants by size and indicates technologies recommended for removal.

Filtration

Filtration is a mechanical process for removal or reduction of suspended solid contaminants. A *filter* is a device or system used to effect such removal by a porous medium.[2] Water passes through the medium, whose porosity is sufficient to remove the suspended solid components. A filter can be either (*a*) a container which is partially filled with a "bed" of a porous medium or (*b*) a manufactured "cartridge," typically constructed of a synthetic porous medium, designed to process smaller flow rates than a bed filter.

Typical bed-type filters are effective in removing suspended solids down to approximately 10 μm in size. Membrane filter cartridges are available for removal of suspended solids down to 0.1 μm.

TABLE 1.1 Water Treatment Processes That Are Appropriate for the Removal of Various Types of Contaminants in Water

Typical Contaminants	Floating Debris	Suspended Material	Dissolved Minerals (Salts)	Dissolved Organics
	Oils Greases Foam Solids	Silt Clay Colloids Dust	Calcium Sodium Sulfate Chloride Heavy Metals Cyanide	Phenols Pesticides Detergents THMs PCBs Bacteria Virus Oils Sewage
Treatment Processes				
Screening	●			
Flotation	●	●		
Aeration/Clarification	●	●		
Coagulation/Settling	●	●		
Biological Treatment	●	●		
Centrifugation		●		
Filtration	●	●		
Carbon Adsorption				●
Ion Exchange			●	
Distillation			●	●
Electrodialysis			●	
Reverse Osmosis			●	●
Ultrafiltration				●
Disinfection				●

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TABLE 1.2 Technologies Commonly Applied in Processing Water for an Entire Building (at the Point of Entry of the Water Supply) and at a Drinking Water Faucet

Process	Entire building	Drinking water faucet
Aeration	X	—
Filtration, bed-type	X	—
Filtration, cartridge	—	X
Adsorption, bed-type	X	—
Adsorption, cartridge	—	X
Ion exchange, softening	X	—
Disinfection, chemical	X	—
Disinfection, distillation/ultraviolet	—	X
Desalting/demineralization		
Reverse osmosis	—	X
Ion-exchange cartridge	—	X
Electrodialysis	X	—

Source: Courtesy of Wes Max Consulting, Ltd.

Bed-Type Filters. In a bed-type filter, water is forced through the filter medium by water pressure. The special bed-type filter shown in Fig. 1.2 contains several different filtration media (coal, sand, and garnet). For this reason it is called a *multimedia filter*. The water enters the top of a gravity-flow filter and percolates down through the bed by the force of gravity.

The porous media in the bed accomplish the desired filtration as the filtered water exits through the bottom of the filter. The flow of water can be either from

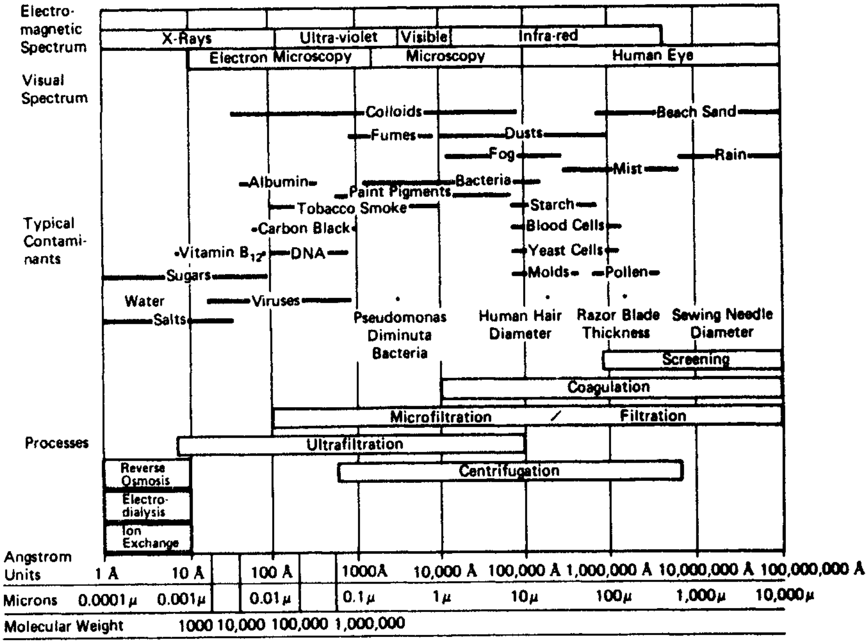

FIG. 1.1 Recommended removal processes for contaminants as a function of size. *(Courtesy of P. S. Cartwright.)*

bottom up or from top down. The porous media can be many types of inert, porous, uniformly sized material. Often, sand and anthracite coal are used.

Cartridge Filters. A typical filter in the form of a cartridge is shown in Fig. 1.3. Cartridge filters are thick-walled tubes measuring typically 2¾ in (7 cm) in outside diameter by 10 in (25 cm) or 20 in (50 cm) long, and they are constructed of one of a number of synthetic materials, including rayon, polypropylene, cellulosic polymers, nylon, or Teflon. One type of construction is "string-wound"; i.e., the medium (in a stringlike form) is wound around the core in a pattern that creates a tortuous path through which the water must flow. Another type of construction, which also forces the water to flow in such a path, is fabricated of nonwoven feltlike materials. A third type contains a membrane consisting of a porous polymer sheet through which the water is forced. Such a cartridge is most effective in removing solid, suspended particles of very small size.

The unit of measurement used in filtration for contaminant removal is the *micrometer*. One micrometer is equivalent to one-millionth of a meter. The smallest suspended solid has a mean diameter of 0.1 μm. Very fine insoluble contaminants which exhibit properties of both dissolved and suspended solids are classified as *colloids*. Colloids, between 0.001 and 0.1 μm in size, tend to contain ionic-type charges and resist settling out of solution.

In order to remove particulate material in the range between 25 to 100 μm, it is usually most economical to employ a cartridge filter that can remove particu-

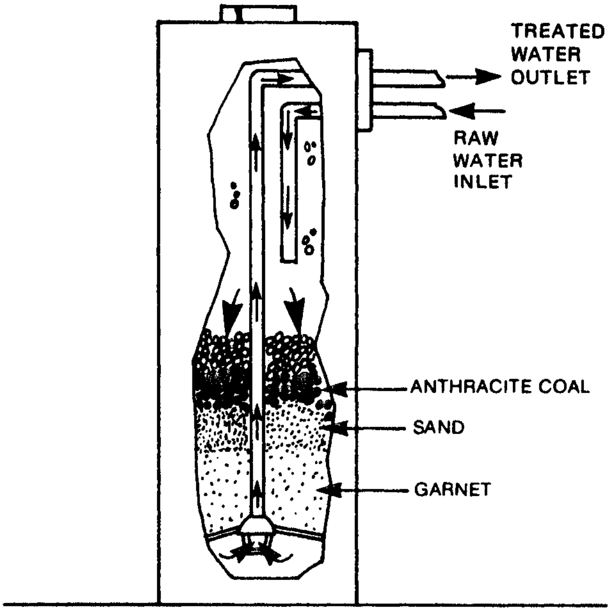

FIG. 1.2 A typical multimedia filter showing stratified bed of media. *(Courtesy of Water Quality Association.*[1]*)*

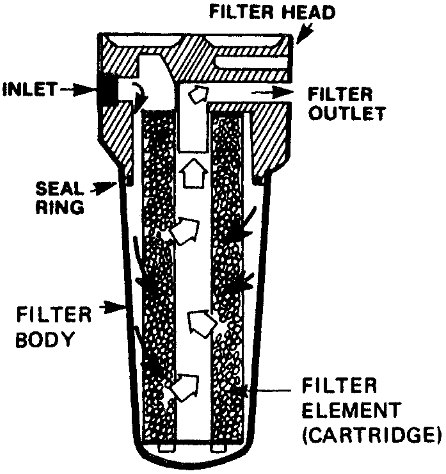

FIG. 1.3 A typical cartridge-type filter in housing. *(Courtesy of Water Quality Association.*[1]*)*

late material as small as 5 or 2 μm. If the flow is as great as 10 gpm (0.63 L/s), a bed-type filter may prove to be less expensive—depending on the quantity of particulate material to be removed. If smaller suspended solids must be removed, more sophisticated filter cartridges are available that are effective in removing particulate material in the submicrometer range.

Ion Exchange

Ion exchange is a chemical process for the removal of dissolved ionic contaminants. This is accomplished by the use of polymeric resins that exchange "more acceptable" ions for the ones to be removed.

Water Softening. The ion-exchange softening of water is the removal of scale-forming calcium and magnesium ions from hard water and the replacement of these ions with sodium ions, which are more soluble. Water softening is technically known as *cation-exchange softening* (once called *zeolite softening*).

Water softeners typically consist of (*a*) two tanks, one of which (i.e., the resin tank) contains the ion-exchange resin and the other of which (i.e., the brine tank) contains salt that is used in the regeneration process, and (*b*) the necessary controls and timer required for operation and regeneration. The differences between residential and commercial water softening equipment is usually only in the size of the tanks and piping. The basic principle is the same for both.

Calcium and magnesium are the cations associated with "hard water." They form insoluble precipitates of calcium and magnesium carbonate called *scale*. The calcium and magnesium ions that are in contact with the softening resin are exchanged for the sodium ion, which is very soluble in water and does not form a scale, as illustrated in Fig. 1.4. The calcium and magnesium ions, which have been adsorbed onto the resin, can be removed during the *regeneration* process by soaking the resin in a sodium chloride solution. This solution reattaches sodium ions to the resin, allowing it to revert to its original state.

Deionization

Deionization is an ion-exchange process used for removal of all dissolved salts from water. Deionization requires the flow of water through two ion-exchange resins in order to effect the removal of all salts. The passage of water through the first ion-exchange resin bed removes the calcium and magnesium ions, as in the normal softening process illustrated in Fig. 1.4.

Unlike the softening process, the resin also removes all other cations and replaces them with hydrogen ions instead of sodium ions. As the cations in the water affix themselves to the cation-exchange resin, it releases its hydrogen ions on a chemically equivalent basis. A sodium ion (Na^+) displaces a hydrogen ion (H^+) from the exchanger; a calcium ion (Ca^{++}) displaces two; a ferric ion (Fe^{+++}) displaces three hydrogen ions; etc.

At this point the deionization process is only half complete. Although the cations have been removed, the water now contains positive hydrogen ions and the associated anions originally in the raw water. The partially treated water now flows through a second unit, containing an anion-exchange resin. This second exchange material normally contains replaceable hydroxyl anions. The negative ions in solution (anions) are adsorbed onto the anion-exchange resin. Released in

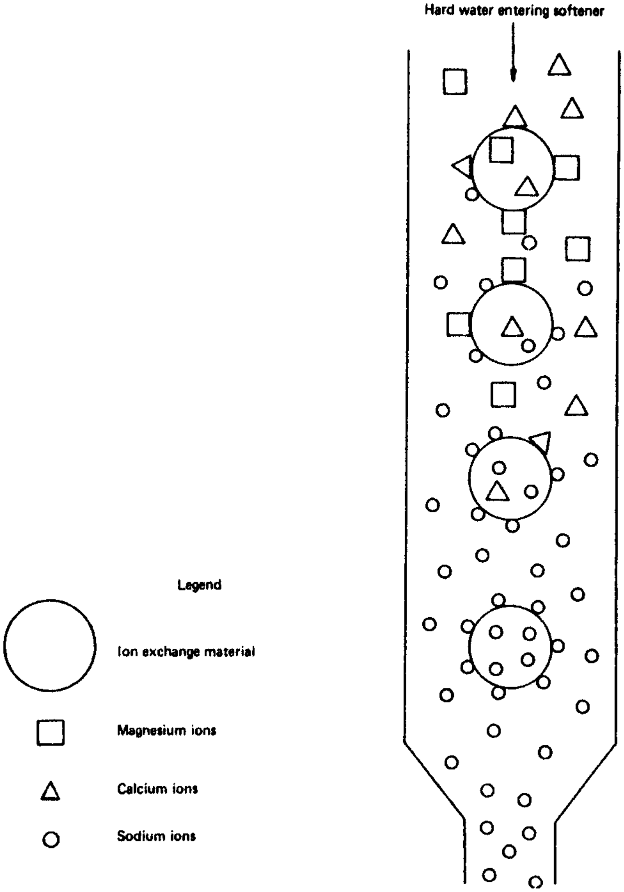

FIG. 1.4 The softening process. *(Courtesy of Water Quality Association.[1])*

their place are hydroxyl ions. What emerges from such a two-unit system is effectively *ion-free* water. It still contains the positive hydrogen ions released in the initial exchange plus the negative hydroxyl ions released in the second exchange. These ions therefore combine to form water.

If each of the resins is kept in separate containers with the water running from one into the other, the process is known as *two-bed deionization*. If both resins are mixed together in a single container, the process is known as *mixed-bed deionization*, which generally produces higher-quality water than two-bed deionization. Mixed-bed deionization produces water of the highest purity, in terms of ion removal, for industrial processes. Figure 1.5 illustrates the deionization process in a two-bed system.

Oxidizing Filters. In addition to hardness ions, iron presents a precipitation problem in many water supplies. Soluble iron can react with dissolved air to form insoluble ferric hydroxide. This can be a particular problem when the concentra-

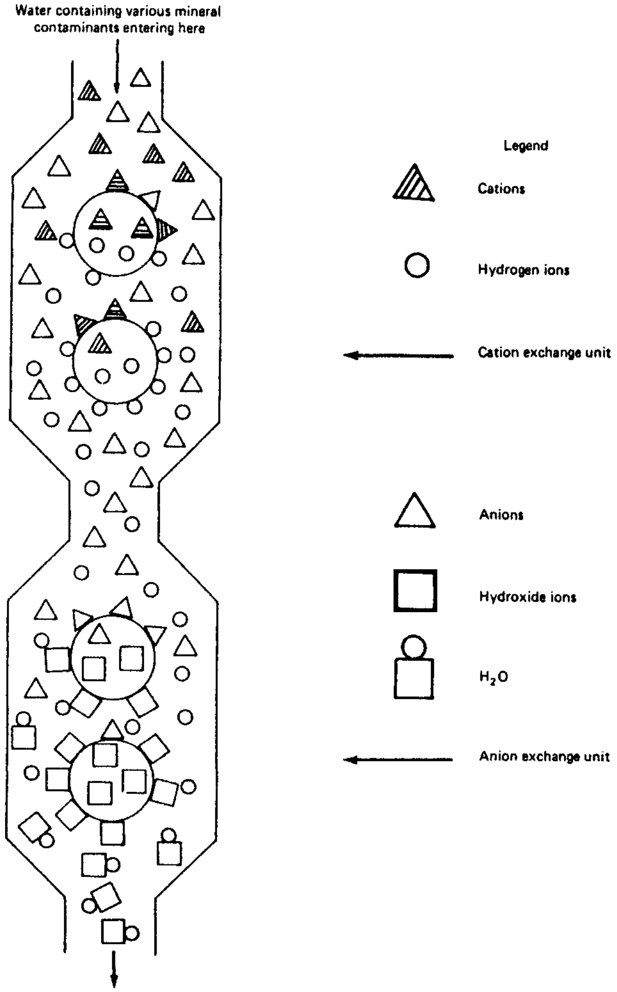

FIG. 1.5 The deionization process in a two-bed system. *(Courtesy of Water Quality Association.*[1]*)*

tion of the iron in the water is above 0.3 ppm and the pH of the water higher than 6.8.

A particular resin known as *manganese greensand* can simultaneously oxidize the soluble iron to ferric hydroxide and filter it out of the water. Manganese greensand filters can be regenerated through the use of a strong oxidizing agent.

Adsorption

Adsorption is a mechanism of contaminant removal making use of the adsorption phenomenon, the act of physical adhesion of molecules or colloids to the surface of a medium without chemical reaction. Certain very porous materials have the ability to attract contaminants to their surfaces, thereby removing them from solution.

Activated carbon (sometimes referred to as *activated charcoal*) is a powdered, granular, or pellet form of amorphous carbon prepared in such a way that it has an extremely large surface area per unit volume because of its enormous number of very fine pores. This material is particularly effective in removing dissolved organic materials in low concentrations, as well as dissolved gases such as chlorine. Activated carbon is available either in bed-type configurations or in cartridge constructions similar to filter cartridges. Various types of activated carbon are available; the choice depends on the contaminant to be removed. Activated carbon is most widely used in the removal and reduction of dissolved organic contaminants.

Activated alumina is an adsorption medium manufactured from aluminum oxide which can selectively remove dissolved fluoride. It is most commonly used in bed-type configurations.

Distillation

Distillation is the process of (*a*) changing water from a liquid to a vapor by boiling it, then (*b*) condensing the water vapor by cooling, to form a liquid. Theoretically, all the contaminants are left behind, except those with the same boiling point as water. Figure 1.6 illustrates the principle of operation of a typical drink-

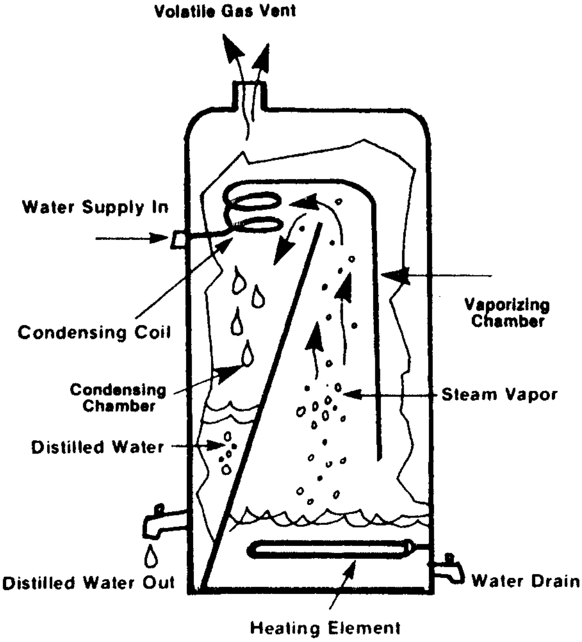

FIG. 1.6 Principle of operation of a typical drinking water distillation unit. (*Courtesy of Water Quality Association.*[1])

ing water distillation unit. An electric heating element raises the water temperature to boiling, causing steam (water vapor) to rise and contact a condensing coil of incoming water. This cold water causes the water vapor to condense back into the liquid form as distilled water.

Distillation is very effective in removing suspended solids and dissolved salts, as well as most microorganisms. Distillation also provides disinfection of water. Its shortcomings include high energy utilization and high maintenance costs.

Membrane Separation

In membrane separation technologies, a semipermeable membrane is used to separate waterborne contaminants from the water. This is accomplished by a process known as *crossflow filtration* (also called *tangential flow filtration*). In this process, the bulk solution flows over (and parallel to) the filter surface, and under pressure, a portion of the water is forced through the membrane filter. The turbulent flow of the solution over the membrane surface minimizes the accumulation of particulate matter on the membrane and facilitates continuous operation of the system. Figure 1.7 compares conventional medium filtration with crossflow membrane filtration. In conventional filtration, the entire solution is pumped through the filter medium, while only a portion of the solution goes through with the crossflow filtration process.

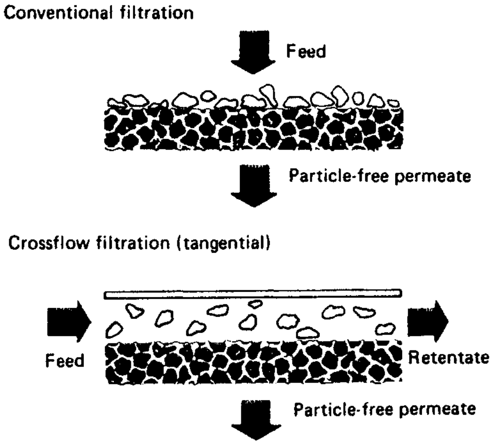

FIG. 1.7 A comparison of conventional medium filtration with crossflow filtration by a semipermeable membrane.

Microfiltration involves the removal of insoluble particulate materials ranging in size from 0.1 to 10.0 μm (1000 to 100,000 Å). Figure 1.8 depicts the mechanism of crossflow microfiltration.

Figure 1.9 depicts ultrafiltration, which is used to separate materials in the 0.001 to 0.1 μm range (10 to 1000 Å). Ultrafiltration is used to remove dissolved materials; microfiltration is used to remove suspended solids. Typical micro- and

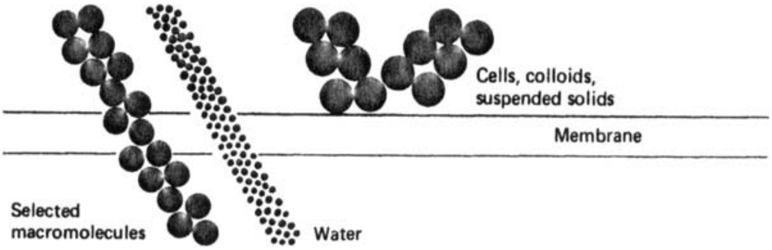

FIG. 1.8 The mechanism of crossflow microfiltration.

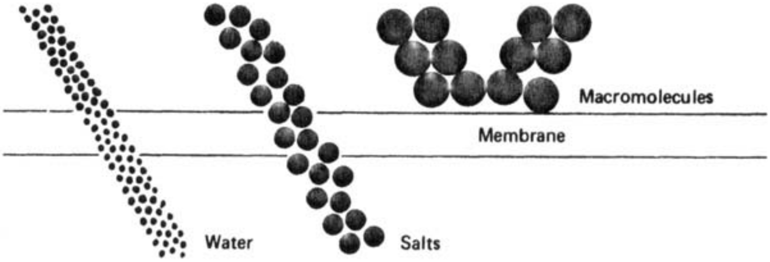

FIG. 1.9 Ultrafiltration to remove dissolved materials.

ultrafiltration membrane polymers include polysulfone, cellulose acetate, and polyamide.

Reverse osmosis is a technique used primarily to remove salts from water. The water is forced, under pressure, to pass through a membrane. The membrane will not pass sodium or chloride ions or macromolecules. Figure 1.10 illustrates reverse osmosis, which typically separates materials less than 0.001 μm (10 Å) in size. Reverse osmosis offers the added advantage of rejecting ionic materials which are normally small enough to pass through the pores of the membrane. As with ultrafiltration, reverse osmosis is used to remove dissolved materials, but its primary application is in salts or mineral reduction. Polymers used in reverse osmosis membranes include cellulose acetate, cellulose triacetate, polyamide, and thin-film composite membranes. These last membranes are typically composed of a thin film formulated from one of a number of amide-type polymers on a polysulfone layer.

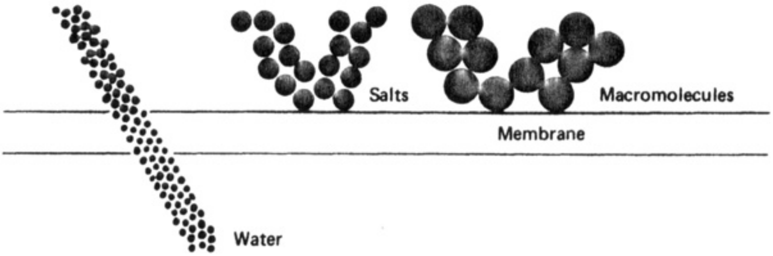

FIG. 1.10 The principle of the reverse-osmosis method. The membrane permits water to pass through it, but blocks salts and macromolecules.

The *electrodialysis* process is an electrochemical membrane separation process in which ions are transferred through a pair of ion-selective membranes, from a less concentrated to a more concentrated solution, as a result of the flow of (direct) electric current. Electrodialysis removes only the ionic solute.

An electrodialysis membrane device consists of alternating ion-exchange membranes that are each permeable to either anions or cations. The solution containing ions to be concentrated is pumped through every other cell. By applying direct current to an anode and cathode positioned parallel to the membranes, salts are attracted through the membrane that is permeable to that particular ionic species and are held back by the impermeable membrane. In this way, two streams are produced, one containing the salts in concentrated form, and the other containing relatively pure water.

DISINFECTION

Viable (growing) microorganisms are a particularly difficult contaminant to remove. The ubiquitous nature of these contaminants, especially bacteria, and the fact that some microorganisms grow under virtually any conditions make it impossible to eliminate them completely from a water treatment system. *Disinfection* is the process used to kill these organisms. Most disinfectants are chemicals that are normally fed into the water treatment system; they are allowed to circulate for a time and are then rinsed out with clean water prior to returning the system to use. The ideal chemical disinfectant

- Kills all strains of bacteria.
- Has no deleterious effect on materials of construction or components of the water treatment system.
- Is stable and retains its effectiveness during the disinfection process.
- Is easily removed from the entire water treatment system.
- Is easily monitored with a simple test kit.

The ideal disinfectant does not exist. Therefore, the selection of the chemical and/or process used must be based on careful evaluation and testing for each specific application. The disinfection of plumbing systems in buildings is described in Chap. 12.

Chemical Disinfectants

The following chemical disinfectants are used in water treatment systems:

Chlorine. This is the most widely used disinfectant in municipal water supply systems in the U.S.A. Chlorine has been under scrutiny because of its propensity to form possible carcinogens (trihalomethanes) upon reaction with naturally occurring organic materials such as humic acid or with human-made organic effluent. Bacteria can be maintained at low levels in the presence of 1 to 2 ppm of free available chlorine in the water supply; however, chlorine is relatively ineffective against acid-fast bacteria such as nontuberculous mycobacteria and cysts such as formed by *Giardia lamblia*. Care must be taken because excessive amounts of chlorine can cause corrosion as a result of its strong oxidation characteristics. Chlorine is normally pumped into the system from a solution of sodium hypochlorite or as a gas. Chlorine is readily removed by activated carbon filters, and can be monitored with simple test kits. It is easily rinsed out of the system.

Chloramines. These compounds, resulting from the reaction of ammonia with chlorine in water solution, are commonly used in municipal water supply systems because of the superior stability of chloramine compounds over chlorine. A further advantage is that chloramine compounds do not form trihalomethanes. However, chloramines are not as strong an oxidant as chlorine and thus have less ability to kill bacteria. Concentrations of these compounds in the range of 5 to 10 ppm are required.

Chlorine Dioxide. Chlorine dioxide exhibits stronger disinfecting characteristics than chloramines, but there is little evidence of extensive use of this disinfectant. Chlorine dioxide does not form trihalomethanes and exhibits rinsing, corrosion, and handling characteristics similar to those of chlorine. Recommended concentrations are 2 to 5 ppm, with removal by activated carbon.

Iodine. This common relative of chlorine has been used for years by campers for disinfecting drinking water of unknown quality. Unfortunately, certain gram-negative bacteria strains can become resistant to iodine. Much less reactive to dissolved organics than chlorine, it will not form trihalomethanes. It is removed with activated carbon and can be monitored with test kits. The recommended concentration is 0.3 to 0.5 ppm.

Ozone. This powerful chemical, which consists of oxygen in a three-atom form, is used to disinfect some municipal water supply systems. It is a very effective bactericide; however, it must be generated on site and has a relatively short life. When used at the recommended concentration of 2 to 3 ppm, ozone will kill bacteria, viruses, spores, and cysts. Both ultraviolet irradiation and activated carbon will remove ozone from water.

Care must be taken in handling any of the above chemicals, and their effect on the materials of construction of the water treatment system must be evaluated.

Nonchemical Processes

The following nonchemical processes are used to reduce bacterial contamination in water treatment systems.

Ultraviolet Irradiation. Exposure to ultraviolet (UV) radiation is a method of treating relatively small-scale water supplies. In this process, the water is exposed to ultraviolet radiation after it has been filtered. Only momentary exposure is required to kill the bacteria, but this condition may not be fulfilled if the bacteria are shielded by particles of sediment in the water. Then, bacteria that survive may multiply rapidly in the tank storing the water after exposure to the ultraviolet radiation. Furthermore, there is some evidence that certain bacteria may merely be inhibited in growth, rather than killed. Such bacteria, after a period of time, may recover and reproduce. If the bacteria recover in the presence of fluorescent light, the process is known as *photoreactivation*. Because ultraviolet irradiation does not involve the addition of chemicals, the only costs in this process are the investment in equipment, replacement of ultraviolet bulbs, electrical power consumption, and the occasional cleaning of the bulb surfaces.

Hot Water. Heated water, 70°F (21°C) or higher, can be used to disinfect specific components in a water supply system—for example, activated carbon filters. However, this method is not practical for disinfecting an entire system because of:

- The difficulty in handling water at such a high temperature
- The special materials required in construction of the system
- Excessive consumption of energy

MONITORING A WATER SUPPLY SYSTEM

Monitoring a water supply system is the periodic measurement of the contaminant concentration levels in the system to provide a check on whether the water treatment system is performing adequately. Different types of contaminants require different types of measurement techniques for highly effective monitoring.

Ionic contaminants can be monitored most easily by the use of instruments that measure electrical conductivity. The electrical conductivity of water is determined by the presence of ionic components in it. If there are none, i.e., if the water is ultrapure, then the water is an excellent electrical *insulator*. The conductivity (reciprocal of resistivity) of the water is directly proportional to the total concentration of ionic contaminants in the water.

Electrical meters are available for monitoring the total ionic concentration of a water stream. Such instruments are sometimes incorrectly called "total dissolved solids" (TDS) meters. This designation is inappropriate because a true total dissolved solids concentration must also include nonionic as well as ion components, and these meters indicate only the ionic concentration. Because different salts conduct electric current differently, a chart such as that shown in Table 1.3, which relates the conductivity (or resistivity) of water to its dissolved solids concentration, is based on an estimate of the makeup of the water tested.

The measurement of dissolved organic contaminants requires sophisticated and time-consuming analytical technologies performed by highly trained personnel. Automatic in-line equipment is available to measure total organic carbon (TOC) continuously.

The following are the most common procedures for monitoring the presence of bacteria:

- *TOC (total organic carbon) test.* This test provides a good indication of bacteria levels, although other organic constituents also contribute to the TOC reading. Monitoring equipment is available to continuously measure TOC levels. This parameter provides a good measure of dissolved organic solids concentration, and extremely low levels can be identified. Monitors are available that are capable of measuring levels as low as 0.001 ppm. Such equipment is high in cost and requires trained operators.
- *LAL test.* This test for *Limulus amebocyte lysate* is a very useful technique for measuring the presence of all bacteria, both alive and dead. Monitoring equipment is available for performing such a test continuously.
- *FDC (fluorescence direct count) test.* This test requires the collection of bacte-

TABLE 1.3 Specific Conductance, Resistance, Approximate Electrolyte Content for Deionized or Distilled Water at 7°F (25°C)

Specific conductance, μS*	Specific resistance, Ω	Approximate electrolyte content, ppm					
		as NaCl	as $CaCO_3$	as NaOH	as $CaCO_3$	HCl	as $CaCO_3$
0.1	10,000,000	0.04	0.03			0.01	0.01
0.2	5,000,000	0.08	0.07	0.03		0.20	0.27
1	1,000,000	0.4	0.34	0.20	0.25	0.13	0.18
2	500,000	0.8	0.68	0.40	0.50	0.26	0.36
4	250,000	1.6	1.35	0.80	1.00	0.55	0.75
6	166,000	2.5	2.10	1.00	1.25	0.90	1.23
8	125,000	3.2	2.70	1.50	1.87	1.20	1.64
10	100,000	4.0	3.40	2.00	2.50	1.50	2.05
20	50,000	8.0	6.80	4.00	5.00	2.00	2.70
30	33,333	14.0	12.00	5.00	6.25	3.00	4.10
40	25,000	19.0	16.00	6.00	7.50	4.00	5.47
50	20,000	24.0	20.00	7.00	8.75	4.50	6.16
60	16,666	28.0	24.00			5.50	7.53
70	14,286	33.0	28.0			6.50	8.90
80	12,500	38.0	32.0	11.0	13.75	7.50	10.30
90	11,111	43.0	36.0			8.00	10.96
100	10,000	50.0	43.0	14.0	17.50	9.00	12.32
200	5,000	100.0	85.0	27.0	33.75	18.00	24.65

**Microsiemens*, μS, may also be expressed as *micromhos*.

Source: Courtesy of Ionac Chemical Company.

ria, incubation of the bacteria for 48 h, then counting the bacteria colonies. This is a time-consuming task and involves highly trained personnel.

WATER QUALITY STANDARDS

Because it is virtually impossible to produce water completely free from measurable quantities of all contaminants, different quality standards have been developed for many different applications. Each standard addresses the particular contaminant which may present problems in the appropriate application.

With very few exceptions, *all* water supplies in the U.S.A. must meet the Safe Drinking Water Act.

REFERENCES

1. *Water Treatment Fundamentals*, Water Quality Association, Lisle, IL 60532, 1983.
2. *Water Processing of Home, Farm and Business*, Water Quality Association, Lisle, IL 60532, 1988.

CHAPTER 2

WATER SUPPLY REQUIREMENTS IN BUILDINGS

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INTRODUCTION

This chapter discusses water supply requirements in buildings. First, the rate of flow furnished by a water supply system to various types of plumbing fixtures and water outlets is described. Then a method is discussed for estimating the total demand of a water supply system in a building.

WATER SUPPLY REQUIREMENTS FOR INDIVIDUAL FIXTURES AND EQUIPMENT

Plumbing fixtures and equipment should be provided with water in sufficient volume, and at adequate pressures, to enable them to function satisfactorily without excessive noise, under normal conditions of use. Water supply valves, piping, and trim to individual plumbing fixtures and equipment should be selected and adjusted to supply the minimum quantity of water consistent with proper performance and cleaning and should be maintained to prevent leakage and excessive waste of water.

Demand is the rate of flow, usually expressed in gallons per minute (or liters per second), furnished by a water supply system to various types of plumbing fixtures and water outlets under normal conditions. *Normal conditions* are those conditions that provide adequate performance while avoiding objectionable effects, such as excessive splashing or inadequate supply conditions.

Excessive Pressure

To avoid excessive flow rates and splashing at fixtures where the available pressure is considerably higher than the minimum required, it is generally necessary to provide some means of reducing the maximum flow rate to match the normal values. This is especially required at fixtures on the lower floors of high and tower-type buildings, for at such locations the pressure in the individual fixture supply pipes is many times the minimum required at water outlets. (See Chap. 4.)

Where the available pressure at water outlets is more than twice the minimum pressure required for satisfactory supply, it is recommended that means to control the flow rate be provided in the individual fixture supply pipe. For this purpose, individual regulating valves, variable-orifice control devices, or fixed orifices may be provided.

A flush valve (flushometer) is a valve designed to supply a fixed quantity of water for flushing purposes; it is actuated by direct water pressure, without the use of a cistern or flush tank. It is usually equipped with adjustment screws for regulating valve operation and a throttling valve at the valve inlet for reducing the available flow pressure to 25 or 15 psi (172 or 103 kPa), as may be required for satisfactory function of water closets, urinals, bedpan washers, flushing-rim slop sinks, or dishwashing machines.

For faucets and flush tank ball cocks, a throttling valve or flow-control orifice may be installed in the fixture supply pipe to reduce the maximum flow rate to match normal demand. To control faucet flow, throttling valves should be adjusted so that flow matches demand when the faucet is wide open. Flow-control orifices should be selected in accordance with desired demand and anticipated supply pressure.

Demand at Individual Water Outlets

Ordinary Pipe Outlets. The demand at ordinary pipe outlets flowing wide open at maximum rate of discharge may be calculated from the following equation:

$$Q = 20d^2p^{1/2} \tag{2.1a}$$

where Q = actual rate of discharge from the pipe outlet, i.e., the demand in gpm
d = diameter of the outlet, in
p = pressure measured in the supply pipe during flow, psi

The corresponding equation in the International System of units is

$$Q = 0.745d^2p^{1/2} \tag{2.1b}$$

where Q = actual rate of discharge from the pipe outlet, i.e., the demand in L/s
d = diameter of the outlet, cm
p = pressure measured in the supply pipe during flow, kPa

Electrically Operated Supply Valves. Equipment having electrically operated supply valves varies considerably in demand requirements, depending on the type and its performance characteristics. Information about the demand may be obtained from data furnished by manufacturers of such equipment. In the absence of adequate information, the demand may be calculated on the basis of flow pressure required and the outlet diameter, just as for any ordinary pipe outlet. Usually, electrically operated supply valves are kept wide open for maximum flow rate.

Common Plumbing Fixtures. The demands at individual water outlets at various plumbing fixtures and hose connections are given in Table 2.1. The values are generally accepted as the normal, suitable rates of flow for the outlets. The values for faucets (which users may adjust manually according to their needs) are not the maximum flow rates which the faucets are capable of providing. Rather, they are the flow rates which are considered suitable for fixture usage without causing excessive splashing, which is related to the shape and depth of the fixture.

Flow Control for Conservation of Water and Energy

As a water conservation measure, flow rates at certain faucet outlets may be reduced slightly below those shown in Table 2.1 without causing any noticeably adverse effect in usage. Fixtures at which this may be applied and the minimum flow rate recommended are as follows: lavatory faucets in private bathrooms, 1.5 gpm (0.095 L/s); shower heads in private bathrooms, 2 gpm (0.126 L/s); and sink faucets at domestic kitchen sinks, 3 gpm (0.189 L/s).

As an energy conservation measure, the maximum flow rate for hot-water lavatory faucets in restrooms to which the general public has access is recommended to be limited by design to ½ gpm (0.032 L/s), and the outlet temperature limited to 110°F (43.4°C). This requirement may be found in state energy conservation construction codes. In view of such requirement as to maximum flow rate for the hot-water lavatory faucet in restrooms for the general public, it is recommended that the same limitation be observed for the cold-water lavatory faucet.

TABLE 2.1 Demand at Individual Water Outlets

Type of outlet	Demand	
	gpm	L/s
Ordinary lavatory faucet	2.0	0.126
Self-closing lavatory faucet	2.5	0.158
Sink faucet, ⅜ or ½ in (1 or 1.3 cm)	4.5	0.284
Sink faucet, ¾ in (1.9 cm)	6.0	0.378
Bath faucet, ½ in (1.8 cm)	5.0	0.315
Shower head, ½ in (1.8 cm)	5.0	0.315
Laundry faucet, ½ in (1.8 cm)	5.0	0.315
Ball cock in water closet flush tank	3.0	0.189
1-in (2.5-cm) flush valve, 25-psi (172-kPa) flow pressure	35.0	2.210
1-in (2.5-cm) flush valve, 15-psi (103-kPa) flow pressure	27.0	1.703
¾-in (1.9-cm) flush valve, 15-psi (103-kPa) flow pressure	15.0	0.946
Drinking fountain jet	0.75	0.047
Dishwashing machine (domestic)	4.0	0.252
Laundry machine (domestic)	4.0	0.252
Aspirator (operating room or laboratory)	2.5	0.158
Hose bib or sill cock, ½ in (1.3 cm)	5.0	0.315

ESTIMATING THE TOTAL DEMAND IN A SUPPLY SYSTEM

The objectives in designing water supply systems for buildings are to ensure adequate water supply to all fixtures at all times and to achieve economical sizing of piping. To do this, it is necessary to estimate as accurately as possible the probable maximum rate of flow or the demand for which provision should be made in every portion of the system, including the water service, main supply lines, risers, and main branches.

Demand in building water supply systems cannot be determined exactly. Most plumbing fixtures in buildings are used intermittently, and the probability of simultaneous use of such fixtures cannot be definitely established. In addition, each type of plumbing fixture imposes its own singular loading effect on the system. This may be attributed to (*a*) average rate of supply required by a fixture for satisfactory service, (*b*) duration of fixture use, and (*c*) frequency of fixture use. Nevertheless, the demand imposed on the building water supply system by intermittently used fixtures is related to the number, type, and probable simultaneous use of the fixtures to be supplied.

For a method to be generally acceptable for estimating the demand of a building water supply system, it must meet three basic requirements:

1. It must produce estimates greater than the average demand for all fixtures on the system during periods of heaviest demand; otherwise failure will occur in the supply to some fixtures during maximum demand periods.
2. The method must yield reasonably accurate estimates of peak demand so as to avoid oversizing of piping and uneconomical waste.
3. The method must be adaptable for estimating the demand of groups of like fixtures as well as of different kinds of fixtures and building occupancy classifications.

Load Values (WSFUs) Assigned to Fixtures

The demand imposed on a system by intermittently used fixtures is related to the number, type, and probable simultaneous use of the fixtures to be supplied.

In the standard method, fixtures using water intermittently under several conditions of service are assigned specific load values in terms of water supply fixture units. The *water supply fixture unit* (WSFU) is a factor so chosen that the load-producing effects of different kinds of fixtures and their conditions of service can be expressed as multiples of that factor.

Values assigned to different kinds of fixtures are given in Table 2.2. For fixtures having both hot- and cold-water supplies, the values for separate hot- and cold-water demands should be taken as being three-fourths of the total value assigned to the fixture in each case. For example, the value assigned to a kitchen sink in a dwelling unit is 2 WSFU, while the separate demands on the hot- and cold-water piping thereto should be taken as being 1.5 WSFU.

TABLE 2.2 Demand Load of Fixtures

Fixture	Occupancy	Type of supply control	Load values assigned water supply fixture units		
			Cold	Hot	Total
Water closet	Public	Flush valve	10		10
Water closet	Public	Flush tank	5		5
Urinal	Public	1-in (2.5-cm) flush valve	10		10
Urinal	Public	¾-in (1.9-cm) flush valve	5		5
Urinal	Public	Flush tank	3		3
Lavatory	Public	Faucet	1.5	1.5	2
Bathtub	Public	Faucet	3	3	4
Showerhead	Public	Mixing valve	3	3	4
Service sink	Offices, etc.	Faucet	2.25	2.25	3
Kitchen sink	Hotel, restaurant	Faucet	3	3	4
Drinking fountain	Offices, etc.	⅜-in (0.95-cm) valve	0.25		0.25
Water closet	Private	Flush valve	6		6
Water closet	Private	Flush tank	3		3
Lavatory	Private	Faucet	0.75	0.75	1
Bathtub	Private	Faucet	1.5	1.5	2
Shower stall	Private	Mixing valve	1.5	1.5	2
Kitchen sink	Private	Faucet	1.5	1.5	2
Laundry trays (1 to 3)	Private	Faucet	2.25	2.25	3
Combination fixture	Private	Faucet	2.25	2.25	3
Dishwashing machine	Private	Automatic		1	1
Laundry machine, 8 lb (3.6 kg)	Private	Automatic	1.5	1.5	2
Laundry machine, 8 lb (3.6 kg)	Public or general	Automatic	2.25	2.25	3
Laundry machine, 16 lb (7.3 kg)	Public or general	Automatic	3	3	4

Note: For fixtures not listed, loads should be assumed by comparing the fixture with 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.

Demand Corresponding to Fixture Load

The demand in gallons per minute or liters per second corresponding to any given load in water supply fixture units may be determined from Table 2.3. Intermediate values may be interpolated for loads between those shown in the table.

The demand corresponding to a load of a given number of water supply fixture units is generally much higher for a system in which water closets are flushed predominantly by means of direct supply-connected flush valves (flushometers) than for a system in which they are flushed predominantly by means of flush tanks. The difference in demand between the two systems gradually diminishes as the total number of fixture units of load rises, until at 1000 water supply fixture units the demand for both types is the same, 208 gpm (13.12 L/s).

Where a part of the system does not supply any water closets, such as is the case with hot-water supply piping and some cold-water supply branches, the demand corresponding to a given number of water supply fixture units may be determined from the values given for systems in which water closets are flushed predominantly by means of flush tanks. The demands determined in such cases undoubtedly are appropriate in view of the average of values assigned to fixtures other than water closets having direct supply-connected flush valves (flushometers).

Total Demand Including Continuous Flow

To estimate the total demand in gallons per minute or liters per second in any given water supply pipe which supplies outlets at which the demand is intermittent and also outlets at which demand is continuous, the demand for outlets which pose continuous demand during peak periods should be calculated separately and added to the demand for plumbing fixtures used intermittently. Examples of outlets which impose continuous demand are those for watering gardens, washing sidewalks, and irrigating lawns and for air-conditioning or refrigeration apparatus.

ESTIMATED WATER SUPPLY DEMAND LOAD

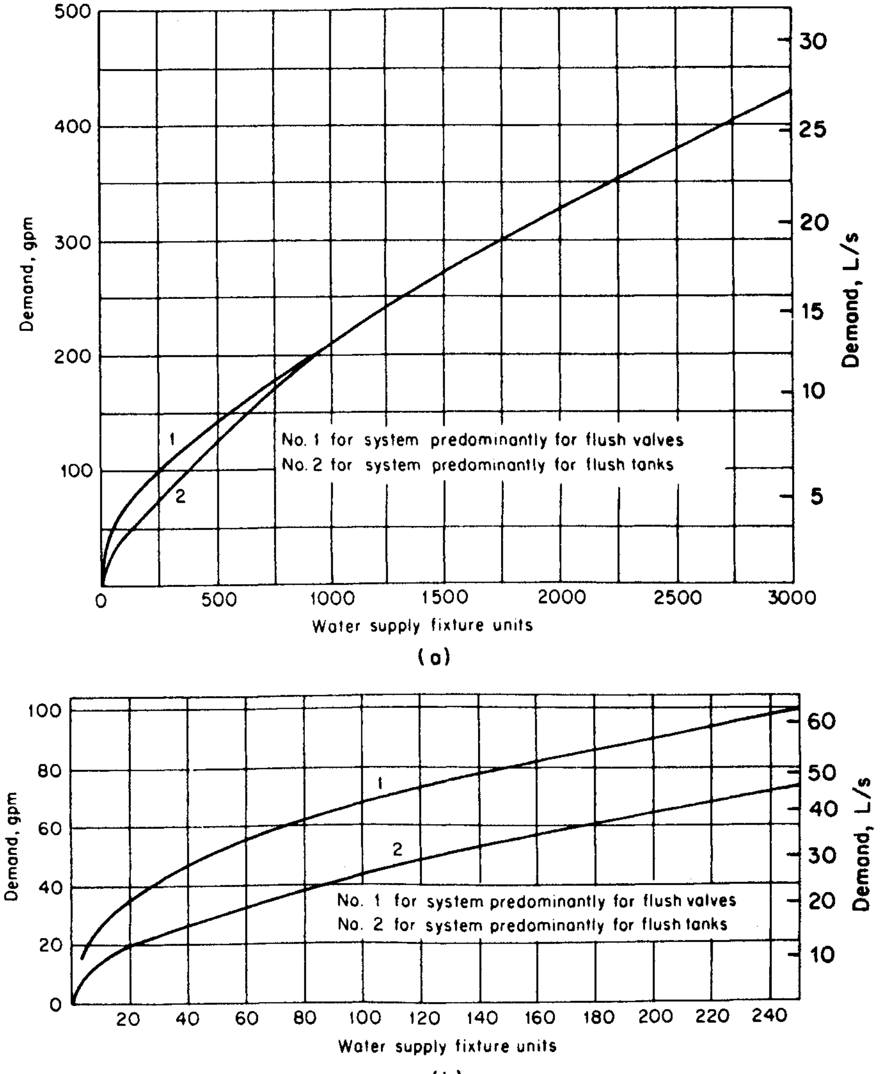
For purposes of estimating the water supply load, the demand load values, in terms of water supply fixture units, for different plumbing fixtures under several conditions of service, are given in Table 2.2.

The estimated demand load for fixtures used intermittently on any supply pipe, in gallons per minute corresponding to the total number of water supply fixture units, is given in two charts in Fig. 2.1.

To estimate the total demand in gallons per minute, the demands for outlets such as hose connections and air-conditioning apparatus, which impose continuous demand during periods of heavy use, should be calculated separately and added to the demand for fixtures used intermittently.

TABLE 2.3 Table for Estimating the Demand in a Water Supply System

Supply systems predominantly for flush tanks			Supply systems predominantly for flushometer valves		
Load	Demand		Load	Demand	
Water supply fixture units (WSFU)	gpm	L/s	Water supply fixture units (WSFU)	gpm	L/s
1	3.0	0.19			
2	5.0	0.32			
3	6.5	0.41			
4	8.0	0.51			
5	9.4	0.59	5	15.0	0.95
6	10.7	0.68	6	17.4	1.10
7	11.8	0.74	7	19.8	1.25
8	12.8	0.81	8	22.2	1.40
9	13.7	0.86	9	24.6	1.55
10	14.6	0.92	10	27.0	1.70
12	16.0	1.01	12	28.6	1.80
14	17.0	1.07	14	30.2	1.91
16	18.0	1.14	16	31.8	2.01
18	18.8	1.19	18	33.4	2.11
20	19.6	1.24	20	35.0	2.21
25	21.5	1.36	25	38.0	2.40
30	23.3	1.47	30	42.0	2.65
35	24.9	1.57	35	44.0	2.78
40	26.3	1.66	40	46.0	2.90
45	27.7	1.76	45	48.0	3.03
50	29.1	1.84	50	50.0	3.15
60	32.0	2.02	60	54.0	3.41
70	35.0	2.21	70	58.0	3.66
80	38.0	2.40	80	61.2	3.86
90	41.0	2.59	90	64.3	4.06
100	43.5	2.74	100	67.5	4.26
120	48.0	3.03	120	73.0	4.61
140	52.5	3.31	140	77.0	4.86
160	57.0	3.60	160	81.0	5.11
180	61.0	3.85	180	85.5	5.39
200	65.0	4.10	200	90.0	5.68
250	75.0	4.73	250	101.0	6.37
300	85.0	5.36	300	108.0	6.81
400	105.0	6.62	400	127.0	8.01
500	124.0	7.82	500	143.0	9.02
750	170.0	10.73	750	177.0	11.17
1000	208.0	13.12	1000	208.0	13.12
1250	239.0	15.08	1250	239.0	15.08
1500	269.0	16.97	1500	269.0	16.97
2000	325.0	20.50	2000	325.0	20.50
2500	380.0	23.97	2500	380.0	23.97
3000	433.0	27.32	3000	433.0	27.32
4000	525.0	33.12	4000	525.0	33.12
5000	593.0	37.41	5000	593.0	37.41



(a)

(b)

FIG. 2.1 (*a*) The estimated demand in gallons per minute or liters per second corresponding to a given load expressed in fixture units. (*b*) A detail of Fig. 2.1*a* for small demand.

CHAPTER 3

WATER DISTRIBUTION SYSTEMS IN BUILDINGS

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INTRODUCTION

This chapter describes the systems used to distribute cold and hot water within various types of buildings. At any point within a building, a water distribution system must deliver an adequate water pressure and volume to operate the fixtures or equipment that it serves, without excessive noise, under all conditions of normal use. The various methods of water distribution described in this chapter make use of upfeed systems, downfeed systems, or some combination thereof. An *upfeed system* is a water distribution system in which the water is supplied and fed *upward* through the vertical piping to the highest point of the system that may be fed using the pressure available. A *downfeed system* is a water distribution system in which the water distribution main is located at the top of the pressure zone; the distribution main supplies the vertical piping (risers) that distributes water *downward* to the lowest point of the zone. A *pressure zone* is an area of a building (it may be an entire floor, several floors, or the entire building) supplied with water having a common pressure origin or a common supply. Buildings having more than one pressure zone are described as having *multiple pressure zones*.

In low-rise buildings, the water pressure in the public water mains is usually sufficient to distribute the water to the hydraulically most remote point. When the pressure of the water main is not sufficient for this purpose, the pressure must be increased or "boosted," as described in this chapter and the one that follows.

The illustrations in this chapter are schematic representations, rather than actual installations. They demonstrate the various methods and techniques used in water distribution systems in low-rise, medium-rise, and high-rise buildings. Pipe sizing and design criteria for such installations are described in Chap. 7.

DISTRIBUTION SYSTEMS IN LOW-RISE BUILDINGS

Upfeed Systems; Single Pressure Zone

Where the pressure in the water main is sufficient to distribute water throughout an entire building, an upfeed system such as that shown in Fig. 3.1 is used. In this system, there is a *single pressure zone*; i.e., all floors in the building are supplied with water using the pressure in the water main.

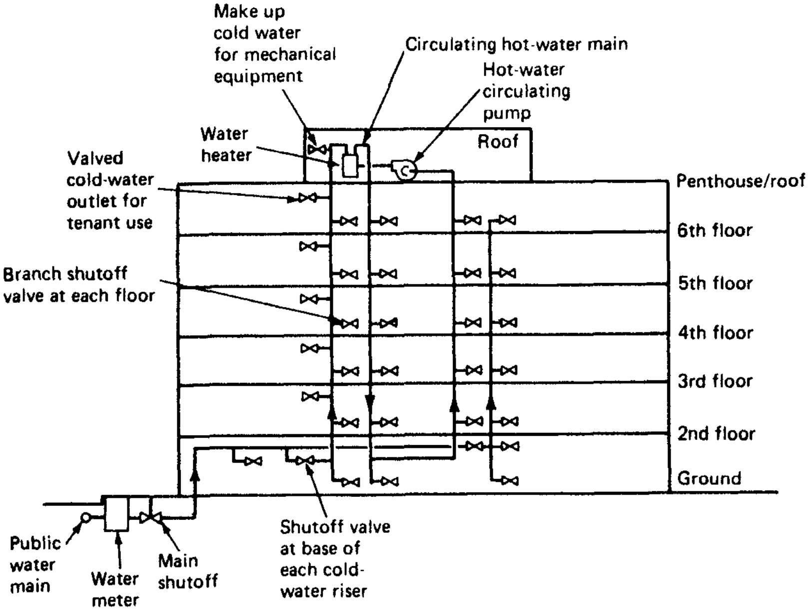

FIG. 3.1 An upfeed water distribution system in a low-rise building; in this system there is a single pressure zone.

The height of building that may be served without pumps to boost the water pressure depends on the available pressure in the water main, the requirements of the fixtures, and the applicable plumbing code. Most plumbing codes place restrictions on the maximum water pressure that may be delivered to a plumbing fixture. Minimum water pressure requirements for representative plumbing fixtures are described in Chap. 5.

The pressure available under no-flow conditions is called the *static pressure*. With water flow, there is a *pressure loss due to friction* as water flows through the pipes. Therefore, the *residual pressure* at the point of use under flow conditions is the static pressure minus the pressure loss due to friction. In Fig. 3.1, the static pressure of the water main is 80 psi (551 kPa); the residual pressure is 70 psi (482 kPa). Since there is a pressure drop of 1 psi (6.9 kPa) for each increase of height of 2.31 ft (0.7 m) and the floor-to-floor height is 11.3 ft (3.4 m), the loss in static pressure per floor is 5 psi (34 kPa).

If the piping in the water distribution system is sized according to the methods presented in Chap. 7, so as to limit the loss of pressure, more than adequate pressure will be available at the top floor to operate ordinary plumbing fixtures. The hot-water distribution in such a building is discussed later in this chapter under "Hot-Water Distribution Systems."

Upfeed Systems; Multiple Pressure Zones

If the pressure in a water main is sufficiently high, say 120 to 150 psi (827 to 1034 kPa), it can be used to distribute water in a high building without a pump to provide additional pressure. Many codes restrict the maximum pressure at any fixture, under no-flow conditions (i.e., under static pressure conditions), to 80 psi (551 kPa). Therefore where the pressure in the main is high, it is necessary to split the water distribution system into multiple pressure zones so that the pressure in any zone does not exceed the value permitted by code.

Figure 3.2 is a schematic diagram of an installation in a 15-story building in which the minimum pressure in the water main is 110 psi (759 kPa). The water-main pressure is split into two zones. In this building the floor-to-floor height is 11.3 ft (3.44 m), the same as in Fig. 3.1. Therefore, since there is a pressure drop of 1 psi (6.9 kPa) for each increase in height of 2.31 ft (0.7 m), there is a static pressure loss of 5 psi (34 kPa) per floor.

In order to reduce the water-main pressure to the maximum pressure permitted by code, a *pressure-regulating valve* (PRV), also called a *pressure-reducing valve* or *pressure regulator*, must be used in the water supply branch to the lower zone; such valves are described in Chap. 4. This valve may be adjusted so that delivery pressure has a maximum value of 80 psi (551 kPa). Direct-acting pressure-regulating valves have a relatively large flowing pressure loss (referred to as *reduced pressure falloff*), which reduces the number of floors served per zone. A pilot-operated type of pressure-regulating valve has a much lower (almost negligible) reduced pressure falloff, if properly selected. Therefore the pilot-operated type of pressure-regulating valve is recommended for this application. It allows a greater number of floors to be served in the pressure zone. In such an application, it is recommended that two or three such valves be piped in parallel to provide a continuous supply to the zone in the event of failure of one valve. A multiple pressure-regulating valve installation for one zone is referred to as a *PRV station*.

The upper zone is served directly from the pressure of the water main. Note that at the 8th floor (the base of the upper zone), the static pressure does not exceed 80 psi (551 kPa).

The cold-water supply to the water heaters for Zones 1 and 2 is provided from the top of a cold-water riser for each of these zones. For the lower zone, it is recommended that the riser closest to the pressure-regulating valve(s) or the main riser be used; for the upper zone, it is recommended that the riser closest to the upper-zone feed main riser be used. This arrangement reduces the size of the pipe to the downstream riser (i.e., in the direction of flow) and reduces the potential pressure loss in the cold-water supply line to the water heater.

Figure 3.2 illustrates a system where the water-main pressure variation is only 5 psi (34 kPa), i.e., from 110 to 115 psi (759 to 793 kPa). If the minimum pressure is higher than 110 psi (759 kPa) or the pressure variation is greater, the design must be modified to maintain code limitations on pressure within each zone. In some instances, it may be necessary to add one or more pressure-regulating

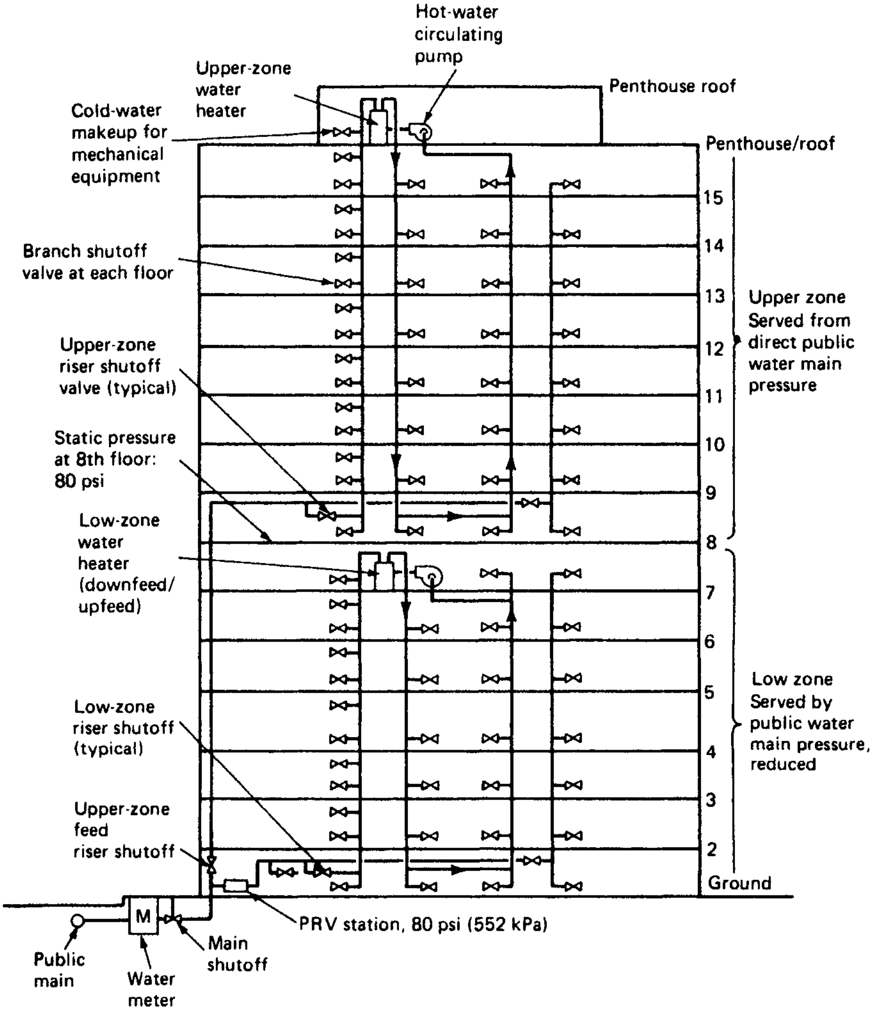

FIG. 3.2 An upfeed water distribution system in a 15-story building; in this system there are two pressure zones.

valves in the feed main riser of the upper zone. The preferred location is at the lowest floor of the upper zone.

DISTRIBUTION SYSTEMS IN MEDIUM-RISE BUILDINGS

Upfeed Systems; Multiple Pressure Zones

Figure 3.3 shows a 28-story building using an upfeed distribution system. Zone 1

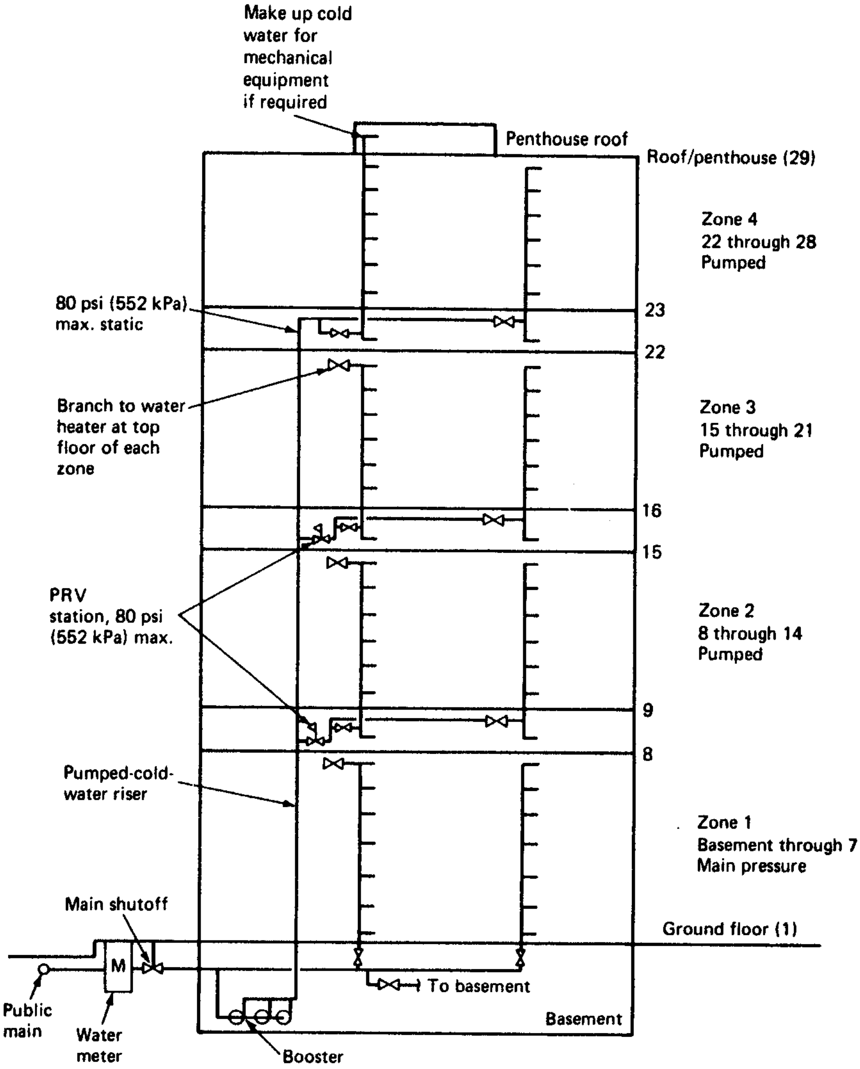

FIG. 3.3 An upfeed water distribution system in a 28-story building; in this system there are multiple pressure zones.

is the lowest zone and is an upfeed system using the pressure of the water main to distribute the water. Zones 2, 3, and 4 are supplied with water at constant pressure from a pumping system. Zones 2 and 3 are supplied at the lowest floor of each zone through pressure-regulating valves. Zone 4 is fed directly from the pump system; its pressure does not require regulation. The controls of the pumping system must be set so that the static pressure in Zone 4 does not exceed the value permitted by code.

The water heater for Zone 1 is located in the basement and is a combination of an upfeed and downfeed system. The water heaters for Zones 2, 3, and 4 are located at the top floor of each zone and are arranged as downfeed/upfeed systems.

Combination Upfeed/Downfeed Systems; Multiple Pressure Zones

Figure 3.4 shows a 31-story building in which a combination upfeed and downfeed cold-water distribution system is installed. Zone 1 is the lowest zone. In this zone there is an upfeed system using the pressure of the water main to distribute the water. Zones 2, 3, and 4 are downfeed systems fed from a gravity tank, located on the roof, as described in Chap. 4. The gravity tank must be sufficiently

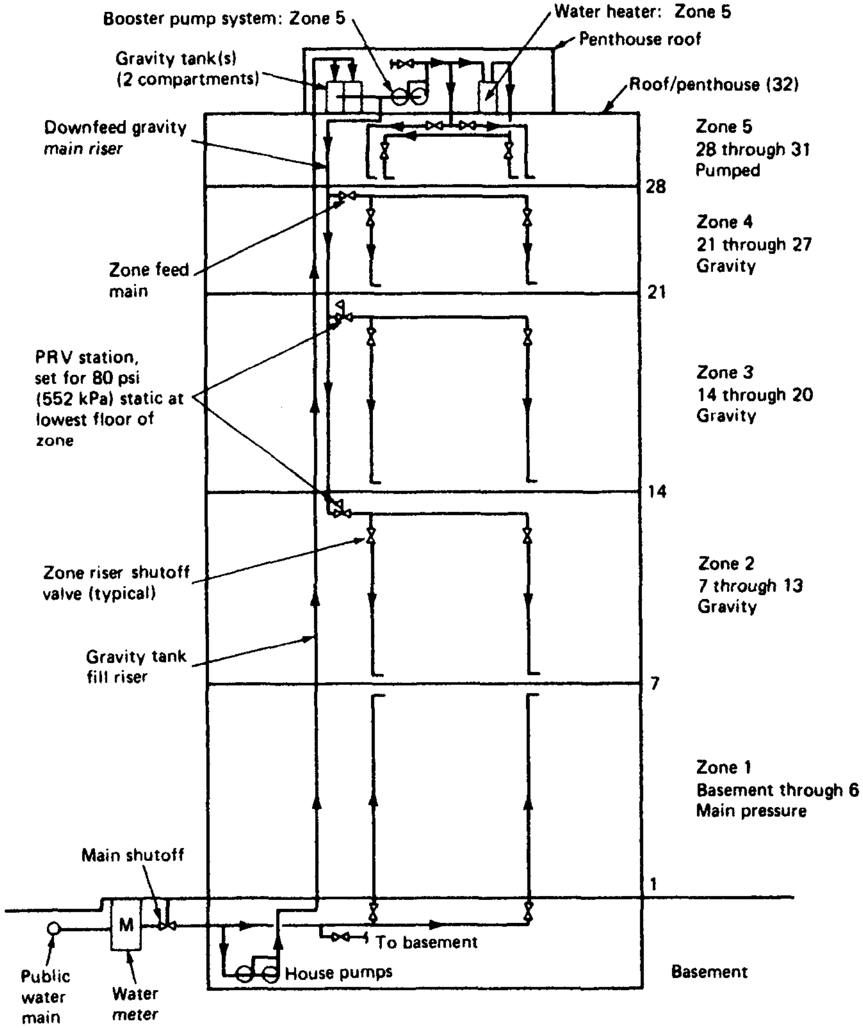

FIG. 3.4 A combination upfeed and downfeed water distribution system in a 31-story building; in this system there are multiple pressure zones.

high to provide adequate water pressure on the top floor. Sometimes the configuration of a building may prevent such elevation of the gravity tank—the condition illustrated. In this case, the gravity tank will not provide adequate pressure at the 28th through the 31st floors (i.e., in Zone 5). Therefore, a pressure-boosting system must be utilized. Zone 5 is a downfeed system fed at constant pressure from a pumping system wherein the pump suction is directly connected to the gravity tank. A hydropneumatic system also can be used to feed this zone. Such pressure-boosting systems are described in Chap. 4.

Zone 4 is supplied by a downfeed system fed directly from the feed riser at the 27th floor. Pressure regulation is not required since the static pressure at the lowest floor of the zone does not exceed the maximum pressure permitted by code.

Zones 2 and 3 are also supplied by downfeed systems fed from the gravity riser, but they require a pressure-regulating valve or a pressure-regulating-valve station at the top floor of each zone because of the higher static pressure of these zones. The pressure-regulating valves are set to deliver the required pressure in these zones.

DISTRIBUTION SYSTEMS IN HIGH-RISE BUILDINGS

Gravity Tanks

A *gravity tank*, illustrated in Fig. 4.1, is a water storage tank in which water is stored at atmospheric pressure. The water is distributed by gravity flow in a downfeed system. The gravity tank is usually located at, or elevated above, the roof of the building and is usually filled by a pumping system. Local codes may require that high-rise buildings be provided with a storage tank above the roof to supply fire protection water. If permitted by the local code, the domestic water and the fire-protection water tank may be combined, as described in Chap. 4. The capacity of the combined tank is usually governed by the fire-protection requirements.

A gravity tank offers a number of advantages, including the following:

1. It provides a reserve of water in the event of a water supply or power failure, to the extent of its capacity.
2. It requires only very simple control equipment.
3. It requires only a minimum of maintenance because of its simplicity.
4. It consumes less overall energy than a constant-pressure pumping system (tankless system), even though the water must be raised to the highest point in the system.
5. It acts as a water supply having minimal and predictable pressure variations.
6. The pumps required to raise water to the gravity tank can be selected for maximum efficiency.

Some of the disadvantages of a gravity tank are as follows:

1. The combined weight of the tank and water increases the cost of the base structure; i.e., the building structure must be strengthened to carry this additional load.

2. The space or volume required for the gravity tank is greater than that required for a tankless system. This results in a reduction of net usable building area.
3. A large volume of water could be released in the event of a rupture of the gravity tank. Although water damage also may occur if there is a pipe rupture in a pumped tankless system, potential damage is greater with rupture of a gravity tank.

Overall, the gravity tank is the most efficient and therefore the most economical of the various distribution systems for tall buildings. Its use is recommended unless other factors preclude incorporating it into the design. Sizing considerations for gravity tanks are discussed in Chap. 4.

Multiple Pressure Zones

The water supply system for a high-rise building is a combination of distribution systems. Figure 3.5 shows an 83-story high-rise building in which several water distribution systems are installed. Zone 1 typically is supplied by the pressure from the water main—to the extent permitted by the residual pressure of the water main; it is an upfeed cold-water system.

Zones 2 through 9 are downfeed systems. Zone 10, the top zone, is fed from a tankless pumping system. The gravity tank is not sufficiently elevated to supply floors 81 through 83. Note the similarity between Figs. 3.4 and 3.5. It is highly desirable that the static pressure in the downfeed gravity main riser not exceed the listed or maximum *working pressure* (i.e., the maximum pressure at which piping materials of the "standard" or "normally used" type may be installed). This is to avoid the necessity of using "extra strength" piping materials, which may increase the cost.

The gravity feed system illustrated here is but one method of supplying the building with water. For example, another method would be to install a constant-pressure pumping system at the 48th floor to feed Zones 6 through 10, then to connect the pumps to the gravity tank which serves as the water source. The pumped water is distributed through an upfeed (pumped) main riser in lieu of the downfeed gravity main riser. The pressures in Zones 6 through 10, which include floors 75 through 83, are adjusted accordingly. For such an arrangement, the PRV stations would be located in the zone feed main at the lowest floor of the zone. This arrangement of pumps is similar to Fig. 3.3.

CIRCULATION-TYPE HOT-WATER DISTRIBUTION SYSTEMS

A *dead end* is an extended portion of pipe that is closed at the downstream end by one or more fixtures. A long dead-end run in a hot-water delivery line results in the wastage of water, since the water cools in the pipe when it is not flowing and the faucet is therefore left open until the water reaches an acceptable temperature. Such long dead-end runs can be eliminated by recirculating the hot water in a loop. A *circulation-type hot-water distribution system* is one in which there is a continuous supply pipe from the water heater to the fixtures, with a return line back to the heater. The return line forms part of a *circulating loop* in which water is circulated continuously by means of a pump. The circulating loop

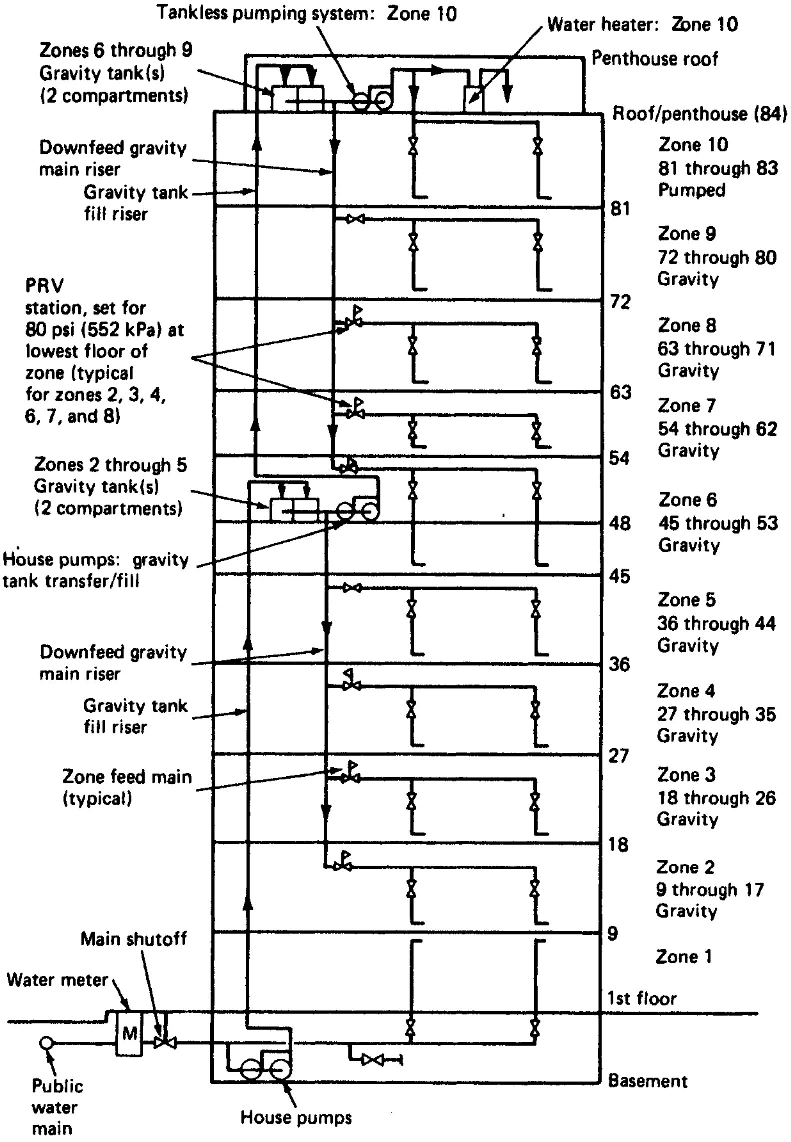

FIG. 3.5 A water supply system in a high-rise building; several water distribution systems are installed; there are multiple pressure zones.

may be a single circuit or multiple circuits, as in a building with multiple hot-water risers.

A circulation-type hot-water system may be an upfeed system, a downfeed system, or some combination thereof. Where natural gas is the fuel source, it is desirable to locate the water heater on the top floor or in the penthouse. This is done to avoid long runs of heater vent.

Determining the Required Flow Rate in a Circulation System

Use the following procedure:

1. Determine the heat loss in British thermal units (Btu) per hour in the hot-water piping from the water heater to the most distant outlet.
2. Determine the minimum acceptable temperature of the water to be delivered at the most distant outlet.
3. Determine the temperature differential (ΔT in °F) between (*a*) the temperature of the water at the outlet of the water heater and (*b*) the minimum acceptable temperature of the water to be delivered at the most distant outlet (Step 2).
4. Calculate the heat loss per minute by dividing the heat loss obtained in Step 1 by 60.
5. Divide the result of Step 4 by the temperature differential (ΔT in °F) obtained in Step 3 to determine the required weight of the water to be circulated. Divide this product by 8.33 (the weight of the water in pounds per gallon) to determine the required flow rate of the pump (in gallons per minute); i.e.,

$$\text{Required flow rate} = \frac{\text{Btu/h}}{60 \times \Delta T \times 8.33} \quad \text{gpm}$$

Upfeed/Downfeed Systems; Single Pressure Zone

Figure 3.6 illustrates a typical hot-water distribution system in a low-rise building, such as a 3-story apartment house or a motel having multiple hot-water risers. In this combined upfeed and downfeed system, the hot-water main is distributed and circulated at the 1st-floor ceiling; it should be run close to the riser

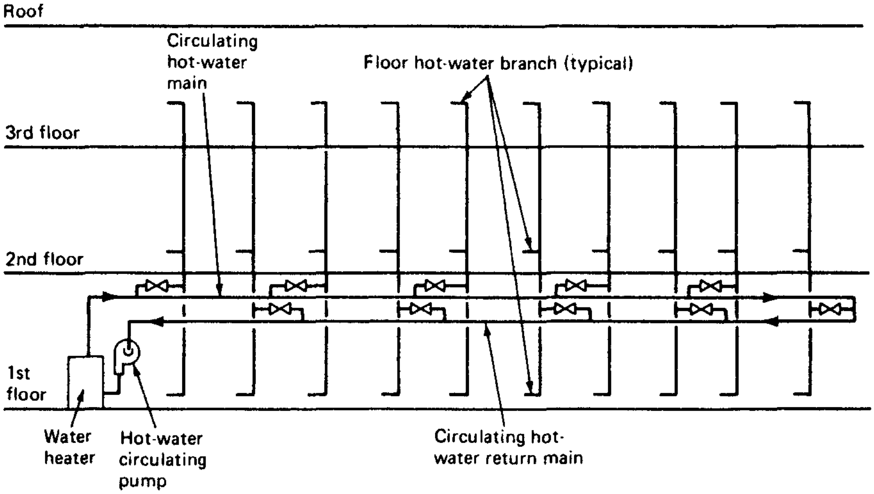

FIG. 3.6 A typical single-zone, hot-water distribution system in a low-rise, 3-story building. There is a circulating hot-water main and return at the ceiling of the first floor.

location to reduce the length of the horizontal branch feeding the riser. This is done to reduce the heat loss in long runs to a dead-end (uncirculated) riser system. The upfeed portion of the riser has a run of only 1 story plus a few feet (meters), so that hot water will be available at the outlet a few moments after a faucet is opened. Therefore little hot water will be wasted. This is also the case for the downfeed portion of the riser, since it has less than a story to drop.

Upfeed Systems; Single Pressure Zone

Figure 3.7 illustrates an upfeed circulation-type hot-water distribution system that is suitable for a building having multiple risers. The circulating hot-water main is located below the lowest floor of the zone. It distributes hot water to each circulating hot-water riser. At the bottom of each riser is a shutoff valve. At the top of each riser is a flow-balancing assembly as described below.

The water heater may be located at the top or bottom of the pressure zone. If located at the top of the zone, a circulating hot-water main riser may be run down to the location of the circulating hot-water main. Alternatively, one of the risers may be used as a downfeed circulating hot-water main riser to the circulating hot-water main at the bottom of the zone.

If the water heater is located at the bottom of the zone, a circulating hot-water return riser is required from the circulating hot-water return main at the top of the zone down to the water heater. In Fig. 3.7, the circulating hot-water return main

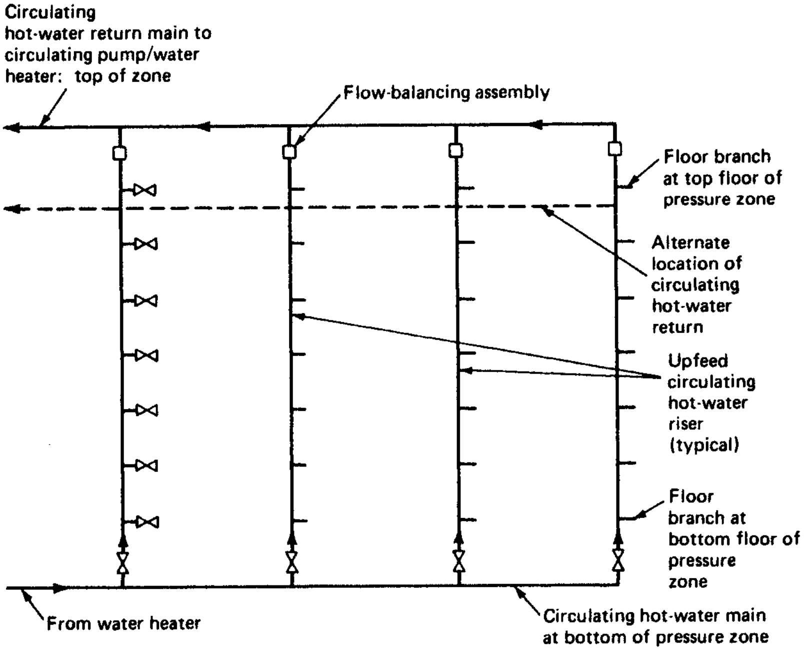

FIG. 3.7 An upfeed hot-water distribution system; in this system there is a single pressure zone. The water heater may be located at the top or bottom of the pressure zone.

(i.e., the *loop*) is located at the top floor of the zone. This loop collects the flow from each riser and returns it to the water heating system by means of a circulation pump. The pump must have adequate flow and pressure capacity to maintain hot water at all points in the system. Instead of being located at the top floor of the zone, the loop may also be located at the floor below the top floor of the zone, with a short dead-end riser to the top floor. This configuration has the advantage of allowing the system to be self-air-venting; it also saves vertical riser piping at the top floor. If preset flow regulators are used in the flow-balancing assembly of the circulating hot-water return, the system will be self-balancing provided the circulation pump is properly sized.

Flow-Balancing Assembly. A flow-balancing assembly consists of (*a*) a flow-control valve, (*b*) a check valve, and (*c*) a shutoff valve. Two configurations of such a balancing assembly are shown in Fig. 3.8. The check valve is required to prevent recirculation between risers or circuits.

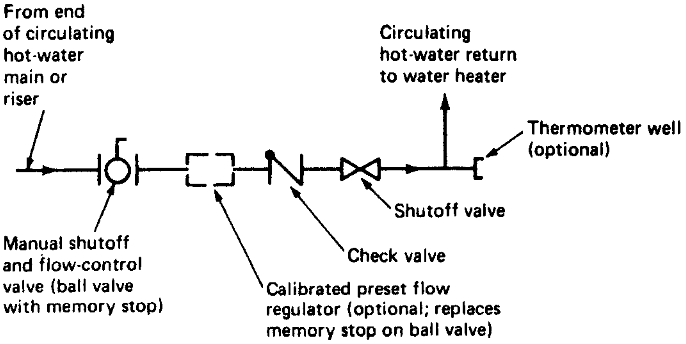

FIG. 3.8 A flow-balancing assembly in a circulating hot-water return.

The flow through the flow-balancing assembly may be controlled by a preset flow regulator or a manually operated ball valve (or throttling valve). The preset flow regulator is preferred because it cannot be tampered with by maintenance personnel and will maintain its flow setting. However, its cost is significantly higher.

A thermometer well may be inserted at this location to provide access for (*a*) making temperature measurements with a thermometer, permitting manual temperature adjustment; (*b*) setting the circulation flow rate; and/or (*c*) verifying circulation in the riser.

Downfeed Systems; Single Pressure Zone

Figure 3.9 illustrates a downfeed system in a hot-water circulation system. The circulating hot-water main is located at the floor below the top floor of the zone. It distributes hot water to each riser, arranged to flow as a downfeed riser, with a short dead-end riser branch feeding the top floor of the zone. A shutoff valve is located in the branch from the main to the riser. At the bottom of each riser is a flow-control assembly. The circulating hot-water return loop is located at the

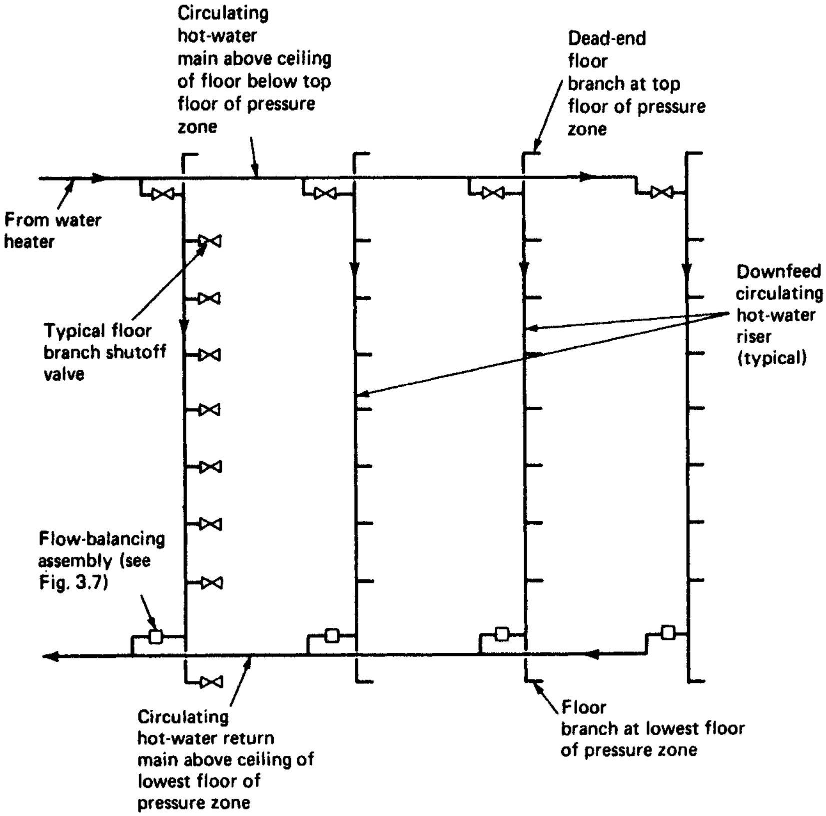

FIG. 3.9 A downfeed circulating hot-water distribution system; in this system there is a single pressure zone.

ceiling of the lowest floor of the zone. The risers (or drops) to the fixtures on the lowest floor are dead-ended.

The water heater may be located at the top or bottom of the zone, or anywhere between. A supply main or return riser must be provided—depending on the location of the water heater. The preferred location of the water heater is at the top of the zone because in this location lower water pressure will act on the heater—possibly prolonging its life.

Combination Upfeed/Downfeed Systems; Single-Zone System

Figure 3.10 shows a typical circulation-type hot-water system that has multiple circulating hot-water risers; there are two risers adjacent, and relatively close, to each other. Such a situation may occur, for example, in the core area serving men's and women's toilets in an office building, hotel, or motel and where the water heater is at the lowest level of the pressure zone. This configuration allows the circulation hot-water supply main and the return loop to be located on the same floor. The riser from the supply main is an upfeed leg, and the riser return-

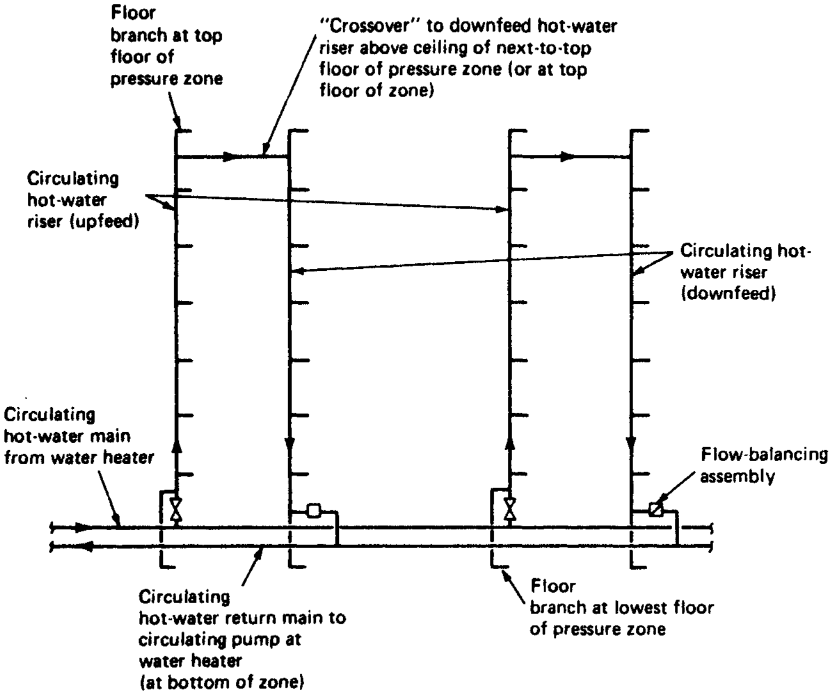

FIG. 3.10 An upfeed/downfeed circulating hot-water distribution system; in this system there is a single pressure zone.

ing to the circulating hot-water return loop is a downfeed leg. In this example, the circulating hot-water supply main and the return loop are located above the ceiling of the lowest floor of the zone. This creates a dead-end condition to the fixtures on the lowest floor, but if the branch is kept short, it should not be detrimental. The circulating hot-water riser has a shutoff valve at the junction with the circulating hot-water main. The downfeed riser has the flow-control assembly located at the same floor as the riser shutoff valve.

Combination Downfeed/Upfeed Systems; Single Pressure Zone

Figure 3.11 is another version of the system illustrated in Fig. 3.10, but here the circulating hot-water main and the return loop are located at the top floor of the zone. Alternatively, the circulating hot-water main and the return loop may be located at the floor below the top floor of the zone, as was the case in Fig. 3.9.

Downfeed Systems; Multiple Pressure Zones

It is sometimes necessary to supply multiple hot-water zones from a single water heater. It is preferable to supply each zone from its own water heater, but when this is not possible, the method shown in Fig. 3.12 may be used. This is a

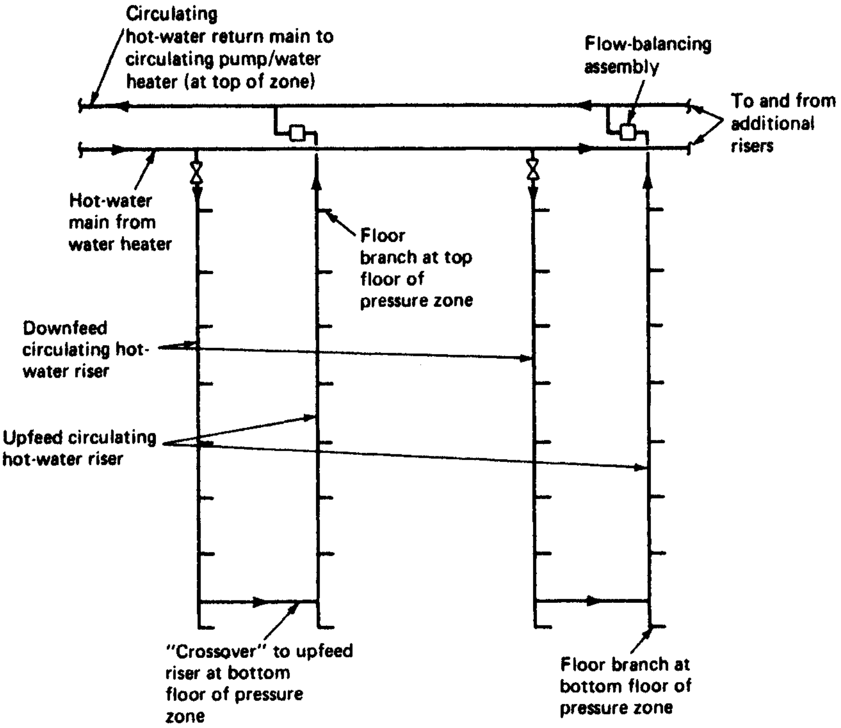

FIG. 3.11 A downfeed/upfeed hot-water system of the circulation type; in this system there is a single pressure zone.

"primary-secondary" type of system with the main water-heating source located at the top of a multiple-zone hot-water distribution system. The circulating hot-water main riser is downfed to the top floor of the lowest zone to be served, and the circulating hot-water return main is upfed to the water heater by a circulating pump. Each zone is a circulated "dead-end" system with a small water heater, usually electric, included in the loop to add heat lost by radiation from the circulated water. For zones requiring pressure regulation for cold water, hot-water pressure-regulating valves are provided for the hot-water branch to that zone; they are set for a pressure that is 5 psig (34 kPa) lower than that for the cold-water supply. This is done to reduce or prevent hot water crossing over into the cold-water system.

Combination Downfeed/Downfeed Systems; Multiple Pressure Zones

Figure 3.13 is a typical zone of a primary-secondary installation in which each hot-water zone (except the top zone) has a pressure-regulating valve to reduce the pressure at the lowest floor within the zone so that it will not exceed the pressure permitted by code. Thus the zone is a closed hot-water (loop) system because the hot water is not circulated back to the main water heater. Instead, the hot water is circulated by means of a pump and is returned to a small local

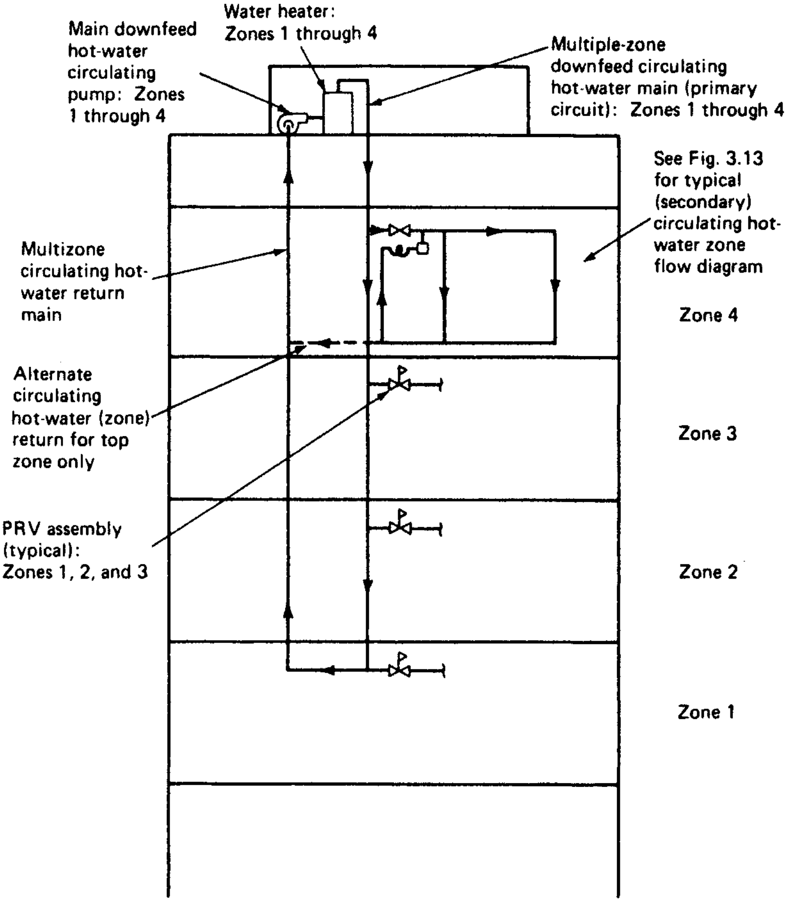

FIG. 3.12 A downfeed hot-water system of the circulation type; in this system there are multiple pressure zones.

electric booster heater located at the end of the zone. This heater, set to deliver the maximum temperature permitted by the system design, is able to replace the heat lost (by radiation) in the closed circulation loop.

Attempts to return the circulating hot water to the high-pressure main by means of repressurizing pumps usually are not successful. The main downfeed hot-water circulation pump must then have sufficient capacity to provide adequate circulation within the risers of the nonregulated zone as well as the main circulating loop. The top zone of this system does not have a pressure-regulating valve. Therefore the return may be taken directly back to the main water heater.

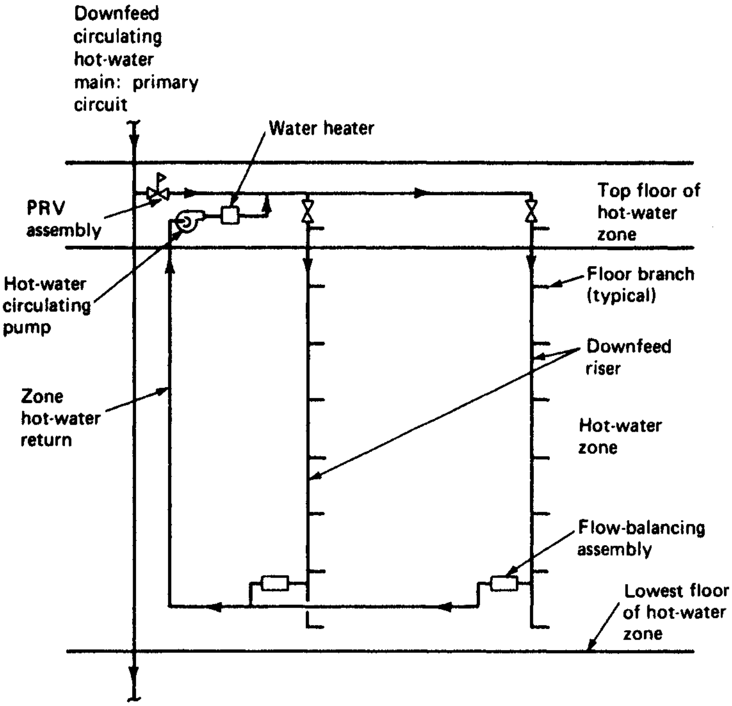

FIG. 3.13 A typical zone in a downfeed/downfeed hot-water system of the circulating type; in this system there are multiple zones. Each zone (except the top zone) has a pressure-regulating valve to reduce the pressure at the lowest floor within the zone so that it will not exceed the pressure permitted by code.

NONCIRCULATING HOT-WATER SYSTEMS

Electrical strip heaters, of the self-regulating type, may be used to maintain the desired delivery temperature at hot-water outlets without the necessity of installing a circulating hot-water system. They also make it possible for a single water heater to serve multiple zones of the system. Figure 3.14*a* illustrates the construction of a strip heater of this type. It is installed directly on the hot-water piping, under the insulation, and held in place with glass-fiber tape or nylon ties. It is available in continuous lengths of up to 400 ft (157 m).

The core material of these strip heaters, which separates the copper conductors, is an extruded semiconductive polymer. At low temperatures, electric current flows through the core from one conductor to the other, generating heat. This heat is conducted to the liquid in the pipe, raising its temperature. As the temperature rises, the resistance of the core increases, thereby reducing the flow of current through the core and decreasing the heat output. This process occurs at all points along the strip so as to regulate the temperature without a thermostat. Figure 3.14*b* shows a typical installation of such a strip heater in a dead-end hot-water system.

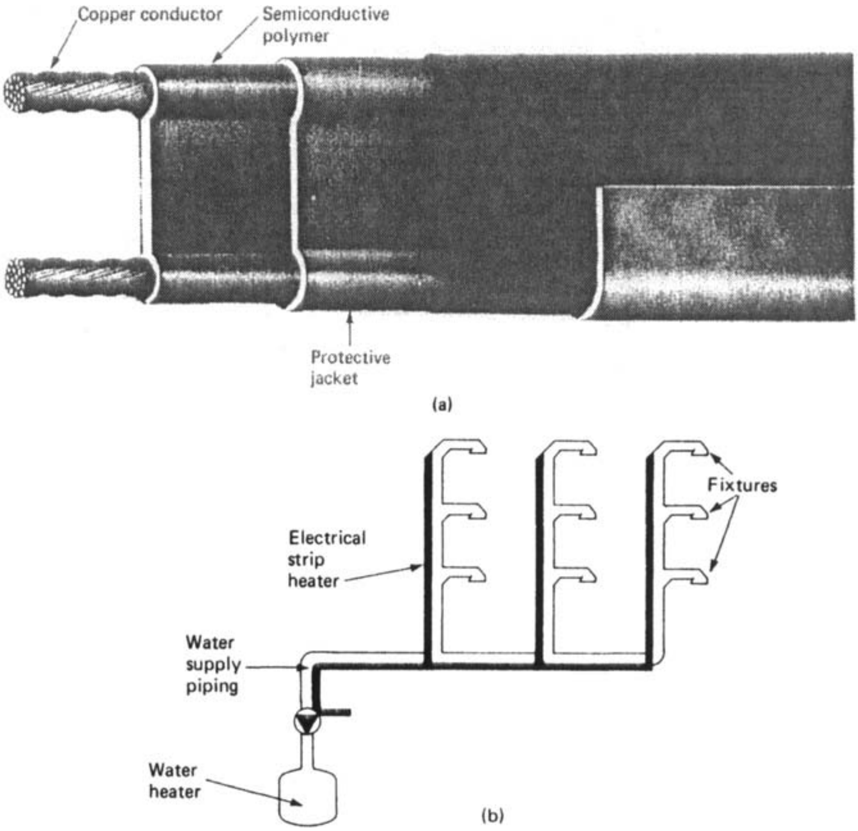

FIG. 3.14 (*a*) A self-regulating electrical strip heater. A strip of this type, approximately ½ in (1.3 cm) wide, is applied directly on the pipe. (*b*) Diagram showing the location of self-regulating electrical strip heaters in a dead-end hot-water system. *(Courtesy of Raychem.)*

CHAPTER 4

WATER PRESSURE IN DOMESTIC WATER DISTRIBUTION SYSTEMS

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INTRODUCTION

This chapter describes the effects of inadequate and excessive water pressure in domestic water distribution systems and discusses the methods used to correct these conditions.

Water pressure is said to be inadequate if the pressure is lower than the minimum acceptable pressure for any specific application. When this occurs, the pressure must be increased to a value high enough to provide satisfactory operation and economical service. Such an increase may be obtained by means of the following:

1. An elevated-water-tank system
2. A hydropneumatic tank system
3. A booster pump system

A combination of two such systems, called a hybrid system, may be used where a single type is impractical. Each of these systems is described in this chapter, along with its advantages and disadvantages. This information makes it possible to select a pressure-boosting system that is reliable, cost-effective, and satisfactory for its intended function.

Chapter 3 describes how pressure-regulating valves may be incorporated into a water distribution system to decrease excessive water pressure to an acceptable value. This chapter includes a description of the characteristics of pressure-regulating valves and provides a guide to their selection.

ACCEPTABLE WATER PRESSURE

The *minimum acceptable pressure* in a water distribution system is the lowest water pressure permitting safe, efficient, and satisfactory operation at the most hydraulically remote fixture or component. The *maximum acceptable pressure* is the highest pressure that will not cause premature or accelerated damage to any component. Between these two extremes is a range of operating pressure that is considered satisfactory.

Many codes stipulate the minimum pressures for various plumbing fixtures as well as a maximum allowable pressure in the system. These values of pressure must be used as a basis for system design unless more stringent values are required for the specific installation. Generally accepted values of minimum operating pressure for various fixtures are given in Table 4.1. For special types of equipment that may not be covered by code requirements, the manufacturer should be consulted for acceptable values.

ELEVATED-WATER-TANK SYSTEM

In an elevated-water-tank system, such as the simplified system shown in Fig. 4.1, water is pumped from the water main to an elevated water storage tank (commonly called a *gravity tank* or a *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, resulting in a higher pressure in the water distribution system. For each 2.31 ft (0.7 m) elevation of the tank, there is an increase in pressure of 1 psi (6.9 kPa).

TABLE 4.1 Minimum Acceptable Operating Pressures for Various Plumbing Fixtures

Fixture	Pressure, psi (kPa)
Basin faucet	8 (55)
Basin faucet, self-closing	12 (83)
Sink faucet, ⅜ in (0.95 cm)	10 (69)
Sink faucet, ½ in (1.3 cm)	5(35)
Dishwasher	15–25 (103–172)
Bathtub faucet	5 (35)
Laundry tub cock, ¼ in (0.64 cm)	5 (35)
Shower	12 (83)
Water closet ball cock	15 (103)
Water closet flush valve	15–20 (104–138)
Urinal flush valve	15 (103)
Garden hose, 50 ft (15 m), and sill cock	30 (206)
Water closet, blowout type	25 (172)
Urinal, blowout type	25 (172)
Water closet, low-silhouette tank type	30–40 (207–276)

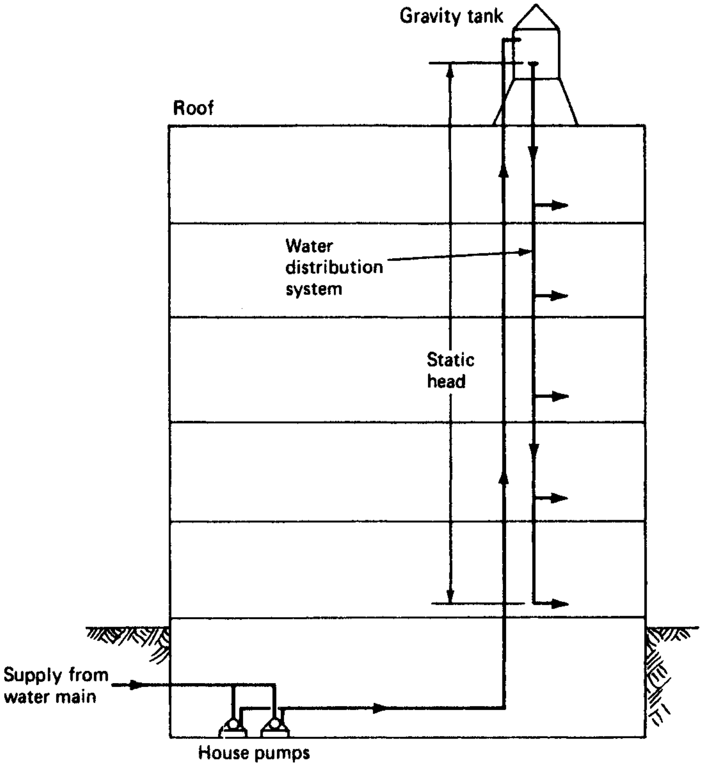

FIG. 4.1 A simplified diagram of an elevated-water-tank system.

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

- A *gravity tank* that stores water at atmospheric pressure
- *Pumps* (commonly called *house pumps*) that fill the tank by pumping water to it from the source
- *Controls* that turn the pump on and off when the water inside the tank reaches preset levels
- *Alarms* that alert operating personnel that a malfunction exists
- *Safety devices* that operate when a malfunction occurs, thus avoiding potential accidents

The piping arrangement between the various components of an elevated-water-tank system is illustrated in Fig. 4.2.

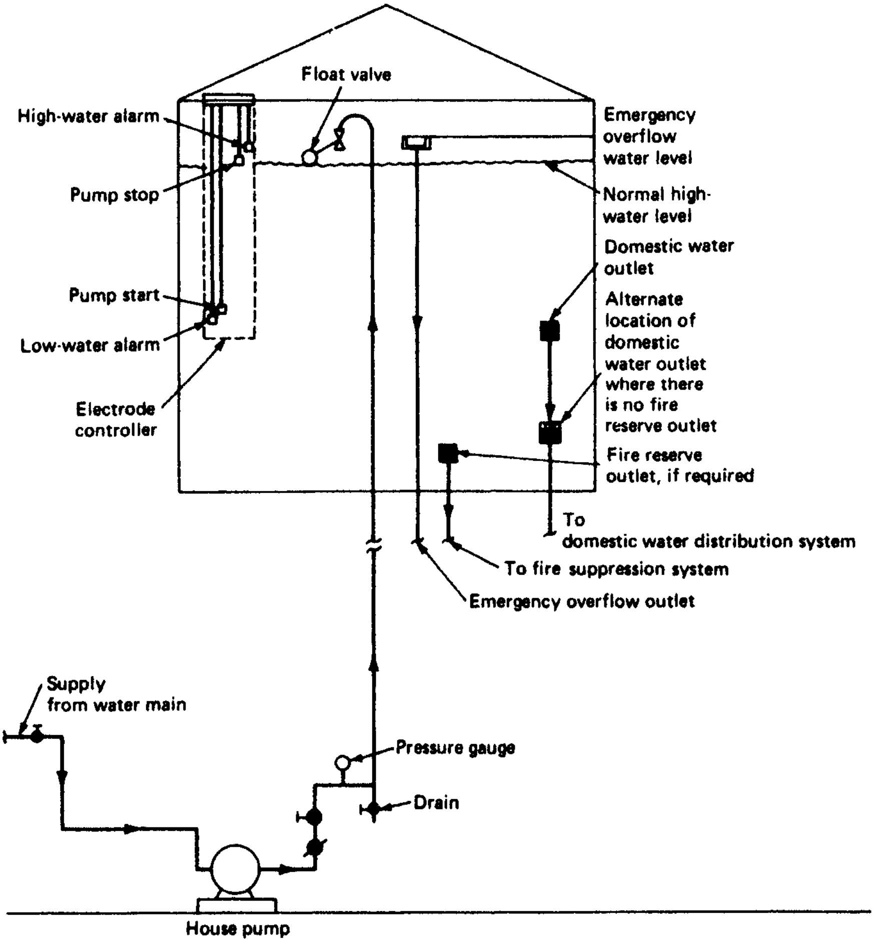

FIG. 4.2 Piping arrangement between the various components of an elevated-water-tank system.

Wood Gravity Tanks

Gravity tanks used for apartment and commercial-type buildings are fabricated either of wood (redwood, cypress, or cedar) or of steel. Wood is preferred where the tank is exposed to the weather. Redwood is highest in initial cost and has the longest life expectancy outdoors—about 20 years. Cypress and cedar are lower in cost, with a life expectancy of about 15 years. The shape of a wood tank is cylindrical for structural and economic reasons. A section through a typical wood tank is shown in Fig. 4.3. It is impractical to partition a wood tank. Wooden tanks do not require maintenance, therefore a single wood tank is common. However,

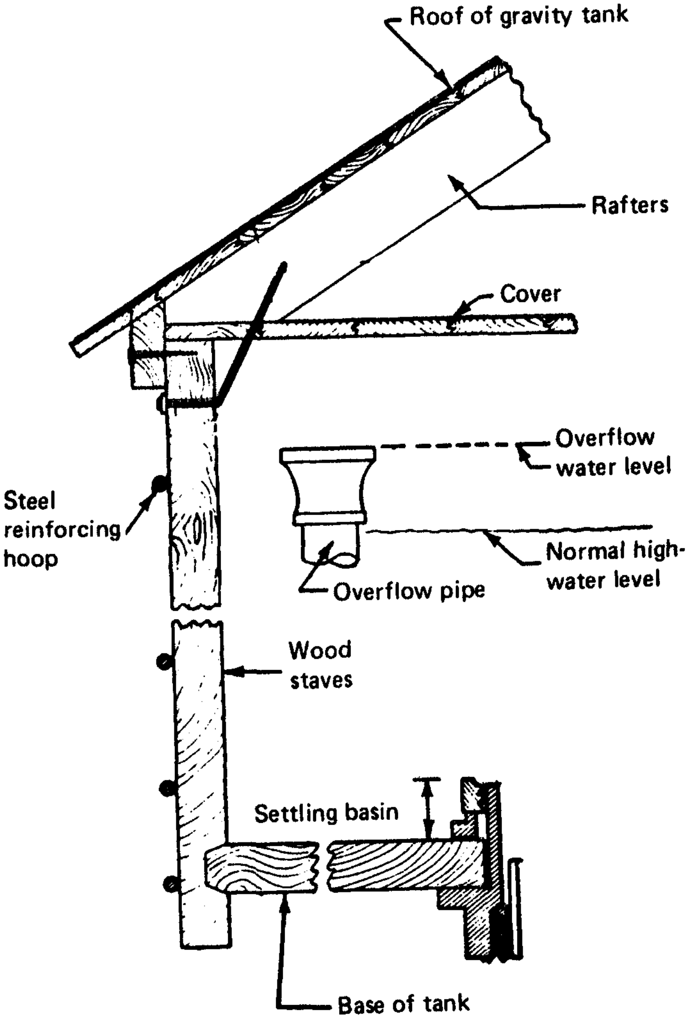

FIG. 4.3 Section through a typical wood tank in an elevated-water-tank system. *(Adapted from Ref. 1.)*

it is generally accepted practice for multiple dwellings larger than 500 apartments to have two tanks.

Steel Gravity Tanks

Steel tanks can be fabricated in any shape; square or rectangular shapes are the most common. A protective coating is applied to both the inside and outside of the tank to prevent corrosion. This coating must be reapplied periodically, generally every 2 to 5 years. Steel tanks can be fabricated in larger sizes than wood tanks and are usually used where a large volume of water must be stored, generally over 15,000 gal (57,000 L). If a steel tank is partitioned, the water flow from each section must be controlled by valves in the water discharge piping outside the tank.

Because steel tanks require maintenance (cleaning and painting) on a regular basis, it is considered good practice always to provide two separate tanks or to provide two compartments within one steel tank. This will allow one tank or compartment to be shut down for cleaning while the other provides water to the building.

Required Capacity of the Gravity Tank

The following guidelines for estimating the required tank capacity are based on design experience. Such estimates must be adjusted for each specific installation, taking its individual requirements into consideration.[1]

Multiple Dwellings. To obtain an estimate of the required capacity, multiply (*a*) the total number of occupants of the building by (*b*) the water consumption, per person. If the number of occupants is unknown, assume a figure of two people per bedroom or four people per apartment—whichever figure is the larger. The water consumption may be obtained from Fig. 4.4.[2] For example, if there are 100 apartments in a building with 400 occupants, according to Fig. 4.4 the water consumption for domestic use is 12 gal (46 L) per person. Therefore, the required capacity is 400 × 12 = 4800 gal (18,240 L). To this figure add the required capacity for fire-suppression purposes to determine the total required storage capacity of the tank. Chapter 15 explains how to determine the required storage capacity for fire-suppression purposes.

Office Buildings. To obtain an estimate of the required capacity, base the estimate on the total number of people expected to occupy the building. This number may be determined, approximately, from the usable floor area in the building as follows:

Ordinary office buildings: Allow 100 ft^2 (9.3 m^2) per person.
Superior types of buildings: Allow 150 ft^2 (14 m^2) per person.
Luxury-type buildings: Allow 200 ft^2 (18.6 m^2) per person.

Estimation Procedure. Either of the following methods can then be used to estimate the domestic storage requirements (also referred to as the *domestic reserve*):

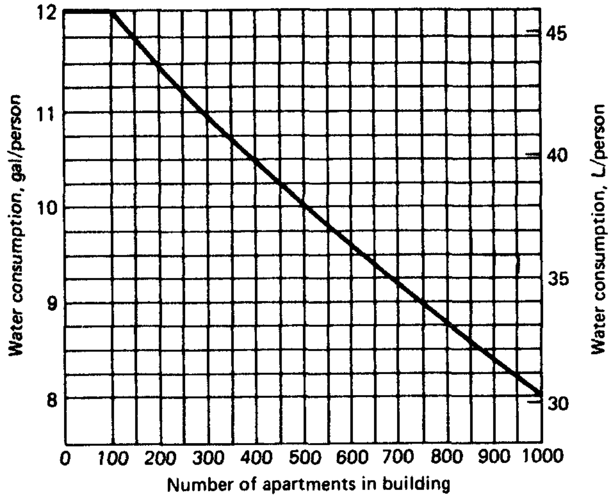

FIG. 4.4 Estimated water consumption for domestic use in apartment houses. *(Adapted from Ref. 2.)*

- *Method 1:* Assume a required capacity for domestic water storage based on population. The storage capacity should be equal to between 4 and 6 gal (15 and 23 L) per person (depending on the type of office building—ordinary or luxury). To this figure, add any other requirements, such as cooling tower makeup and lawn watering.
- *Method 2:* Assume a required capacity for domestic water storage based on gross floor area. The storage capacity should be equal to 0.025 gal/gross ft^2 (1 L/m^2). To this figure, add any other requirements, such as cooling-tower makeup and lawn watering.

House Pumps

Although many types of pumps are suitable as house pumps, the centrifugal pump is most commonly selected because of its wide range of capacity, pressure, and availability. See Chap. 6 for additional information concerning pumps.

The capacity required of a house pump 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 up to 2 h—usually a figure of 1 h is used. A duplex pump arrangement (i.e., two pumps in parallel), with each pump full size, should be selected to allow for any unexpected peak demands and to provide an extra measure of safety if one pump is out of service.

Controls

Several types of devices are available for controlling the flow of water into a tank:

- Float switches

- Float valves
- Electrode controllers

A *float switch* is a mechanical device consisting of an on-off switch that is activated by a thin rod connected to a movable float that rides on the surface of the water. When the water level rises or falls beyond set points, the on-off switch is activated, thereby turning the pumps on or off. One type of float switch is illustrated in Fig. 4.5.

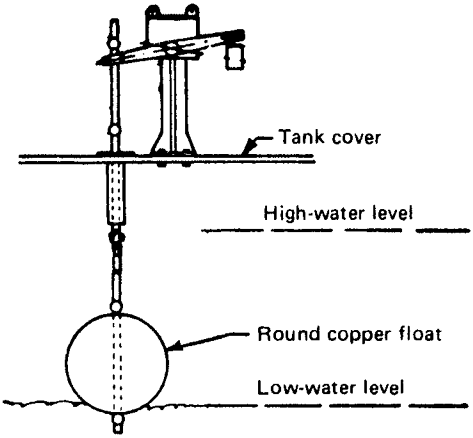

FIG. 4.5 A typical pump float switch used in an elevated water tank.

A *float valve* is a valve that is opened and closed by the movement of a rod; one end of the rod is attached to a float that rises and falls with the changes in level of water in the tank. Such a valve is located at the tank water inlet (pump discharge line) inside the tank. When the water level reaches its preset maximum level, the float rises, thereby closing the valve and shutting off the flow of water. When the water level drops to its minimum acceptable level, the float drops, thereby opening the valve and initiating the flow of water.

An *electrode controller* is an electrical device used to start or stop a house pump. Its primary component is a conductor called an *electrode*. Several such electrodes are immersed at different levels inside the house tank. When the water level covers (or uncovers) two or more of the electrodes, the water makes (or breaks) an electrical circuit that stops (or starts) the pumps.

Alarms and Safety Devices

The following conditions require the immediate attention of operating personnel in a building:

1. A *low-water alarm condition*, indicating that the house pumps have not started and that the water has dropped below a predetermined low-water level in the tank

2. A *high-water alarm condition*, indicating that the house pumps did not shut off when the water reached its maximum level and that the water continues to pump into an already full tank

These two conditions must alert operating personnel by audible and/or visible alarms.

If the house pumps fail to shut off and water continues to pump into the tank, the excess water is carried off by the *emergency overflow*. The pipe from the emergency overflow should be at least one pipe size larger than the line that supplies water to the tank. The overflow can either (*a*) discharge into the building storm-water drainage system or (*b*) spill directly onto the roof. If it discharges into the storm-water drainage system, a very large size drainage pipe may be required because of the large volume of overflow water. If allowed to spill onto the roof, a large volume of water may flood the roof and possibly flow down the side of the structure on which the tank is erected—unless the roof drains are sized large enough to accept the anticipated flow.

House pumps should be provided with a low-suction-pressure shutoff device that stops the pumps if there is a loss of suction pressure.

Advantages of the Elevated-Water-Tank System

The advantages of the elevated-water-tank system compared with the hydropneumatic tank system or booster pump system are as follows:

- It is simpler than either of the other two systems.
- It requires the fewest components to control and operate the system.
- Water distribution is provided if the electrical power fails.
- Operating costs are lower than for the other two systems.
- The range of operating conditions is narrow, so that the most efficient house pump can be selected for the system.
- A smaller pump capacity is required than for either of the other systems.
- Pressure fluctuations in the system are small.
- Maintenance requirements are minimized.
- A downfeed water distribution system can be used. This results in more economical sizing of pipe.

Disadvantages of the Elevated-Water-Tank System

The disadvantages of the elevated-water-tank system compared with the other two systems are as follows:

- An exposed tank (or the enclosure around it) may be considered unsightly.
- The building structure may require reinforcement to support the additional weight of the tank and water.
- The water in the tank and the water in the supply pipes from the tank are subject to freezing if the tank is exposed.
- The water pressure on the highest floors may be inadequate.

- A catastrophic tank failure may flood the roof with water.

Hybrid Systems

A common problem with the gravity tank system is the lack of water pressure on the upper floors of the building. Often, fixtures on these floors may require a pressure greater than that provided by the gravity tank, unless the tank is elevated to an impractical height. Under these conditions, it is useful to employ a hybrid system consisting of the elevated-tank system plus a small booster pump system for only the top several floors, i.e., for those floors where the the tank provides insufficient static pressure.

BOOSTER PUMP SYSTEM

In a booster pump system, illustrated schematically in Fig. 4.6, the booster pump is fed by a water supply that is both insufficient and variable in pressure. A control system senses variations in the distribution system and adjusts either the speed of the pump or a pressure-regulating valve to maintain a constant pressure of acceptable value.

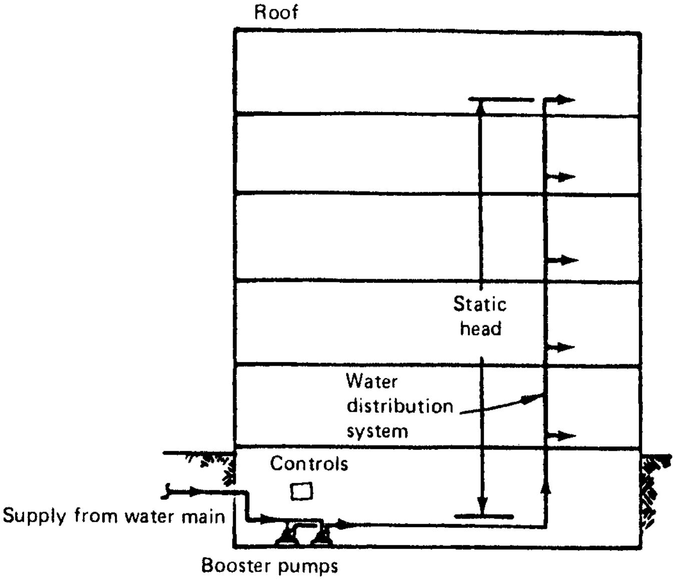

FIG. 4.6 Simplified diagram of a booster pump system.

The components of a booster pump system include:

- A *booster pump* (one or more)

- *Control devices* to maintain preselected values of pressure
- *Alarms* to alert operating personnel that a problem exists

A schematic diagram of the piping arrangement between components of a booster pump system is shown in Fig. 4.7.

Booster Pumps

Several types of pumps are suitable for use in a system of this type. A multistage diffuser pump is most commonly used because of its wide range of capacity, pressure, and efficiency. However, in small sizes this type of pump is high in initial cost. A horizontally split case centrifugal pump should also be considered in the intermediate pressure range; a vertically split case centrifugal pump should be considered only in the low-pressure range.

Two types of booster pump drives are available for adjusting the pressure and flow in the water distribution system:

- *Constant-speed drive.* This type of drive should be considered (*a*) where water demand requirements are relatively constant, (*b*) where a low-to-medium boost pressure is required, and (*c*) where a low initial cost is important. It should also be considered for use where the frictional losses in the piping network are relatively minor.
- *Variable-speed drive.* This type of drive is recommended (*a*) where there are large fluctuations in the water-main supply pressure to the pumps, (*b*) where there is a requirement for a high pressure boost, or (*c*) where a great variation is expected in the system water demand. Variable-speed drives are also recommended where the friction losses in the water distribution system are relatively

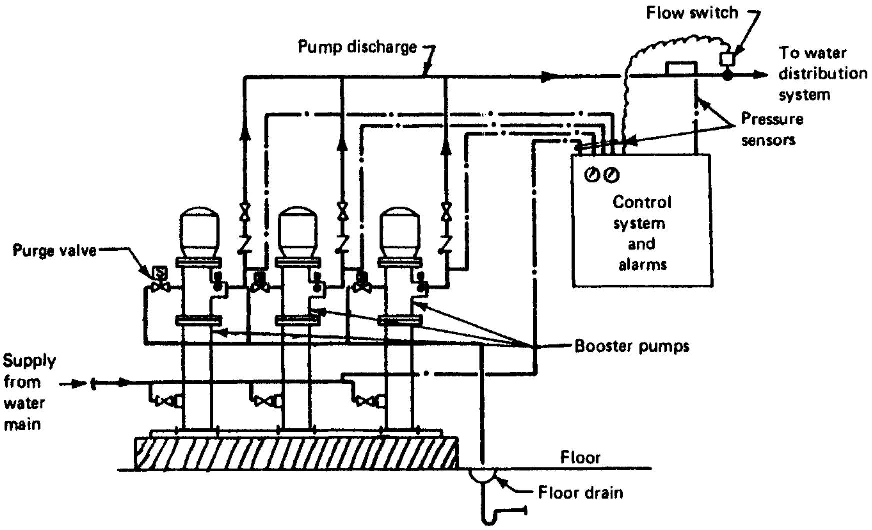

FIG. 4.7 Schematic diagram of the piping arrangement between components of a booster pump system.

high. A variable-speed drive system is higher in initial cost than a constant-speed drive.

Number of Pumps

For pumps that are driven by motors of less than 40 hp, a constant-speed drive should be considered if the fluctuation in suction pressure is more than 20 psi (140 kPa). For motors 50 hp and larger, a variable-speed drive should be considered, controlled by a silicon-controlled rectifier (SCR) unless a fluid coupling can be cooled by recirculated water. Smaller booster pump systems can use variable-speed drives having air-cooled fluid couplings in motor sizes up to 5 hp; larger couplings generally are water-cooled and are not recommended unless the coupling can be cooled with recirculated water.

A booster pump system that runs continuously should include pumps of more than one size, so that during periods of little use, a smaller pump is used, resulting in a more economical operation. A hybrid system, including a small hydropneumatic tank, should be considered to provide additional operating economy by allowing the system to be shut down during extended periods of little or no water demand.

A two-pump system is usually selected for reasons of economy where there are no other special requirements. Each of the two pumps should be capable of supplying at least 50 percent of the total estimated peak water demand. A total of 100 percent provides no additional capacity for flow above the estimated demand. It is generally possible to select two pumps, each providing slightly greater than half the full capacity—say 60 percent of the total estimated peak demand. If maintenance of an uninterrupted supply of water is a prime consideration, select three pumps, each of which can supply 50 percent of the total requirements. Then full system capacity will be maintained even if one of the pumps is out of service.

Water usage studies have shown that in most buildings, the actual water demand is approximately 25 percent of estimated peak demand during three-quarters of a normal working day. If operating cost is the determining factor, the use of three pumps is desirable, sized to provide 50, 50, and 25 percent of the peak estimated demand flow. In this configuration, the smaller pump operates most of the day when the load is low. It also operates in conjunction with the larger pumps during periods of peak demand.

Control Devices

A control device in a booster pump system is used to (*a*) adjust the flow of water, (*b*) maintain satisfactory distribution system pressure, and/or (*c*) maintain appropriate pump speed. Such controls are provided by the pump manufacturer; they are not selected by the design engineer. The various values of pressure at which the control device is set to operate are established by the engineer. These values are given to the manufacturer for use in the design of an integrated booster pump and control system.

Variable-Speed Control

The following control devices are commonly used to vary the speed of either the pump or motor to maintain satisfactory pressure in the water distribution system:

- *Silicon-controlled rectifier.* A silicon-controlled rectifier is a solid-state device that controls the current supplied to the motor, thereby varying its speed. This allows the motor to be connected directly to the pump.
- *Fluid coupling and magnetic coupling.* These variable-speed couplings are used to connect the motor to the pump. These devices use either a fluid (usually water or oil) or electrically induced magnetism to adjust the speed of the pump while the motor rotates at a constant speed.

Constant-Speed Control Devices

A pressure-regulating device in the pump discharge piping is used to maintain satisfactory pressure in the water distribution system.

Alarms and Safety Devices

The following conditions at the booster pumps require the immediate attention of operating personnel in a building:

1. Insufficient water pressure in the water distribution system with the pumps running
2. Excessive water pressure in the water distribution system with the pumps running
3. Failure of the booster pumps to start
4. Excessive water temperature in the booster pump casing

Booster pumps should be provided with a shutoff device to protect the pumps from damage in the event of loss of pump suction pressure. A casing relief valve should be provided to purge water from the pump casing if the water temperature becomes excessive as a result of impeller rotation with no pump discharge.

Advantages of the Booster Pump System

The advantages of the booster pump system compared with the other two systems are as follows:

1. It requires the least floor space.
2. It generally has the lowest initial cost.
3. It is the most flexible system in terms of available flow and pressure to meet a variety of distribution requirements.
4. The installation does not impose a large weight on the building structure.

Disadvantages of the Booster Pump System

Disadvantages of the booster pump system compared with the other two systems are as follows:

1. It has the highest operating cost.
2. It has the the highest maintenance cost.
3. Its control system is sophisticated and requires a knowledgeable maintenance staff.
4. It has couplings and variable-speed drives that require considerable maintenance.
5. It will shut down the water supply for the entire building if there is an electrical power failure.
6. The instantaneous fluctuations in water pressure during normal use may be greater than in the other systems.

Component Selection

The following operating conditions influence component selection:

- *Peak flow rate* of water in gallons per minute (liters per second)
- *Minimum sustained flow rate* that is likely to occur
- *Frequency and duration of flow* for very low flow or no-flow conditions
- *Range of acceptable pressure* in the distribution system
- *System head requirements*, taking into account the most hydraulically remote fixture, the extreme system pressure range, and the operating pressure requirements for special fixtures

System Selection

The following operating conditions influence booster pump system selection:

- *Anticipated peak- and constant-flow* requirements
- *Initial cost* of the system
- *Operating cost*
- *Building type*
- *Importance of uninterrupted operation*

Many of the controls, motorized valves used to govern water flow, and variable-speed drives for controlling the speed of the pump are assembled at the factory and shipped as a "packaged" unit that has been factory-tested and adjusted. The following detailed information should be available from the manufacturer to allow the engineer to verify the suitability of the equipment for a specific project and to ensure that the equipment meets the system pressure requirements:

- Pump curves indicating (*a*) the range within which the various pumps can be used, (*b*) minimum speed for proper pump operation, and (*c*) the speed, flow, head, and power relationship
- Control system description indicating recommended points of installation of the various components

- Pressure set points for pump operation
- Pressure losses through the various control system components installed in the distribution piping
- Variable-speed-drive description and efficiency
- Water wasted through all components of the system (including casing purge and the cooling system of the variable-speed drive)

HYDROPNEUMATIC TANK SYSTEMS

In a ***hydropneumatic tank system***, such as that shown in the schematic diagram Fig. 4.8, water is pumped from the water supply into a pressure tank for storage. The air in the tank is compressed by the water entering the tank. As the pressure in the tank is increased, the pressure in the water distribution system is also increased, since it is connected to the tank. The pressure tank may be located anywhere in the building. The water stored in the tank and the pressure in the tank are sufficient to allow the pumps to shut down for a period of time and yet satisfy the demand for water. This conserves energy, since the pump need not be in continuous operation.[3]

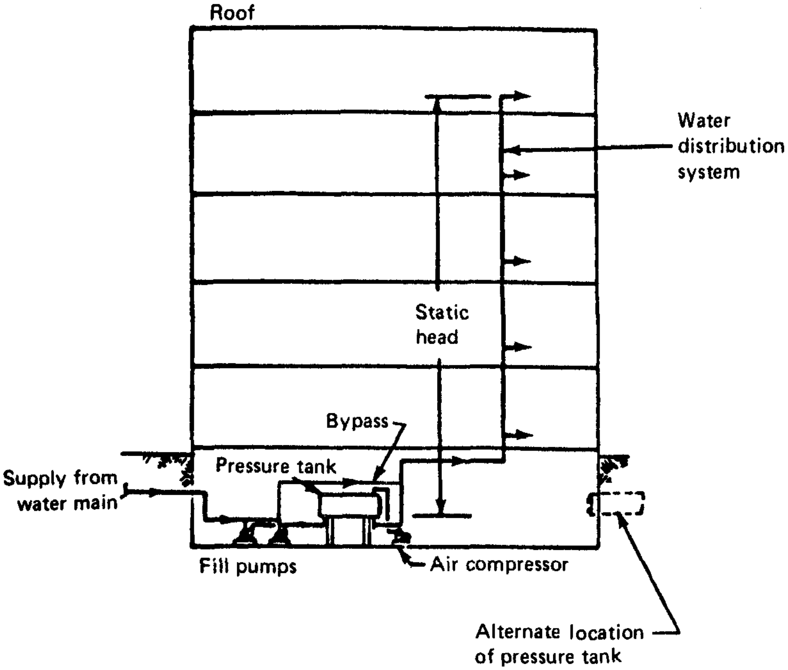

FIG. 4.8 Simplified diagram of a hydropneumatic pump system.

The components of a hydropneumatic tank system include:

- A *pressure tank* to store the water for use in the system
- *Fill pumps* to pump water from its source into the tank
- An *air maintenance device* (either an air compressor or a snifter valve) to introduce air into the pressure tank
- A *control system* to turn the pump and/or air compressor on and off as required
- *Alarms* to alert operating personnel that a malfunction exists
- *Safety devices* to relieve excess pressure.

A schematic detail drawing showing the piping arrangement between components of the system is shown in Fig. 4.9.

Pressure Tank

A *pressure tank* is a closed cylindrical steel container designed to store water under pressure. It can be installed either horizontally or vertically. In smaller systems, the tank may have an internal diaphragm that provides a physical separation between air and water. The exact configuration and thickness of the walls of the tank depend on the pressure for which the tank is designed.

Fill Pumps

A fill pump is a pump that supplies water to a pressurized storage tank or to the water distribution system. Although many types of pumps are suitable for this purpose, the centrifugal pump usually is used because of its ready availability and wide range of capacity and pressure. See Chap. 6 for additional information on pumps.

Unless a very large tank is selected, the total amount of stored water is relatively small, and a pressure tank may run out of water during periods of peak demand. Therefore, fill pumps must be sized to supply the peak demands of the building at the lowest calculated system pressure. The piping arrangement of such a system must include a tank bypass arrangement to allow the fill pumps to supply the building directly if a sustained peak demand occurs and if there is not enough water in the pressure tank to supply the peak demand for an extended period of time.

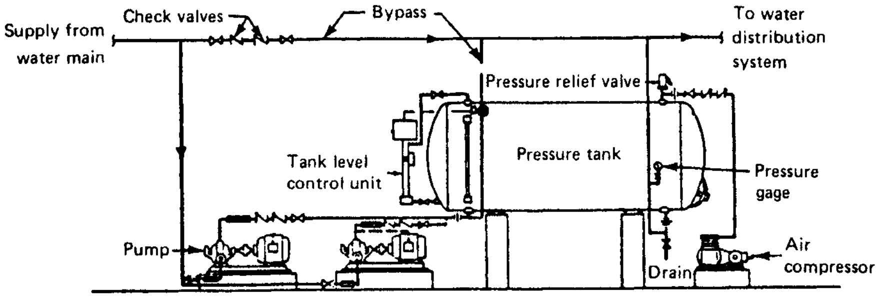

FIG. 4.9 Schematic diagram of the piping arrangement between components of a hydropneumatic pump system.

To size the fill pumps, determine the peak instantaneous demand as outlined in Chap. 7. The capacity of the pumps should equal the peak demand. Select two pumps to operate in parallel, each pump sized to supply 50 percent of the peak flow.

Air Compressor

The size of the air compressor is determined by the size of the tank. Select an air compressor that can supply 2 ft^3/min (0.09 L/s) for a tank having a total capacity in excess of 4000 gal (15,000 L). Select a compressor that can supply 1.5 ft^3/min (0.07 L/s) for tanks having a total capacity of 4000 gal (15,000 L) or less.

Control System

The control system maintains a predetermined water pressure, water level, and air-water ratio within the tank. Air is added to the tank only when the tank pressure at the high-water level is below normal.

An *air maintenance device* is required to introduce air into the pressure tank. If the tank does not have a diaphragm, the water in the tank will absorb the air above it. Additional air must be added to replace the absorbed air. Otherwise, water will eventually fill the entire tank. In larger systems an air compressor pumps air directly into the pressure tank. In smaller systems, a snifter valve is placed on the inlet (suction) side of the fill pump, permitting air to be introduced continuously in the water line and to be pumped into the pressure tank along with the water.

Controls are needed to start and stop the air compressor and the fill pumps. The air compressor is controlled by means of a combination level-sensing and air-pressure control that starts the compressor when the water drops to the low-water level and there is insufficient pressure in the system. The fill pump is controlled by a sensor that starts the pump when the water pressure reaches a predetermined low level; it stops the pump when the water pressure reaches a predetermined high level.

Alarms and Safety Devices

Alarms are used to alert operating personnel to one or more of the following conditions:

- Excessive water pressure
- Inadequate water pressure
- Excessive air pressure
- Inadequate air pressure

Individual sensors are used to control the pumps, to activate the alarms, and to shut off appropriate components when the predetermined set points are reached.

A pressure relief valve on the pressure tank permits excessive air to escape when the pressure in the tank exceeds a predetermined set point. The fill pumps should be provided with a low-suction-pressure shutoff device to protect the pumps from damage from inadequate pump suction pressure.

Advantages

The advantages of the hydropneumatic system, compared with the other two systems, are as follows:

- The tank system may be located at any convenient location in the water distribution system.
- The hydropneumatic tank may act as a cushion to prevent water hammer.

Disadvantages

The disadvantages of the hydropneumatic system, compared with the other two systems, are as follows:

- It has the highest initial cost.
- The tank size must be impractically large if it is used to store a large volume of fire-suppression water.
- More floor space is required for components than for other systems. (However, if the tank is located below grade, it may be possible to reduce floor space requirements by installing the tank through the foundation wall, so that only the head of the tank is exposed in the building.)
- Because a hydropneumatic tank cannot be partitioned, the tank fill pumps must operate continuously to supply the building's water supply requirements when the tank is being cleaned and/or repaired.

EXCESSIVE WATER PRESSURE

Water pressure in a water distribution system is considered to be excessive if it will damage, or create conditions that will damage, components of the water distribution system or create a nuisance. One such condition results from the pressure surge that accompanies water hammer (see Chap. 11). In this case the pressure may exceed the design rating of the components in the system. This may cause (*a*) bursting of pipes, (*b*) fracture of valves and equipment bodies, and (*c*) enough movement of portions of the piping system to cause failure of pipe joints and/or supports. Excessive water velocity in the water distribution system may create (*a*) noise, (*b*) accelerated component wear due to erosion of component parts, and (*c*) a nuisance because of the splashing of water from faucets.

There is no precise value of water pressure below which the pressure will never damage a water distribution system and above which it will always damage the system. A value of pressure that is widely used is approximately 70 psi (480 kPa). Often, the maximum permissible water pressure is stipulated by code.

Water-Pressure-Regulating Valves (also see Chap. 3)

A *pressure-regulating valve* (PRV), also called a *pressure-reducing valve*, is a device used to reduce and to maintain automatically the pressure of water within predetermined design parameters, for both dynamic flow and static conditions. This is accomplished by a device that opens and closes an orifice in response to fluctuations in outlet (regulated) pressure. The degree of closure depends on the ability of a sensing mechanism to detect changes in water pressure at the outlet side of the valve. The installation of a strainer on the inlet (unregulated) side of the valve is recommended.

Pressure-regulating valves fall into two general categories: (*a*) direct-operated and (*b*) pilot-operated.

Direct-Operated Valves. The direct-operated valve has the closure member controller in direct contact with water pressure in the outlet (regulated) side of the valve. When the outlet pressure varies, the differing pressure causes the closure member to open or close by an amount necessary to achieve the desired outlet pressure.

Direct-operated valves are lowest in initial cost and provide the least accuracy in regulating the outlet pressure. They produce a pressure reduction in proportion to the flow—the larger the flow, the less the pressure in the discharge line.

Pilot-Operated Valves. A pilot-operated valve is a combination of two pressure-regulating valves in a single housing. It consists of (*a*) a primary valve (or pilot) that is in direct contact with water pressure in the outlet (regulated) side of the valve and (*b*) a main valve that contains the closure member. The pilot valve senses variations in the outlet pressure and magnifies closure member travel to achieve the desired outlet pressure.

Pilot-operated valves are higher in initial cost but provide a greater degree of accuracy over a wider range of pressure and flow conditions than a direct-operated pressure-regulating valve.

Selecting a Pressure-Regulating Valve

Various manufacturers offer different types of pressure-regulating valves. The different valves represent a compromise between price, capacity, accuracy, and speed of response. Such information is provided by the manufacturers for use in valve selection.

The following considerations affect the selection of a pressure-regulating valve:

- *Minimum flow rate.* What is the minimum rate of flow (other than zero) expected in the piping where the pressure-regulating valve is installed?
- *Maximum flow rate.* What is the maximum rate of flow expected in the piping where the pressure-regulating valve is installed?
- *Nature of flow.* Is the flow rate reasonably constant, or is flow intermittent?
- *Location of the pressure-regulating valve.* Is the valve located at the beginning or end of a branch?
- *Maximum inlet pressure.* What is the highest pressure expected at the inlet of the pressure-regulating valve?
- *Outlet pressure.* What pressure must the pressure-regulating valve maintain?
- *Falloff.* What is the difference between the pressure at which the system has been set and the actual outlet pressure delivered to the piping? [The difference is usually limited to approximately 15 psi (105 kPa).]

- *Pressure differential.* What is the difference in pressure at the inlet and outlet of the pressure-regulating valve? If this difference is excessive, cavitation may damage the valve. *Cavitation* is a phenomenon in the flow of water caused by the formation and collapse of cavities, which result in the pitting of surfaces on which the cavitation occurs.
- *Accuracy of pressure regulation.* How accurately must the set pressure be maintained within the water distribution system?
- *Speed of response.* If response to changes in pressure is too rapid, a noise called *chatter* may result. If the response is too slow, an unacceptably wide variation of pressure may occur at the outlet. The speed of response of a direct-acting pressure-regulating valve depends on the ratio between the effective area of the diaphragm and the diameter of the *valve port* (i.e., the diameter of the opening through which the water stream passes). The higher this ratio, the more rapid the response.

Selection Procedure

The following steps are taken in selecting a pressure-regulating valve:

1. Review the drawings of the water distribution system and establish locations where the static pressure may exceed the acceptable value and where pressure-regulating valves may be required.
2. Calculate the pressure in the locations determined in Step 1.
3. Tabulate the operating pressure range for all equipment—particularly in those areas where pressure-regulating valves are likely to be required. (This may require the assignment of estimated pressure drops through the pressure-regulating valves and the piping network in which they are located.)
4. Determine the maximum pressure expected at the inlet of each pressure-regulating valve. Compare this value with the minimum acceptable pressure calculated in Step 3. If this difference exceeds that which can be obtained a single valve, then use two valves in series. (This difference in pressure may also provide an indication of whether cavitation is likely to occur.)
5. Calculate the maximum and minimum rates that might be expected through each pressure-regulating valve. If the difference between these values is large, it may not be possible to obtain a single pressure-regulating valve that will satisfy both the flow requirement and pressure falloff requirement. Then, installation of two pressure regulating valves of different sizes, in parallel, will be necessary. A set of multiple pressure-regulating valves is commonly called a *pressure-regulating-valve station* (i.e., a *PRV station*). An example of such an installation is shown in Fig. 4.2.
6. Compare the above requirements with manufacturers' values of capacity, flow, and pressure ratings for various pressure-regulating valves. Select a valve that best satisfies the critical requirements, i.e., (*a*) the necessary pressure differential without cavitation and (*b*) the necessary flow rate.

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CHAPTER 5

PLUMBING FIXTURES AND FITTINGS

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INTRODUCTION

This chapter discusses plumbing fixtures, fixture fittings, and trim. It includes a discussion of the application of standard code regulations, applicable code provisions, standards for quality of plumbing fixtures, plumbing appliances, fixture fittings and trim; characteristics and qualities of various plumbing fixtures, fixture overflows, and strainers; fixture traps and their sizes and types for various fixtures; use of intercepting fixture traps for certain fixtures; use of vapor relief vents and local vents for specific fixtures; and plumbing appliances.

STANDARD CODE REGULATIONS

Plumbing code regulations are relatively standard throughout the U.S.A. These include regulations concerning plumbing fixtures, fixture fittings and traps, and their installation and usability in buildings. All such regulations, in addition to applicable local requirements, should be observed. Their purpose is to provide basic and uniform rules and regulations (in terms of performance objectives implemented by specific requirements) that establish safeguards for sanitation in and adjacent to buildings in order to protect the public health against the hazards of inadequate or insanitary plumbing installations.

Recommended standard regulations include:

National Standard Plumbing Code, NAPHCC[1]/ASPE[2] (a jointly sponsored standard)

National Plumbing Code, ANSI[3] A40.8-1955

TABLE 5.1 Standards for Plumbing Fixtures and Appliances

Standard number	Title
ANSI[3]/ASME[4] A112.19.1M	*Enameled Cast Iron Plumbing Fixtures*
ANSI/ASME A112.19.2M	*Vitreous China Plumbing Fixtures*
ANSI/ASME A112.19.3M	*Stainless Steel Plumbing Fixtures (Designed for Residential Use)*
ANSI/ASME A112.19.4M	*Porcelain Enameled Formed Steel Plumbing Fixtures*
ANSI Z124.1	*Plastic Bathtub Units*
ANSI Z124.2	*Plastic Shower Receptors and Shower Stalls*
ANSI Z124.3	*Plastic Lavatories*
ANSI/ASME A112.21.1	*Floor Drains*
ANSI/ARI[5] 1010	*Drinking Fountains, Self-Contained, Mechanically Refrigerated Drinking Water Coolers*
ANSI/ARI 1020	*Application and Installation of Drinking Fountains and Drinking Water Coolers*
ANSI/AHAM[6] DW-2PR	*Plumbing Requirements for Household Dishwashers*
ANSI/AHAM HLW-2PR	*Plumbing Requirements for Home Laundry Equipment*
ANSI/AHAM FWD	*Performance Evaluation Procedures for Household Food Waste Disposers*

Quality of Fixtures

Plumbing fixtures should be constructed so as to provide sanitary quality. They should be designed for their intended uses and for convenience in cleaning. They should be made of nonoxidizing, nonabsorbent material with smooth, abrasion-resistant, impervious surfaces; they should be free from defects and concealed fouling surfaces, and should be reasonably durable for their intended services.

Over a period of about 140 years, experience with many plumbing fixture designs and kinds of materials has led to development of generally accepted standards with respect to strength, durability, corrosion resistance, abrasion resistance, performance under suitable tests, and other important characteristics necessary in fixtures before they may be considered to be of satisfactory quality. Many standards that are applicable to plumbing fixtures and appliances are listed in Table 5.1 as a guide for architects, engineers, contractors, and suppliers.

Plumbing Fittings and Trim

Plumbing trim is the exposed metal appurtenances of plumbing fixtures, such as faucets, spigots, and exposed traps. Standards for plumbing fixture fittings and trim, which supplement the standards for plumbing fixtures and appliances, are listed in Table 5.2.

TABLE 5.2 Standards for Plumbing Fixture Fittings and Trim

Standard number	Title
ANSI/ASME A112.1.2(R 1979)	*Air Gaps in Plumbing Systems*
ANSI/ASME A112.6.1M	*Supports for Off-the-Floor Plumbing Fixtures for Public Use*
ANSI/ASME A112.18.1M	*Finished and Rough Brass Plumbing Fixture Fittings*
ANSI/ASME A112.19.5	*Trim for Water Closet Bowls, Tanks and Urinals*
ANSI/ASME A112.19.8M	*Suction Fittings for Use in Swimming Pools, Wading Pools, Hot Tubs and Whirlpool Bathtub Appliances*
ANSI/ASSE 1001	*Anti-Siphon Vaccum Breakers, Performance Requirements, Methods of Test for*
ANSI/ASSE[7] 1002	*Water Closet Flush Tank Ballcocks*
ANSI/ASSE 1011	*Hose Connection Type Vacuum Breakers*
ANSI/ASSE 1014	*Hand Held Showers*
ANSI/ASSE 1016	*Individual Shower Control Valves, Anti-Scald Type*
ANSI/ASSE 1017	*Thermostatic Mixing Valves, Self-Actuated for Primary Domestic Use*
ANSI/ASSE 1018	*Trap Seal Primer Valves*
ANSI/ASSE 1020	*Vacuum Breakers, Anti-Siphon Pressure Type*
ANSI/ASSE 1025	*Diverters for Plumbing Faucets with Hose Spray, Anti-Siphon Type, Residential Application*

WATER CLOSETS AND URINALS

A *water closet* is a plumbing fixture used to receive human excrement and to discharge it through a *drainpipe*, using water as a conveying medium. Many models of sanitary water closets, conforming to quality standards established by industry, are currently available. An appropriate selection may be made for any type of building occupancy. For public use, it is recommended that water closets be of the elongated bowl type so as to avoid unsanitary and objectionable conditions which might otherwise arise.

In kindergartens, nurseries, and similar occupancies where fixtures are provided for the use and training of children under 6 years of age, water closets should be of suitable type (such as primary or junior models) having a height of 10 or 13 in (25 or 33 cm).

Water closets should be equipped with seats of smooth nonabsorbent material. However, it is preferable that the seats be made of material having relatively low thermal conductivity so as to avoid excessive thermal shock when bare skin contacts material that is very cold. Seats should be of suitable shape for the type of water closet. Open-front-type seats should be provided for water closets intended for public use.

Many models of sanitary urinals, both floor-standard and wall-hung types, conforming to quality standards established by industry, are available. An appropriate selection should be made for the particular use intended.

Trough-type urinals have been deemed by most health and code authorities to be of insanitary design for use inside buildings. The walls of such urinals are not thoroughly washed at each flushing. This results in objectionable conditions in the vicinity of the fixture. Consequently, trough-type urinals are prohibited in buildings, in general. However, they may be permitted by the authority having jurisdiction as a temporary outdoor facility for workmen during building construction or demolition, or for public use at temporary carnival sites.

Water closets of insanitary design should not be installed in buildings. Included in this category are all water closets that have one or more of the following insanitary design features: (*a*) an invisible seal, (*b*) unventilated spaces, (*c*) walls of the water closet bowl which are not thoroughly washed at each flushing, and (*d*) a design which might permit siphonage of the contents of the water closet bowl back into the flush tank. Numerous obsolete types which had one or more such insanitary features are often named in regulatory codes, and may still be found in some very old buildings. Such types were rendered obsolete and insanitary by the development in 1890 of the washdown water closet, the first whose design was considered to be sanitary. Since then, many improvements have been made in water closet design for quieter action, quicker function, and stronger siphonic action, as well as for uniting water closet and flush tank design as a unit and for installation of water closets on walls.

FLUSH TANKS, FLUSH VALVES, AND FLUSHOMETERS

Each water closet and urinal should have a flushing device designed and installed so as to supply water at adequate rate and volume for satisfactory flushing of the

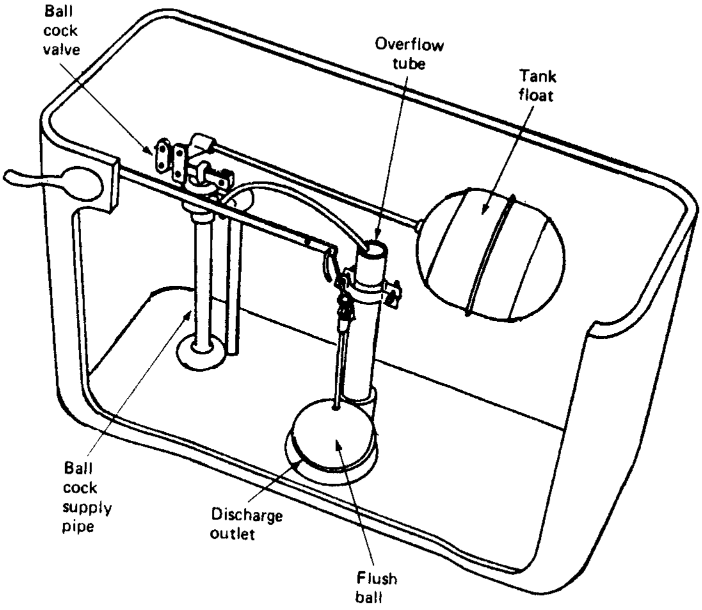

FIG. 5.1 A flush tank for a water closet.

interior of the fixture. A flush tank or flushometer should be provided for this purpose. A *flush tank*, illustrated in Fig. 5.1, is a tank which holds a supply of water for flushing a water closet or one or more urinals. A *flushometer* (also called a *flush valve*), illustrated in Fig. 5.2, is a valve designed to supply a fixed quantity of water for flushing purposes; it is actuated by direct water pressure, without the use of a flush tank or cistern.

Flush tanks should have sufficient water capacity for flushing thoroughly the water closets or urinals they are intended to serve. No flush tank should supply more than one water closet or urinal. However, where specially approved by the authority having jurisdiction, more than one urinal may be permitted to be flushed by a single flush tank, provided it is automatic in operation and has sufficient water capacity for flushing thoroughly and simultaneously all the urinals served thereby. Flush-valve seats in water closet flush tanks should be at least 1 in (2.5 cm) above the rim level of the water closet connected thereto, except in the case of an approved water closet and flush tank combination specially designed so that when the water closet is clogged and the tank is flushed, the flush valve closes tightly and prevents water from spilling continuously over the rim of the water closet. Flush tanks should be provided with overflows of adequate size to prevent tank flooding at the maximum rate at which they are supplied with water. The overflow should be arranged so as to discharge into the water closet or urinal connected thereto.

A *ball cock* is a valve that controls the flow of water; its opening or closing depends on the position of a float that rides on the surface of water in a flush tank. A ball cock should be designed to operate automatically, refilling the tank after each discharge and shutting off completely when the tank is filled to operational capacity. In low-down flush tanks, the ball cock should have a means for bypassing an adequate amount of water to refill the trap seal while the tank refills after each flushing. A flush pipe is a pipe that conveys flushing water from the source of supply to a water closet. Flush pipes and fittings between flush tanks and water closets or urinals should also be of adequate size to provide sufficient rate of flow for proper flushing of the fixture.

Flushometers or flush tanks connected directly to a potable water supply sys-

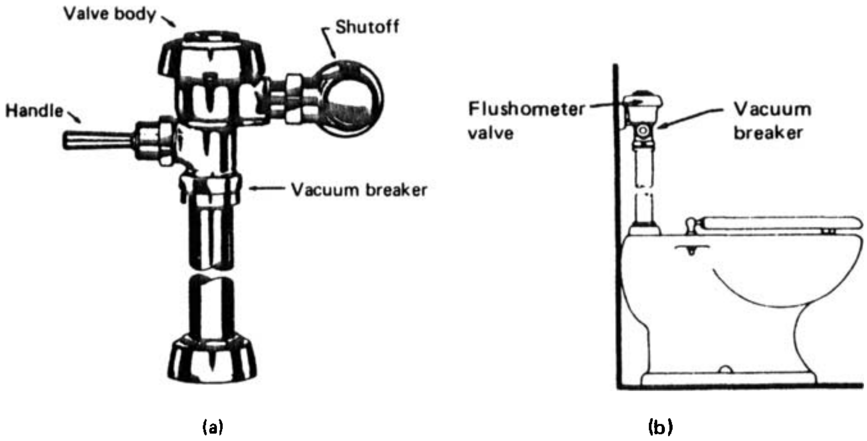

FIG. 5.2 A flushometer. (*a*) Detail; (*b*) a flushometer mounted above a water closet.

tem should be equipped with means for protecting the system against contamination from back siphonage of water from the fixtures. (See "Backflow due to Back Siphonage," Chap. 13.) Direct-supply flush valves should be readily accessible for repairs, and they should be provided with convenient means for adjustment of the rate and volume of water discharged. They should be designed so that, when manually activated, they complete their normal cycle of operation, opening fully and closing positively under service pressure and delivering water in sufficient rate and volume to flush thoroughly the fixture and refill the fixture trap seal.

LAVATORIES, BATHTUBS, AND SHOWERS

Lavatories

Lavatories should be provided with waste outlets having a diameter of not less than 1¼ in (3.1 cm). Multiple-type lavatories, such as circular or straight-line multiple wash sinks or wash fountains, should be considered equivalent to ordinary lavatories on the basis of one lavatory for each 18-in (45.5-cm) unit length of usable space at which hot and cold water are available along the perimeter of the fixture.

Bathtubs

Bathtubs should be provided with waste outlets and overflows having diameters of at least 1½ in (3.75 cm) and should be equipped with suitable stoppers. Where shower heads are installed above built-in bathtubs, waterproof joints should be provided between the tub and walls, and the walls should be constructed of smooth, noncorrosive, and nonabsorbent materials to a height of not less than 6 ft (1.8 m) above the floor.

Showers

Waste outlets of shower floors and receptors should have diameters of at least 2 in (5.1 cm) so as to permit water to drain off without puddling when the shower head discharges at normal maximum rate. A removable strainer should be provided in the waste outlet so that the shower trap may be cleaned from the waste outlet. Such provision need not be made where shower heads are installed above bathtubs, or where emergency showers are provided for dousing persons exposed to contact with severely irritating chemicals.

Individual shower compartments should be of adequate floor area for satisfactory use by adults. For such service, the minimum floor area deemed necessary is 900 in^2 (0.58 m^2) and the minimum span between walls for any compartment shape should be 30 in (0.76 m). Floors under shower compartments should be smooth and structurally sound. Floors of public or institutional shower rooms should be drained in such manner that water from any shower head will not drain across areas occupied by other bathers.

Shower compartment floors, other than those installed directly on the ground or those having watertight receptors, should be constructed in a watertight shower pan of durable material. All sides of the pan should be turned up and extended at least 2 in (5.1 cm) above the finished floor level. The pan should be securely fastened to the shower waste outlet pipe at the seepage entrance so as to make a watertight joint between the pan and the outlet pipe. Where shower compartments are installed directly on the ground, they should have floors or receptors made of smooth, noncorrosive, and nonabsorbent waterproof materials and be fastened securely to the fixture waste-outlet pipe so as to make a watertight joint therewith. Walls of shower compartments should be constructed of smooth, noncorrosive, and nonabsorbent waterproof materials to a height of not less than 6 ft (1.8 m) above the floor.

SINKS AND LAUNDRY TRAYS

Sinks and laundry trays should be provided with waste outlets having a diameter of at least 1½ in (3.8 cm) to provide fixture drainage at a satisfactorily rapid rate. Each waste outlet of laundry trays should be provided with a suitable stopper so that water may be retained in the fixture.

A sink and one or two laundry trays, two or three sinks, or two or three laundry trays, grouped immediately adjacent to each other in the same room, may have their waste-outlet piping branched together into a single outlet pipe for the group of fixtures and may be connected to the drainage system as a combination fixture. A one-piece combination fixture in which such sink or laundry tray compartments are grouped together should be treated and connected in the same manner.

Where a food-waste-grinder unit is to be installed in a sink, the waste opening in the fixture should have a diameter of at least 3½ in (9 cm). Food-waste-grinder units should be equipped with either automatic or hand-operated water supply controls so that the unit operates only when water flows. This feature is necessary to minimize the incidence of stoppage in the fixture drain. In some jurisdictions, such units should be installed only in sinks which are connected to a separate drainage system in order to avoid pumping ground food waste into the public sewer systems. In other areas, authorities may deliberately encourage directly connected installations for their own reasons.

DRINKING FOUNTAINS

Nozzles of drinking fountains should be of nonoxidizing, impervious material. They should be located so that the lower edge of the nozzle orifice is at least ¾ in (2 cm) above the *flood-level rim* of the fixture (i.e., the top edge of a receptacle at which water overflows) and should be set at an angle so that no water can drip back onto the nozzle when the fixture is in use. A nonoxidizing guard should be provided above and around the nozzle to prevent the mouths and noses of users from coming into contact with the nozzle. Guards should be designed to minimize the possibility of transmitting infection. Both nozzle and guard should be positioned so that the water jet does not strike the guard and cause spattering. Means must be provided for regulating and adjusting the supply of water to the drinking-fountain nozzle so that a suitable jet of water occurs when the fountain is turned on by users.

Drinking-fountain bowls should be designed free of corners so as to facilitate cleaning and to prevent unnecessary splashing when the jet falls into the bowl.

The waste outlet of the bowl should have a diameter of at least 1 in (2.5 cm) and should be provided with a durable strainer. The height of the bowl and nozzle of a drinking fountain should be suitable for convenient use by the persons for whom it is intended.

Drinking fountains equipped with more than one nozzle above the receptacle should be deemed equivalent to the number of nozzles provided at reasonable spacing and accessible to users. Similarly, where properly installed drinking-fountain nozzles are provided and approved for use at sinks or lavatories, such nozzles should be deemed equivalent drinking-fountain fixtures.

DISHWASHING MACHINES AND FIXTURES

Domestic dishwashing machines may be provided in dwelling units to serve as convenient, labor-saving devices for washing and cleaning dishes, glasses, and cutlery. Many well-designed and highly efficient models are available. However, they should not be considered equivalent to, or suitable substitutes for, kitchen sinks which are required to be provided in dwelling units. Domestic machines may drain by gravity or by integral drainage pumps.

A separate trap should be provided for each domestic dishwashing machine drained by gravity. Machines equipped with drainage pumps may discharge through a direct connection to the waste-outlet piping of an adjacent kitchen sink by means of a Y-branch fitting on the inlet side of the sink trap, provided that the pump discharge line rises to an elevation at least as high as the underside of the sink rim or counter before connecting to the Y-branch fitting. This provision prevents backup of waste into the machine when the sink drain is clogged. Where the machines are indirectly connected to the drainage system, they should discharge through an air gap (see "Air Gap," Chap. 13) into a fixture approved for such use.

Commercial dishwashing machines or three-compartment sinks of suitable type are required to be provided where food or drink is served for human consumption in public or employee dining establishments. In such establishments, all dishes, glasses, and cutlery which are to be reused must be washed and sanitized in conformity with standards established by the health authority having jurisdiction. Hot-water supply for commercial dishwashing machines and dishwashing fixtures should be provided at 140 to 160°F (60 to 71.1°C) for washing and at 180 to 190°F (82 to 88°C) for sanitizing. Commercial dishwashing machines must meet sanitary standards. Such machines are required to be indirectly connected to the sanitary drainage system.

A minimum flow pressure of 15 psi (100 kPa) should be available in the 180°F (82°C) hot-water supply line to each commercial dishwashing machine during final sanitizing rinse spraying. Where the flow pressure exceeds 30 psi (200 kPa), either a pressure-reducing valve or a flow-control valve should be installed in the hot-water supply line in order to keep the pressure in the line between 15 and 30 psi (100 and 200 kPa).

FLOOR DRAINS

A floor drain is a fixture which provides an opening in the floor to drain water into a plumbing system. It should be of adequate size to serve the purpose for which it is intended without causing puddling at the drain inlet. The minimum size recommended for floor drains is 3 in (7.6 cm). Floor-drain inlets should be located so as to be readily accessible at all times and should be provided with removable strainers. The clear open area of such strainers should be at least two-thirds of the cross-sectional area of the drain pipe to which the floor drain connects. Floor drains should be provided with traps of the deep-seal type. They should also be provided with convenient water supply by means of a faucet located not more than 3 ft (0.9 m) above the floor area drained, unless other suitable means for maintaining the trap seal are permitted. Further information is given in Chap. 18 (see "Drains").

Objections to the unnecessary installation of floor drains sometimes are raised by authorities. Their objections are based on the fact that the water seals of floor drain traps evaporate when they receive no waste over extended periods of time. Then, objectionable odors and gases escape from the drainage system into the building space where the floor drain is located.

FIXTURE OVERFLOWS AND STRAINERS

Integral overflow passageways and separate overflow pipes provide a means of removing excess water from fixtures and preventing overflow. Such passageways at a level below the flood-level rim, as illustrated in Fig. 5.3, are connected to the fixture waste-outlet fitting or pipe on the outlet side of the outlet stopper, plug, or control valve; they are on the inlet side of the fixture trap. In this way, water may overflow from the fixture and be conveyed into the drainage system, and the fixture trap serves to prevent drainage system odors and gases from escaping through the overflow.

A *standing waste* is a device for the control of the outlet and overflow of a plumbing fixture; an overflow pipe is inserted in the outlet at the bottom of the fixture or tank permitting water to be retained. Standing-waste-and-overflow fit-

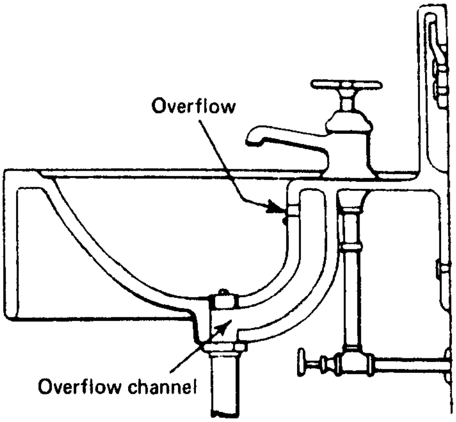

FIG. 5.3 Cross section of a sink showing the flood-level rim and the overflow pipe to remove excess water and prevent overflow.

tings on fixtures promote insanitary conditions. Therefore, the use of such fittings is generally prohibited. Where overflows are provided on fixtures, the waste fittings should be arranged so that water cannot rise in the overflow when the fixture is being filled or remain in the overflow when the fixture is empty.

Durable strainers should be provided in the waste outlets of all plumbing fixtures except those which are designed with integral fixture traps. Fixture strainers should be provided except where specially required to be of the removable type. The clear waterway area of strainers should be not less than that required of the fixture waste outlet so that satisfactory fixture drainage will not be impaired.

INTERCEPTING STRAINERS

An intercepting strainer, basket, or equivalent acceptable device should be provided at the waste outlet of every fixture or receptacle which receives wastes containing large, objectionable solid substances to prevent them from entering the drainage system where they could clog the piping. The device should be designed to intercept solids ½ in (1.3 cm) and larger in size and should be easily removable for cleaning purposes. (Also see the discussion of grates in Chap. 18, under "Drain Components.")

Such a device should be provided at the waste outlet of a fixture or receptacle receiving the wash from garbage cans, or wastes containing strings, rags, buttons, broken glass, bottle tops, feathers, entrails, or similar substances. Fixtures which receive sewage containing large, objectionable solids from indirect waste pipes should be equipped with a readily removable metal basket or beehive strainer having a height of not less than 4 in (10 cm), installed at the waste outlet of the fixture.

SPECIAL-USE FIXTURES

Fixtures intended to receive and discharge objectionable quantities of detrimental wastes, such as substances which can clog pipes, destroy pipes or their joints, interfere unduly with the sewage disposal process, or produce explosive mixtures, should not be connected to the building sanitary drainage system unless such fixtures are provided with efficient and suitable means for the satisfactory treatment and handling of such wastes to render them unobjectionable and harmless. Intercepting strainers or intercepting fixture traps may be used where suitable. Where such means are unsuitable, fixtures receiving detrimental wastes should be connected to an independent drainage system specially designed to dispose of the wastes in an acceptable manner.

Fixtures which receive the discharge of indirect waste pipes should be of suitable shape and capacity to prevent splashing and flooding. No fixtures provided for domestic or culinary purposes should be used to receive the discharge of an indirect waste pipe, except that a sink or laundry tray in a dwelling unit may serve to receive indirect wastes from domestic appliances. However, in no case should a water closet, urinal, bathtub, or shower be used to receive indirect wastes, for such service would impede normal use of such fixtures and promote insanitary conditions.

FIXTURE INSTALLATION

Plumbing fixtures should be located in spaces which are adequately lighted and ventilated in conformity with applicable building regulations. This is a basic sanitary requirement. Wherever fixtures are installed, moisture is added to the air when water flows, spattering is prone to occur, and fixture odors develop. Lack of adequate lighting or ventilation promotes poor maintenance and insanitary conditions. Artificial light of suitable intensity should be provided in all rooms or spaces where fixtures are installed. Ventilation may be either natural or mechanical.

Water closets, urinals, bathtubs, and showers should be located only in rooms or compartments which are adequately ventilated directly to the outer air or are provided with independent mechanical ventilating systems which exhaust air from such spaces to the outer air. For natural ventilation, the minimum openable area for windows should be at least 1½ ft^2 (0.14 m^2) for a private toilet room or bathroom and at least 1 ft^2 (0.09 m^2) per water closet or urinal, but no less than 3 ft^2 (0.28 m^2) for a toilet room or bathroom used by the public or employees. For mechanical ventilation, air should be exhausted at a rate of 25 ft^3/min (0.012 m^3/s) for private bathrooms or toilet rooms, and at a rate of 40 ft^3/min (0.019 m^3/s) per water closet or urinal for a toilet room or bathroom used by the public or employees.

Fixtures which receive the discharge of indirect waste pipes should not be located in any unventilated storeroom or closet, as insanitary conditions are bound to result. They should be located in well-lighted and amply ventilated spaces where the use of such fixtures does not constitute a nuisance. Preferably, they should be located where any need for maintenance will be readily apparent to building occupants.

In one- and two-family dwellings, it is recommended that the floors of toilet rooms and bathrooms be of materials that are impervious to moisture so that they may be washed and cleaned thoroughly. In buildings other than one- and two-family dwellings, toilet rooms and bathrooms should be provided with waterproof floors and with waterproofing extending at least 6 in (15 cm) above the floors, except at doors. This is required so that floors of such rooms may be quickly and easily maintained in sanitary condition by mopping or hosing. Walls and floors adjacent to urinals should be finished with noncorrosive and nonabsorbent materials extending at least 1 ft (0.3 m) in front of the urinal lip, 1 ft (0.3 m) on each side of the urinal, and 4 ft (1.2 m) above the floor. This too has been found to be necessary as a sanitary measure for normal service.

Water closets, urinals, bathtubs, and showers should not be located on the floor directly above space used for the manufacture, preparation, packaging, storage, or display of food unless an additional watertight barrier is provided to intervene between the toilet room or bathroom floor and such space immediately below.

In general, it is recommended that no drinking fountain or equivalent drinking-fountain fixture be located in bathrooms or toilet rooms. However, it has been deemed permissible to provide drinking fountains in rooms containing no more than one water closet or urinal, such as may be considered to be the condition existing in bathrooms or toilet rooms for private use where drinking water normally is obtained at lavatories.

Fixtures and equipment should be located so as not to interfere with the normal operation of windows, doors, or exit openings. Fixtures should be set level and in proper alignment with adjacent walls. They should be installed with regard to spacing so as to be reasonably accessible for their intended use, and for cleaning and repairs. Where fixtures are installed in contact with walls or floors, the space at the outer edge of fixture contact should be sealed against water seepage so that moisture cannot get between the fixture and the wall or floor and promote development of vermin.

Wherever practicable, fixture supply and drain pipes should be run to piping connections on the nearest wall rather than through the floor. Similarly, wall-hung and built-in fixtures are preferred over floor-standing types because of greater ease in cleaning and maintaining floors. Fixtures having concealed packing or gasket-type slip-joint connections should be provided with an access panel or utility space to make the slip joint accessible for repair when necessary.

Wall-hung water closets, urinals, and lavatories should be rigidly secured against the wall and rigidly held in place by durable, concealed supports so that no strain is transmitted to the piping connections. Fixture connections between drainage pipes and water closets, pedestal urinals, floor-outlet service sinks, and earthenware trap standards should be made by means of approved flanges. They should be soldered, screwed, or otherwise securely attached to the drainage pipes in a manner suitable for the type of drainage piping. The flange should be installed on a firm base made of materials impervious to moisture. An acceptable gasket, washer, or setting compound should be placed between the earthenware fixture outlet and the flange, and the fixture should be bolted tightly to the flange so as to form a gastight joint. Commercial putty and plaster of paris are unsuitable for use as fixture gasket material for they tend to wash away in service.

FIXTURE TRAPS

A *trap*, illustrated in Fig. 18.22*a*, is a device that maintains a water seal against the passage of sewer gas, air, and odors originating inside a drainage system, while permitting unrestricted passage of liquid waste into the system. Each fixture directly connected to the sanitary drainage system should be equipped with such a trap; the vertical distance from the fixture outlet to the trap weir must not exceed 2 ft (0.6 m), as illustrated in Fig. 5.4. Similarly, fixtures which discharge wastes indirectly through drainage piping exceeding 4 ft (1.2 m) in developed length, measured from the fixture outlet, should be equipped with a trap. Any greater length of untrapped waste piping produces an excessive and objectionable amount of odor and warrants installation of a trap to prevent air circulation through the fixture waste outlet.

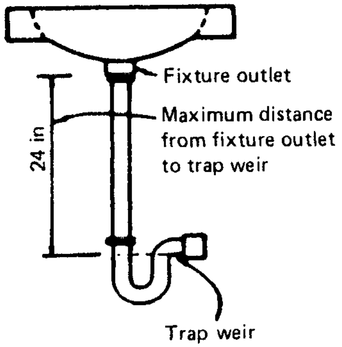

FIG. 5.4 The distance between a fixture outlet and the weir of a trap to which it is connected may not exceed 24 in (0.6 m).

A single trap may be provided for a sink and one or two laundry trays, two or three sinks, or two or three laundry trays grouped immediately adjacent to each other in the same room. But in this combination or group of fixtures, no sink should be equipped with a food-waste-grinder unit because in the event of a stoppage in the fixture trap or drain, ground food waste would be pumped into other fixtures of the group when the grinder was used.

Several designs of fixture traps used in the past and found to be unsatisfactory and objectionable are stated in codes as prohibited types; they include traps which depend upon the action of movable parts for their seal, crown-vented traps, or bell traps except where installed in refrigerator safes or receptors. Bell traps cannot perform their function when the bell is removed, displaced from normal position, or broken. Nevertheless, this type of trap is permitted for refrigerator safes and receptors which are set at floor level. In this location, the bell is visible, may be easily removed, and may serve as a convenient means of access for cleaning the indirect waste piping to which the trap connects.

To avoid stoppages, fixture traps should be self-cleaning, except for those types that are specially designed to intercept grease or sediment. Traps which are integral with fixtures should have uniform interiors and smooth waterways. Traps should contain no movable parts, nor should they be designed with interior partitions, except where they are integral with fixtures or are designed for grease or sediment interception. The bodies of drum traps should have a diameter of either 3 or 4 in (7.6 or 10 cm). In the design of intercepting traps, provision should be made to prevent them from becoming airbound.*

Fixture traps should have a water seal whose depth is not less than 2 in (5.1 cm) but not more than 4 in (10.2 cm), except where permitted for use in special conditions. Traps having a seal whose depth is less than 2 in (5.1 cm) should be avoided, because the criterion for sizing the vent piping system is based upon the use of traps having a minimum depth of seal of 2 in (5.1 cm).

Convenient access to the interior of fixture traps is necessary so that they may be readily cleared whenever stoppages occur. An accessible brass screw cleanout or plug should be provided in the water seal of each common fixture trap, preferably at the bottom of the trap where it may serve as a drain plug. However, such a cleanout provision is unnecessary where the fixture trap is integral, or combined with the fixture, and the trap seal is readily accessible from the fixture, or where a portion of the trap is easily removable for cleaning purposes. Where a fixture serves as a receptor for indirect wastes and is set below floor level, a running trap with a cleanout extended to floor level should be provided adjacent to the fixture. (A *running trap* is a depressed U-shaped section of pipe in a drain; it allows the free passage of fluid, but always remains full, whatever the state of the pipe, so that it forms a seal against the passage of gases.) Special fixture traps designed for interception of grease, hair, or similar substances may have gastight covers, handholes, or other cleanout provisions held in place by lugs or bolts.

Traps should be installed level with respect to their water seals so that the seal strength for which they are designed may be fully effective in resisting pneumatic pressure fluctuations in the drainage system. They should be located in areas where they are not subject to damage from freezing, or should be provided with adequate protection against frost conditions. It is recommended that fixture traps be installed as close as practicable to the fixture waste outlet to minimize loss of trap seal due to momentum of waste flow when the fixture discharges and to minimize odors from the fouled interior of piping between the fixture waste outlet and the trap. The maximum developed length† between the fixture waste outlet and trap should be limited to 2 ft (0.61 m). However, this length may be as much as 4 ft (1.2 m) where fixtures are remote from all walls, as in "island" sinks, wash

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* A pipe is said to be *airbound* when the presence of a pocket of air prevents or reduces the desired liquid flow in the pipe.

† *Developed length* is the length of a pipeline measured along the center of the pipe and fittings.

fountains, and lavatories, provided the fixture has a large interior flat bottom [120 in^2 (7.7 cm^2) or more in area] or is not equipped with a waste-outlet stopper or plug. Excessive trap seal losses do not occur with such fixtures when they discharge because of the high amount of trail flow which refills the seal at the end of discharge. The greater length of piping between the trap and the waste outlet is no more than would be exposed to room atmosphere where a combination fixture was installed, and should be no more productive of objectionable odors.

The size of trap for any given fixture should be sufficient to permit satisfactorily rapid fixture drainage. In no case should a fixture trap be larger than the fixture drain to which it connects, for then an obstruction or ledge would be formed at the trap outlet and promote stoppage of the trap. Recommended minimum sizes for fixture traps are given in Table 5.3.

Use of Intercepting Fixture Traps

Intercepting fixture traps should be provided only where they constitute the most suitable and acceptable means of removing objectionable substances from detrimental wastes. Such traps should be installed strictly in accordance with their approvals in respect to type, size, rating, and location. No wastes should be discharged through intercepting traps other than those which the traps are designed to handle. Each intercepting trap should be installed and located so as to provide ready access to the trap cover or access to other means for maintaining the device in efficient operating condition. All intercepting traps require maintenance. Accumulated intercepted material must be removed periodically so that they can operate efficiently and perform satisfactorily.

An approved grease-intercepting trap, such as the one shown in Fig. 18.17, should be installed in the drain of any fixture through which an objectionable amount of grease usually enters the building drainage system, such as in a restaurant, cafeteria, commercial kitchen, or bar kitchen. In such establishments, grease-intercepting traps should be installed in the fixture drains of pot, scullery, or food-scrap sinks and in floor drains which receive waste or spillage from soup or stock kettles. However, grease-intercepting traps should not be installed in the fixture drain of a sink that is equipped with a food-waste-grinder unit; in that case, the trap would intercept and be rapidly filled with ground food waste.

In commercial establishments, an approved sediment-intercepting trap, for intercepting plaster, hair, silt, sand, or similar solid substances, should be installed in the fixture drain of each fixture at which such substances are introduced into the drainage system in objectionable quantities. For example, approved sediment-intercepting traps of suitable type should be installed in the fixture drains of dental and orthopedic laboratory sinks, as well as sinks that receive wastes resulting from various activities such as hair-removal processes and commercial car washing.

VAPOR RELIEF VENTS AND LOCAL VENTS FOR FIXTURES

A vapor relief vent (also called a *local vent* or *local ventilating pipe*) is a pipe on the fixture side of a trap through which vapor or foul air is removed from the

TABLE 5.3 Minimum Sizes of Traps for Various Plumbing Fixtures

Fixture	Size in	Size cm
Bathtub (with or without overhead shower)	1½	3.8
Bidet	1½	3.8
Combination sink and wash tray	1½	3.8
Combination sink and wash tray with food-waste grinder	1½*	3.8
Dental unit or cuspidor	1¼	3.2
Dental lavatory	1¼	3.2
Drinking fountain	1¼	3.2
Dishwasher, commercial	2	5.1
Dishwasher, domestic	1½	3.8
Floor drain	3	7.6
Kitchen sink, domestic	1½	3.8
Kitchen sink, domestic, with food-waste grinder	1½	3.8
Lavatory, common	1¼	3.2
Lavatory (barber shop, beauty parlor, or surgeon's)	1½	3.8
Lavatory, multiple-type (wash fountain or wash sink)	1½	3.8
Laundry tray (one or two compartments)	1½	3.8
Shower stall	2	5.1
Sink (surgeon's)	1½	3.8
Sink (flushing-rim-type, flush valve supplied)	3	7.6
Sink (service-type with floor outlet trap standard)	3	7.6
Sink (service-type with P-trap)	2	5.1
Sink, commercial (pot, scullery, or similar type)*	2	5.1
Sink, commercial (with food-waste-grinder unit)	2	5.1
Urinal (pedestal-type, integral type)	3 nominal	7.5
Urinal (all types with integral traps except pedestal type)	2 nominal	5.1
Urinal (stall-washout-type, separate trap)	2	5.1
Urinal (wall-hung washout-type, separate trap)	1½	3.8
Water closet	3 nominal	7.5

*Separate traps required for the wash tray and for the sink compartment with food-waste-grinder unit.

fixture. Many years ago, water closets and urinals were equipped with special ventilation pipes connected directly to the fixtures and extended outdoors, so as to ventilate foul odors from the insanitary types of fixtures used at the time. These pipes were called local vents or local ventilation pipes, since they were intended to ventilate the odorous fixtures and remove air from adjacent areas, rather than to ventilate the interior of the sanitary drainage system. With the development of modern sanitary types of water closets and urinals, and the requirement of adequate ventilation of toilet rooms and bathrooms, the need for installing local ventilation pipes for such fixtures disappeared. Vapor relief pipes should be independent of other vent pipes, ventilating ducts, and flues.

Where vapor relief pipes are provided for fixtures on two or more floors and they are connected as branches to a vapor relief stack, the stack should be extended independently through the building roof, or to an approved location in the open air, and terminated as required for stacks of the sanitary drainage system. Vapor relief pipes in which condensation can collect should be provided with drip pipes. The drip pipe for an individual vapor relief pipe may be connected to the waste outlet piping on the inlet side of the trap of the fixture served by the relief pipe. Other drip pipes should drain in the same manner as indirect waste pipes and discharge into a fixture or receptacle approved for such use.

The size of individual vapor relief pipes should be at least as large as the relief outlet of the fixture in each case. Vapor relief stacks and branch pipes serving two or more individual vapor relief pipes should be at least one standard size larger than the largest individual pipe connected thereto, but in no case having a diameter of less than 1¼ in (3.2 cm). Vapor relief stacks should extend upward undiminished in size from the lowest vapor relief branch to the vent terminal in the open air. Drip pipes connected at the base of vapor relief stacks should have a diameter of at least 1¼ in (3.2 cm).

PLUMBING APPLIANCES AND THEIR VIBRATION ISOLATION (ALSO SEE CHAP. 20)

The term *plumbing appliance* is defined in standards as any one of a special class of plumbing fixture which is intended to perform a special function. Its operation and/or control may be dependent upon one or more energized components, such as motors, controls, heating elements, or pressure- or temperature-sensing elements. Such fixtures may operate automatically through one or more of the following: a time cycle, a temperature range, a pressure range, or a measured volume or weight. Or the fixture may be manually adjusted or controlled by the user or operator. Automatic dishwashing machines, automatic clothes washing machines, and food-waste-grinder units—domestic, household, and commercial types—are included in the term *plumbing appliance*.

Electrical connections to such equipment should conform to applicable provisions of the *National Electrical Code*®.* Water-supply and drainage connections to such equipment should conform to applicable provisions of the National Standard Plumbing Code.

Use of energized components, such as electrical motors and solenoid valves, as part of or in conjunction with such fixtures may result in severe noise, shock, and vibration being transmitted into the building structure unless appropriate means are provided to isolate, eliminate, or suppress such undesirable effects.

Plumbing appliances should be installed with due consideration for vibration isolation. Flexible connections between such appliances and the building plumbing system, and between the appliances and the building structure, are necessary features for satisfactory installation of plumbing appliances. For example, Fig. 5.5 shows the installation of a garbage-disposal (food-waste-grinder) unit, de-

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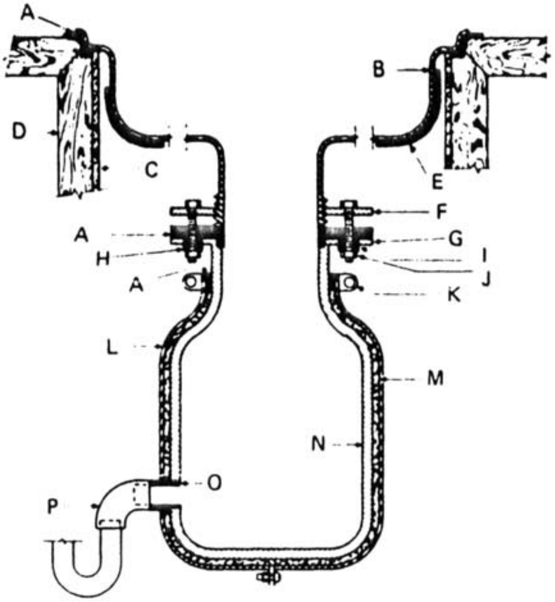
* National Electrical Code® and NEC® are registered trademarks of the National Fire Protection Association, Quincy, Massachusetts.



A – Rubber Gasket
B – Sink
C – Acoustic Mat'l
D – Cabinet
E – Mastic Coat
F – Ring Plate
G – Disp'l-Flange
H – Steel Washer
I – Rubber Washer
J – Nut
K – Ring Clamp
L – Metal Cover
M – Glasswool
N – Disp'l-Housing
O – Rubber Sleeve
P – Rubber Hose

FIG. 5.5 Installation of a food-waste grinder, designed to reduce the transmission of vibration to the cabinet in which it is installed.

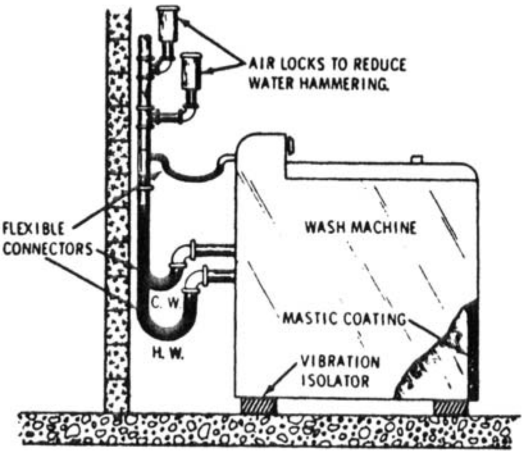


FIG. 5.6 Installation of a washing machine, showing methods of reducing transmission of vibration.

signed for quiet operation. The unit is resiliently isolated by a rubber gasket from the cabinet in which it is set. The cabinet is lined with a sound-absorptive material. The disposer housing is isolated from the sink by rubber gasketing. It is also isolated from the waste line by a rubber sleeve.

Figure 5.6 shows the design and installation of a washing machine for quiet operation. Neoprene pads are under each of the legs to reduce the transmission of solidborne noise to the building structure. Adjustable leveling screws are used to prevent the unit from wobbling. The housing of the washing machine has been treated with a vibration-damping material to reduce noise output. Rubber hose connects the unit to the water supply.

REFERENCES

1. National Association of Plumbing, Heating and Cooling Contractors (NAPHCC), 1016 20th Street, N.W., Washington, DC 20036.
2. American Society of Plumbing Engineers (ASPE), 15233 Ventura Blvd., Sherman Oaks, CA 91403.
3. American National Standards Institute (ANSI), 1430 Broadway, New York, NY 10018.
4. American Society of Mechanical Engineers (ASME), 345 East 47th Street, New York, NY 10017.
5. Air-Conditioning and Refrigeration Institute (ARI), 1501 Wilson Boulevard, Arlington, VA 22209.
6. Association of Home Appliance Manufacturers (AHAM), 20 North Wacker Drive, Chicago, IL 60606.
7. American Society of Sanitary Engineering (ASSE), P.O. Box 9712, Bay Village, OH 44140.

CHAPTER 6

WATER PUMPS

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INTRODUCTION

Pumps are primarily of three types: centrifugal, reciprocating, and rotary. The most common pump used in residential and commercial buildings is the centrifugal type, the subject of this chapter. The other types are used in special industrial applications—for example, reciprocating pumps are used in actuating large forming presses and rotary pumps in transporting viscous liquids.

A *centrifugal pump*, illustrated in Fig. 6.1, is a continuously acting pump that moves liquid by accelerating it radially outward in a rotating member (called an *impeller*) to a surrounding case. The impeller is essentially a rotating disk with vanes attached to it, as shown in Fig. 6.2. Arrows indicate the direction of rotation and the direction of flow. The vanes on the impeller are curved backward, since this shape provides the most stable flow characteristics. This type of pump

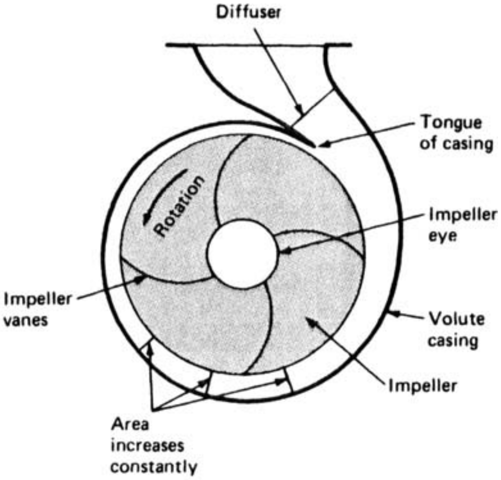

FIG. 6.1 Centrifugal pump.

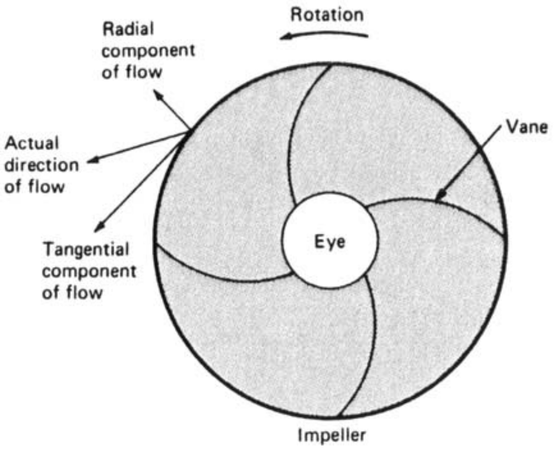

FIG. 6.2 Impeller.

is by far the most common in use in buildings because of its simple construction and relatively low cost.

This chapter describes the different types of centrifugal pumps, how they are constructed, and their performance and efficiency characteristics, applications in buildings, installation, and maintenance. Reference 1 provides extensive detail on pumps and their applications.

PUMP TYPES AND NOMENCLATURE

The types of centrifugal pumps used in buildings are often confusing because such pumps are identified in a number of different ways, according to (*a*) the internal design, (*b*) single-suction vs. double-suction configuration, (*c*) the shape of the impeller and its operating characteristics, (*d*) the casing design, (*e*) the type of connection between the motor and pump, (*f*) the position of the pump in relation to the water being pumped, and (*g*) the number of stages of the pump.

Internal Design

The *casing* of a pump is the housing that encloses the impeller and collects the liquid being pumped. The liquid enters at the *eye*, located at the center, of the impeller. It is the impeller that imparts energy to the liquid. After being rotated by the *vanes* on the impeller, the liquid is discharged with a greatly increased velocity at the periphery, where it is guided to the discharge nozzle through a spiral-shaped passage called a *volute*. This shape is designed to result in an equal flow velocity at all points around the circumference.

Single-Suction vs. Double-Suction Configuration

The *single-suction* pump, illustrated in Fig. 6.3, has a spiral-shape casing and is

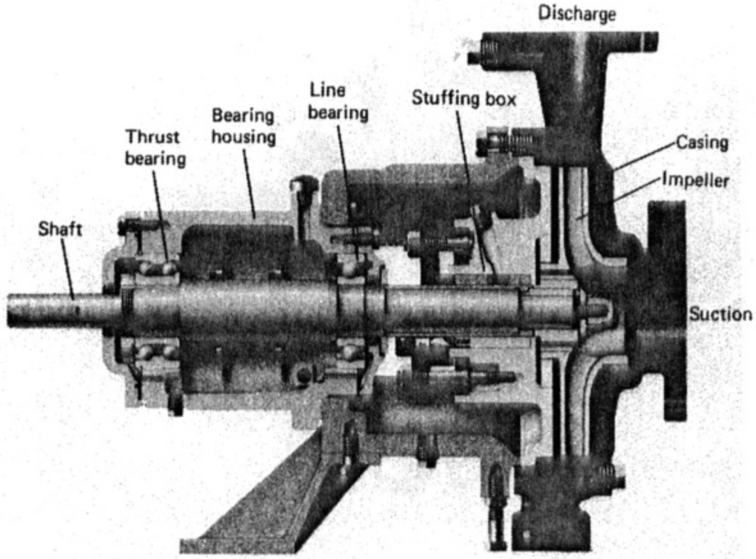

FIG. 6.3 Single-suction, radial-split, overhung impeller pump. (*Courtesy of Dresser Pump.*)

most commonly used. The water enters the impeller from only one side. In the *double-suction pump,* illustrated in Fig. 6.4, the water enters both sides of the *double-suction impeller* so that hydraulic unbalance is practically eliminated. Since only half the flow enters each side of the impeller, problems with inlet design of higher-flow pumps are somewhat relieved. The impeller is usually mounted between two bearings, and the casing is split axially (see "Casing Design," below) to permit convenient servicing of the pump.

Shape of the Impeller

Impellers are curved to minimize the shock losses of flow in the liquid as it moves from the eye to the shrouds, which are disks that enclose the impeller vanes. If an impeller has no shrouds, as shown in Fig. 6.5, it is called an *open impeller,* this type usually is used where the water being pumped contains suspended solids. If an impeller has two shrouds, it is called a *closed impeller*; it requires little maintenance and usually retains its operating efficiency longer than open impellers. If the impeller has one shroud, it is called a *semiopen impeller.*

Casing Design

Casing are typed as radially split or axially split. The axially split casing illustrated in Fig. 6.4 is one that is split parallel to the shaft axis so that the pump may be opened without disturbing the system piping, which makes it convenient to service. Radially split casings, illustrated in Fig. 6.3, are split perpendicular to the shaft axis, resulting in a simpler joint design.

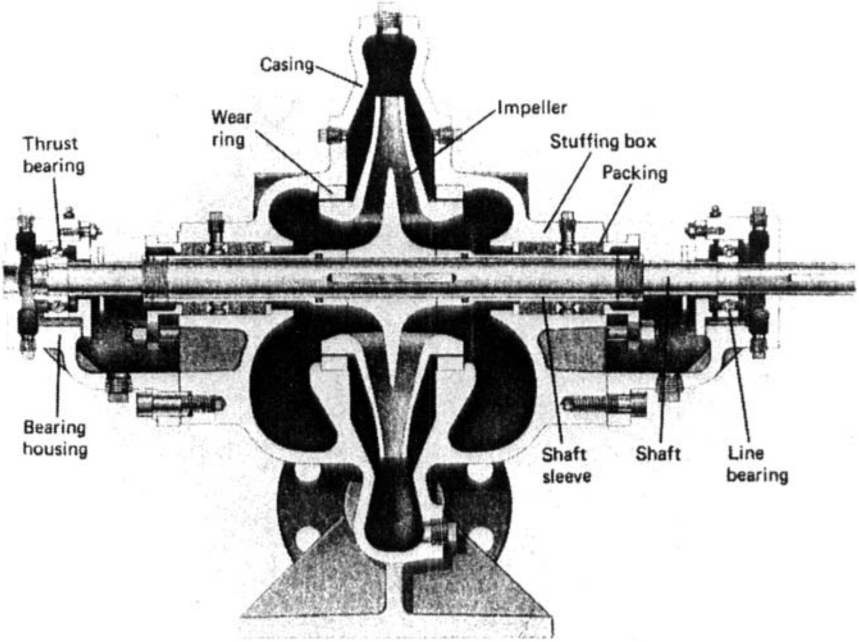

FIG. 6.4 Double-suction, axial-split, between-bearing pump. *(Courtesy of Dresser Pump.)*

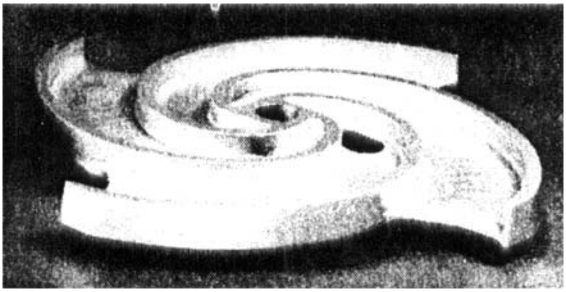

FIG. 6.5 Open impeller.

Type of Connection between Motor and Pump

A *separately coupled pump* is one in which the electric motor drive is connected to the pump by means of a flexible coupling. Both pump and motor are mounted on a structural baseplate to provide support and maintain shaft alignment.

A *close-coupled pump* is one in which the same shaft is used for both the motor and pump. This construction results in low initial cost and installation cost and avoids alignment problems. It may also result in motor noise being transmitted to the pump and piping.

A *motor-face-mounted pump* is one in which the pump is separately coupled with a face-mounted motor. This arrangement substitutes a structural connection between the pump and motor. It eliminates the need for a structural baseplate and minimizes coupling alignment problems.

Support of the Pump

Horizontal dry-pit support is one where the pump is located with the shaft in a horizontal position in a dry location such as a basement floor or even a special pit constructed for the pump. The pump assembly is supported by the floor, and the structural baseplate is usually grouted to the floor. This is the most common support arrangement.

In-line pumps are supported directly by the system piping; i.e., the piping carries the weight of the pump. The pump-motor assembly is usually mounted vertically in order to save floor space and center the weight over the piping. Some smaller pumps may hang horizontally from the piping, and some larger vertically mounted pumps may also rest on the floor.

Wet-pit pumps are those which are immersed in the liquid to be pumped. This is most common with sump pumps where the pumping end is immersed in the liquid in the sump. The pump may be supported on the floor of the sump, or it may be suspended from a structural floor above the sump.

Bearing Support

Shaft support is usually provided by ball bearings which are lubricated by grease or oil. Some types of pumps, such as submersible pumps (described below), depend on the liquid being pumped to lubricate the bearings. In such pumps, sleeve or journal bearings are used.

A *between-bearing pump* is a centrifugal pump whose impeller is supported by bearings on each side, as shown in Fig. 6.4. This design is usually built with a double-suction impeller and with the casing split in the axial direction so that the top can be lifted off and the rotating element removed.

An *overhung impeller pump* is a centrifugal pump that has the impeller mounted on the end of a shaft that overhangs its bearings as shown in Fig. 6.3. In-line circulating pumps are of this type.

Single-Stage vs. Multistage Pumps

A *single-stage* pump is one which has only one impeller. The total head is developed by the pump in one stage.

A *multistage* pump is one which has two or more impellers. The total head is developed in multiple stages.

Vertical turbine pumps are a unique type of multistage pump. They are designed primarily to pump water from deep wells and are long and slender.

CENTRIFUGAL PUMP CONSTRUCTION

Materials

Centrifugal pumps used for most building services are built with cast-iron casings, bronze impellers, and bronze small parts. Stainless-steel impellers and stainless-steel small parts also are common. Cast-iron impellers may be used, but the life of a cast-iron impeller is shorter than that of a bronze or stainless-steel impeller. Reference 2 has extensive tables on appropriate materials for pumping different types of liquids.

Shafts, Seals, and Bearings

The shaft used to drive the impeller of the pump enters the casing through an opening that must be sealed to prevent leakage around the shaft; i.e., the seal must prevent liquid from leaving and air from entering. Two types of seals are used: soft fiber packing and mechanical face seals. Where packing is used, the shaft enters the opening through a *stuffing box*. Liquid is prevented from leaking out by filling this opening with a soft fiber packing. The packing material, which is relatively inexpensive, can usually be replaced without disassembling the pump. However, the packing will leak about 60 drops per minute and requires periodic adjustment. Mechanical seals are commonly used instead of packing because they are reliable, have good life expectancy, are practically leak-free, and do not require periodic adjustment.

PUMP CHARACTERISTICS

Capacity

The *capacity* Q of a pump is the rate of flow of liquid through the impeller expressed in gallons per minute, gpm (cubic meters per hour, m^3/h).

Total Head

Head h is the energy per unit weight of a fluid due to (*a*) its *pressure head* h_p, (*b*) its *velocity head* h_v, and (*c*) its *elevation head* Z above some datum. It is commonly expressed as the height of a column of water in feet (or meters) which is necessary to develop a specific pressure. The *total head* developed by a pump is equal to the discharge head h_d minus the suction head h_s. The *discharge head* is the energy per unit weight of fluid on the discharge side of the pump. The *suction head* is the energy per unit weight on the suction side of the pump. According to these definitions:

$$\text{Discharge head} \qquad h_d = h_{pd} + h_{vd} + Z_d \qquad \text{ft (m)} \tag{6.1}$$

$$\text{Suction head} \qquad h_s = h_{ps} + h_{vd} + Z_s \qquad \text{ft (m)} \tag{6.2}$$

Therefore, by definition, the total head H is equal to the difference between Eqs. (6.1) and (6.2); i.e.,

$$\text{Total head} \qquad H = h_d - h_s \qquad \text{ft (m)} \tag{6.3}$$

Therefore,

$$H = h_{pd} + h_{vd} + Z_d - h_{ps} - h_{vs} - Z_s \qquad \text{ft (m)} \tag{6.4}$$

If there is some distance between the points of measurement of the discharge head and the suction head, there will be a *friction loss head* h_f that must be added to Eq. (6.4); i.e.,

$$H = h_{pd} + h_{vd} + Z_d - h_{ps} - h_{vs} - Z_s + h_f \qquad \text{ft (m)} \qquad (6.5)$$

Values of h_f in pipes and fittings can be determined from data given in several handbooks. Reference 3 is recommended.

The *pressure head* h_p is given by

$$h_p = \frac{p}{\gamma} \qquad \text{ft} \qquad (6.6)$$

where p = pressure in pounds per square foot and γ = specific weight of the liquid in pounds per cubic foot.

In the metric system h_p is given by

$$h_p = \frac{p}{\gamma} \qquad \text{m} \qquad (6.6a)$$

where p = pressure in newtons per square meter, or pascals, and γ = specific weight of the liquid in newtons per cubic meter.

The *velocity head* h_v is given by

$$h_v = \frac{V^2}{2g} \qquad \text{ft} \qquad (6.7)$$

where V = velocity of flow in feet per second and g = acceleration of gravity in feet per second per second.

In the metric system h_v is equal to

$$h_v = \frac{V^2}{2g} \qquad \text{m} \qquad (6.7a)$$

where V = velocity in meters per second and g = acceleration of gravity in meters per second per second.

The *static head* Z is the static elevation measured in feet (meters) at the same point where the pressure is measured. Note that if a pressure gage is used, the center of the gage is the measurement point for the static head. The centerline of the pump impeller is usually used as the reference point for such measurements.

The symbols and units used in this section are the same as those used by the Hydraulic Institute and published in Ref. 2.

Input Power

The *input power* or *brake horsepower* P_p required to drive such a pump also varies with capacity, as shown in Fig. 6.6.

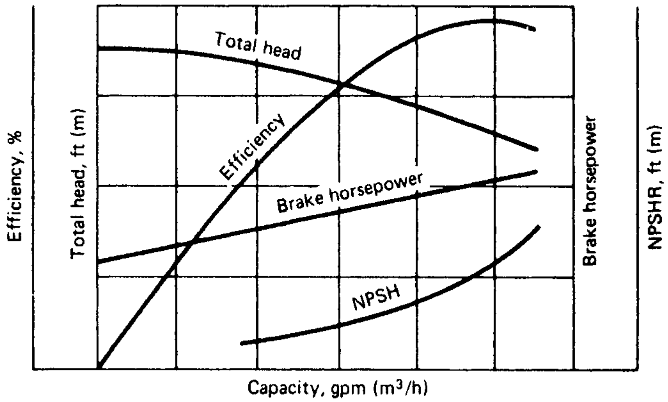

FIG. 6.6 Centrifugal pump performance characteristics.

Output Power

The pump *output power* or *water horsepower* P_w is given by

$$P_w = \frac{Q \times H \times S}{3960} \quad \text{hp} \tag{6.8}$$

where Q = capacity of the pump, gpm
H = total head, ft
S = specific gravity of liquid pumped

In the metric system, the pump output power is given by

$$P_w = \frac{Q \times H \times S}{367} \quad \text{kw} \tag{6.8a}$$

where Q = capacity of the pump, m^3/h
H = total head, m
S = specific gravity of liquid pumped

Efficiency

The *efficiency* in percent with which the pump operates is the ratio of the output power to the input power multiplied by 100. It is given by

$$\text{Pump efficiency} = \frac{P_w}{P_p} \times 100 \tag{6.9}$$

Efficiency varies with capacity, as shown in Fig. 6.6, reaching a maximum value at one capacity where the sum of all losses is a minimum.

Net Positive Suction Head

Net positive suction head (NPSH) is the total suction head in feet (meters) of liquid in absolute pressure terms determined at the pump impeller, minus the vapor pressure of the liquid in feet (meters). The net positive suction head required (NPSHR) by the pump is determined by test and is the NPSH value at which the pump total head has decreased by 3 percent because of low suction head and resulting cavitation within the pump. In multistage pumps, the 3 percent head reduction refers to the first stage head. As illustrated in Fig. 6.6, the NPSHR increases with capacity.

Speed

Usually a centrifugal pump is driven by a constant-speed electric motor. However, it is more efficient to control a pump by a variable-speed drive. The extra cost of variable-speed drives can be justified by the resultant savings in electric power.

Centrifugal pump characteristics vary with speed according to the following relationships:

$$\text{Capacity} \qquad Q_2 = Q_1 \times \frac{N_2}{N_1} \tag{6.10}$$

$$\text{Total head} \qquad H_2 = H_1\left(\frac{N_2}{N_1}\right)^2 \tag{6.11}$$

$$\text{Input power} \qquad P_2 = P_1\left(\frac{N_2}{N_1}\right)^3 \tag{6.12}$$

where N_1 = initial rotating speed, rpm
N_2 = second rotating speed, rpm
Q_1 = capacity at N_1, gpm (m^3/h)
Q_2 = capacity at N_2, gpm (m^3/h)
H_1 = total head at N_1, ft (m)
H_2 = total head at N_2, ft (m)
P_1 = input power at N_1, hp (kW)
P_2 = input power at N_2, hp (kW)

The total head vs. capacity characteristics for a typical pump at several different speeds are illustrated in Fig. 6.7.

System Head Curve

In order to move liquid through any system of pipes, the pump must produce a total head equal to or greater than the total head required by the system. The system head usually increases with flow rate, and if plotted vs. capacity, it is called the *system head curve*.

The shape of the *system head curve* is an important consideration in the proper selection of a pump in building services. The total head required to pump

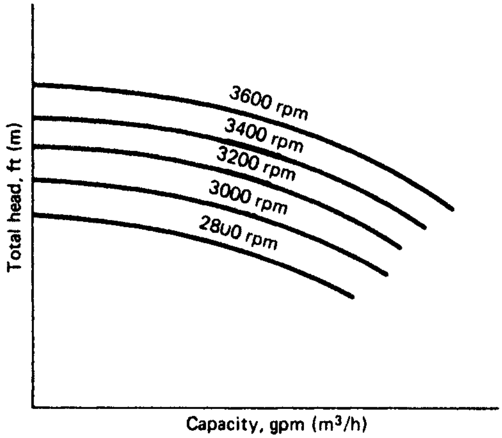

FIG. 6.7 Variable-speed pump curve.

liquid through a system is the sum of the static head and the head due to friction loss in the system. For example, to pump water to the top of a 50-ft (15-m) building, the total head required is 50 ft (15 m) plus some friction loss. If the friction loss at the required flow is equivalent to a head of 10 ft (3 m), the total head required is 60 ft (18 m). When the flow is zero, there is no friction loss so the total head required is only 50 ft (15 m). As the head due to friction loss gradually increases, the total head required as a function of capacity looks like curve 1 in Fig. 6.8. In circulating water systems where overcoming friction is the principal concern, the system head curve for 60 ft (18 m) total head looks like curve 2 in Fig. 6.8.

If a typical *pump characteristic curve* from Fig. 6.6 is combined with either of the above system head curves, a result such as that shown in Fig. 6.9 is obtained.

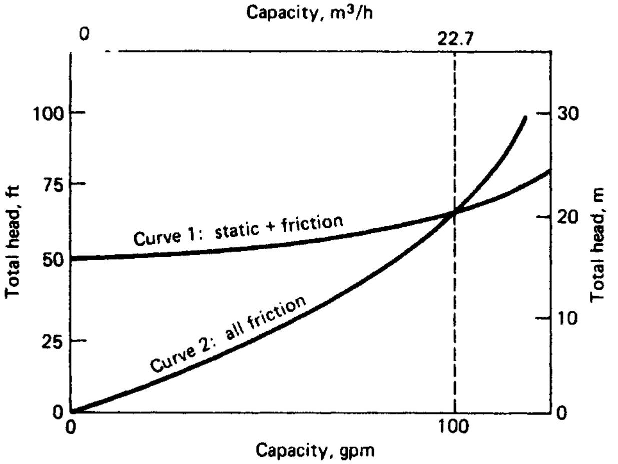

FIG. 6.8 System head curves.

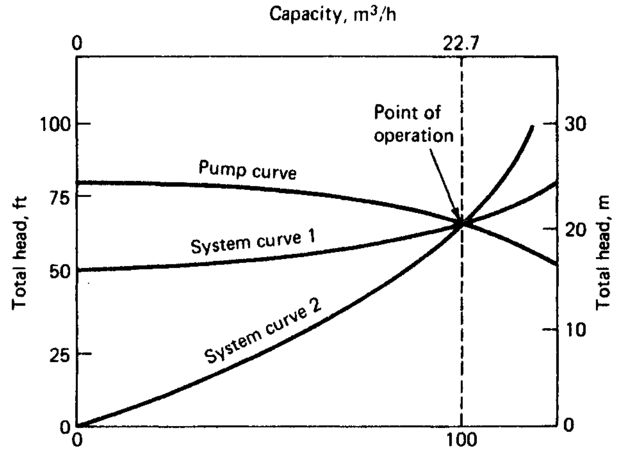

FIG. 6.9 Pump curve plus system head curve.

The pump will operate where the pump curve intersects with the system head curve; at this point the full flow required will be pumped.

Because the pump is subject to wear, the total head output is reduced. As a result, there is a reduction in flow. However, note that the reduction is greater when there is a high static head than when the head is due only to friction losses. Hence, it is important that the system head curve and pump characteristic curve be compared at the time of pump selection to ensure that a 10 percent reduction in pump output, due to wear, does not result in a significant reduction in flow rate.

Pump Efficiency

Centrifugal pumps are more efficient at high flow rates and moderate heads than at low flow rates and high heads. Figure 6.10 shows a chart of total head vs. capacity. The chart is divided into four regions indicating the type of centrifugal pump required to provide good efficiency:

Region 1. In this region, pumps, including many single-stage pumps that are used in building applications, operate efficiently and at low cost at 3600 rpm.

Region 2. In this region, where pump capacities may exceed 1000 gpm (225 m^3/h), single-stage pumps are efficient, but the pump operating speeds must be less than 3600 rpm because of limitations of performance on the suction side of the impeller.

Region 3. In this region, where the total head has a high value, single-stage pumps operating at 3600 rpm are inefficient. Here multistage pumps are commonly used, but single-stage pumps with gear drives or variable frequency drives, operating at high speeds (up to 20,000 rpm), are sometimes used.

Region 4. In this region, where the capacity is very low, small multistage pumps with as many as 20 stages may be required.

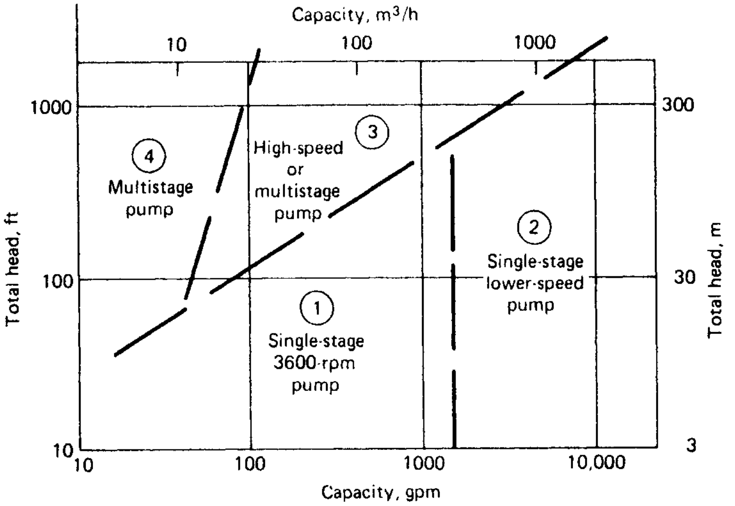

FIG. 6.10 Pump type selection chart.

To use this chart, simply plot the capacity and total head required and the chart will indicate the type of pump most suitable for the application. For example, if the required capacity is 50 gpm (11 m^3/h) at a total head of 500 ft (152 m), the condition point is in Region 4 and a multistage pump is most efficient.

PUMP APPLICATIONS IN BUILDINGS

Booster Pumps

A *booster pump* is a pump used to increase the pressure in a water supply line. Water usually is supplied by most utility water companies at a pressure of 75 psig (500 kPa). This is adequate for most relatively low buildings but is inadequate for buildings of 5 to 10 stories or higher. To provide additional pressure, one or more booster pumps may be required as described in Chap. 4. Booster pumps require no special design features; most of those described in this chapter can be used if properly selected for head and capacity. On the other hand, the capacity demand on such pumps may vary from a daytime maximum to a nighttime low of practically nothing. Such operation wastes power and causes rapid wear in pumps. For these reasons, water reserve tanks on the roof of the building or tanks under air pressure should be used to even out demand as described in Chap. 4. A pressure switch and check valve should be used to shut down the booster pump automatically when it is not required.

Pumps for Circulating Hot and Cold Water

Central heating and air-conditioning systems may require the circulation of hot or cold water for space heating or cooling. In such applications, quiet operation of the circulator pump is important. Pump noise can be carried through the piping system and be a source of disturbance in quiet rooms some distance away. To minimize noise generation, besides implementing other noise control measures, the rotational speed of the pump is often limited to 1800 rpm. It is also helpful to select a pump that provides wide clearance between the impeller and casing volute tongue, with a minimum value of 15 percent of the impeller radius, since this will minimize hydraulic pulsations and therefore the generation of noise.

For water circulation systems, an in-line circulator pump is usually used. These pumps are generally operated at low speeds with a very flexible coupling between the pump and motor and cushioned motor mountings to minimize the transmission of motor noise to the circulation system.

The circulation of water in high-rise buildings sometimes presents problems because a high-pressure system may be required to accommodate the height of the vertical pipes. Steel pump casings may be required to withstand the high system pressure; care must be taken to ensure that mechanical seals also can withstand these pressures, particularly in hot-water systems.

A high-pressure hot-water system is difficult to seal because the hot water turns to steam between the seal faces, thereby eliminating any lubricating or cooling action. As a result, the seal faces wear quickly.

Fire Pumps

Fire pumps are designed for connection to automatic sprinkler systems; they are rarely, if ever, used. However, they are usually turned on periodically for a short time to ensure their proper operation if needed. Most fire insurance companies require that pumps be certified by Underwriters Laboratories, Inc., or Factory Mutual Research Corporation to show that they meet the requirements for fire pump service. The horizontal axial-split, double-suction pump, Fig. 6.4, is most commonly used. However, in some smaller sprinkler systems, the end suction pump, illustrated in Fig. 6.3, is used. For sprinkler systems that use well water as a source of supply, vertical turbine pumps are available.

All fire pumps are certified by Underwriters Laboratories, Inc., or Factory Mutual Engineering and Research Corporations for a specific capacity in gallons per minute and total head in pounds per square inch gage and carry a special nameplate to that effect.[4]

Sewage Service and Sump Pumps

A *sump* is a tank or pit, located below the normal grade of the gravity system that receives and temporarily stores sewage or liquid waste, and is emptied by means of a pump called a *sump pump* or *sewage pump*.

Sewage pumps are centrifugal pumps of special design, having impellers that can pump large pieces of solid matter without clogging. Even the smallest pumps of this type are subject to the requirement that the impeller pass a sphere 2.5 in (6.4 cm) in diameter. In addition to wide impellers, handholes are provided in the pump casing for access to remove obstacles that may lodge in the pump. Such a pump usually is mounted vertically to save floor space in the confined area of a sump. This arrangement raises the motor relatively high so that it is protected in the event of flooding of the sump. Many installations purposely raise the motor even higher with an extended drive shaft.

Other installations include the vertical sump pump of the volute type. If used for handling sanitary sewage, the impeller of such a pump must have the same solids-handling capability described above. If the pump is used to remove storm drainage and other runoff water, a more conventional impeller can be used. In either case, the design and lubrication of the lower support bearing is of paramount importance since this bearing is the weakest component in the structure. A hard shaft sleeve which runs in a wear-resistant material is important. It will prolong the life of the pump if this bearing is flushed periodically with an independent source of clean water.

Submersible pumps are frequently used in sewage and sump application. A *submersible pump* is usually of close-coupled construction with the electric motor protected by a waterproof housing that permits the pump and motor to be submerged in the liquid to be pumped. Such a pump may be mounted on a slide rail to permit removal from the sump for service with a minimum of effort. The pressure connection between the casing and the piping is designed for automatic release when the pump is removed from the sump.

Vertical sump pumps are mounted to the floor above the sump. A rigid floor supporting the pump is extremely important to avoid vibration problems. The floor should have a natural frequency of vibration well above the operating speed of the pump.

Pump Installation

The pump manufacturer's instruction manual is the first place to refer to for information on the proper installation of a centrifugal pump. The Hydraulic Institute standards[2] provide much helpful information on this subject. Experience has shown that the most critical steps in any installation include the following:

- Rigidly support the foundation of a pump. This is particularly important with vertically mounted pumps, which are more likely to vibrate excessively because of resonance with relatively flimsy supports.
- Minimize piping strain where practical. Pumps should not be used as pipe hangers or supports. Excessive forces on pumps from expanding or heavy pipes should be avoided.
- Accurately align the pump and drive shaft to minimize vibration and load on pump and motor bearings.
- Ensure that the inlet piping is relatively straight where it is connected to the pump so that flow entering the impeller is uniform.
- Avoid water hammer (described in Chap. 11) by avoiding control valves or check valves which quickly stop the flow of water, thereby creating a surge in pressure.

When noise and vibration are of particular concern, it is best to install pumps on an inertia block which is in turn mounted on vibration isolators. Such arrangements are described in Ref. 5.

Centrifugal Pump Operation

Centrifugal pumps are usually designed to operate continuously without problems for at least 5 years. Proper lubrication of bearings and adjustment of stuffing box packing at regular intervals are important. It is also common to replace mechanical seals regularly. In addition, to ensure proper operation of the pump,

- *Operate the pump as closely as possible to its point of highest efficiency.* When pumps operate below 50 percent of this value, recirculating flow within the impeller can result in cavitation and excessive forces on the shaft and bearings, causing damage.
- *Avoid pumping abrasive solids.* Most centrifugal pumps are not designed to handle liquid with abrasive solids. Although this is generally not a problem in building services, sump pumps may collect dirt with water runoff. Therefore a settling chamber upstream of the sump pump is helpful.
- *Provide sufficient NPSH margin.* The value of net positive suction head required by the pump is indicated by the pump manufacturer. This value is based on a pump test with some cavitation occurring. Experience shows that to avoid cavitation, about 5 times this value may be required. However, if the output power of a pump is below 300 hp (400 kW), an NPSH value equal to the NPSH required by the pump will usually result in satisfactory pump life.

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CHAPTER 7

SIZING A WATER SUPPLY SYSTEM

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DESIGN OBJECTIVES

The most important design objective in sizing the water supply system is the satisfactory supply of potable water to all fixtures, at all times, and at proper pressure and flow rate for normal fixture operation. This may be achieved only if adequate sizes of pipes and appurtenances are provided. The sizes established must be large enough to prevent occurrence of negative pressures in any part of the system during periods of peak demand in order to avoid the hazard of water supply contamination due to backflow and backsiphonage from potential sources of pollution. Hence, the sizing of building water supply systems is a matter of vital concern in protecting health and must be regulated by codes.

Other important objectives in the design of water supply systems are: (*a*) to achieve economical sizing of piping and eliminate overdesign; (*b*) to provide against potential supply failure due to gradual reduction of pipe bore with the passing of time, such as may result from deposits of corrosion or hard-water scale in the piping; (*c*) to avoid erosion-corrosion effects and potential pipe failure or leakage conditions owing to corrosive characteristics of the water and/or to excessive design velocities of flow; and (*d*) to eliminate water hammer damage and objectionable whistling noise effects in the piping due to excessive design velocities of flow.

DESIGN FOR MINIMUM AVAILABLE PRESSURE

The water supply system should be designed in accordance with the minimum pressure available at the public water main, or other source of water supply pressure, and the minimum pressure required at all times at water outlets of the system. Where the pressure available at the public main is insufficient to maintain the minimum required at the highest water outlet of the system, a pressure-booster pump system, approved as to capacity and reliability, or an automatically controlled water supply tank of either the hydropneumatic pressure type or the elevated gravity type should be provided. Such methods are described in Chap. 4.

As a general rule, the minimum pressure required at ordinary faucets of plumbing fixtures is 8 psi (55 kPa). However, at direct-supply-connected flush valves (flushometers), the minimum is 25 psi (172 kPa) for blowout-type water closets and 15 psi (103 kPa) for other types of fixtures. At electrically operated supply valves of equipment, where higher than ordinary pressure frequently is recommended, the minimum should be that suggested by the manufacturer for satisfactory equipment performance.

PRELIMINARY INFORMATION REQUIRED FOR SIZING A SYSTEM

At the outset, obtain all information necessary for establishing a proper basis for sizing the building water supply system. The appropriateness of the basis for sizing depends on the accuracy and reliability of the information applied. Thus, such information should be obtained from responsible parties and appropriate authorities.

The kinds of piping materials to be installed in the system should be determined. This is a matter of selection by the owner of the building or an authorized representative, who may be the architect, engineer, or contractor.

Characteristics of the Water Supply

The corrosivity of a given water supply with respect to various kinds of piping materials, and its scale-forming tendency, is information which most officials, architects, engineers, and contractors in a water district normally have at their fingertips as a result of years of experience. For anyone without such experience and knowledge, the significant characteristics which may be applied to indicate the water supply's corrosivity and scale-forming tendency are its pH value, CO_2 content, dissolved air content, carbonate hardness, Langelier index, and Ryznar index. The most appropriate source of such information is the local water authority having jurisdiction over the system supplying the water, or over the wells from which water is pumped from the underground water table.

Location and Size of Water Supply Source

The location and size of the public water main, where available, should be obtained from the local water authority. Where a private water supply source, such as a private well system, is to be used, the location and size as designed for the premises should be applied.

Developed Length of System

The *developed length* of a piping system is the length taken along the centerline of the pipe and fittings. Information should be obtained regarding the developed length of the piping run from the source of water supply to the service control valve of the building, i.e., the developed length of the water service pipe as shown on the plans. Also determine the developed length of the piping run from the service control valve to the highest and the most remote water outlets on the system. This may be established by measurement of the piping run on plans of the system.

Pressure Data Relative to Source of Supply

Data as to pressure available in the public water main should be obtained from the local authority having jurisdiction over the public system. Maximum and minimum pressures available in the public main at all times should be obtained from that authority, as it is the only one recognized as the source of accurate and reliable information on this subject. Where a private well water supply system is to be used, the maximum and minimum pressures at which it will be adjusted to operate may be applied as appropriate in such cases.

Elevations

The relative elevations of the source of water supply and the highest water supply outlets to be supplied in the building must be determined. In the case of a public water main, the elevation of the point where the water service connection is to be made to the public main should be obtained from the local water authority. It has the most authoritative record of elevations of the various parts of the public system, and such elevations are generally referred to datum as the reference level, and related to curb levels established for streets. Elevation of the curb level directly in front of the building should be obtained from the building plans, as such information is required to be shown on the building site plans. Elevations of each floor at which fixtures are to be supplied may be determined also from the building plans.

Minimum Pressure Required at Highest Water Outlets

Information regarding the minimum pressure required at the highest water outlets for adequate, normal flow conditions, consistent with satisfactory fixture usage and equipment function, may be deemed to be as follows: 8 psi (55 kPa) for all water supply outlets at common plumbing fixtures, except for direct-supply flush valves at which the minimum required flow pressure should be considered to be 15 psi (103 kPa) for supplying floor-outlet-type water closets and urinals, and as 25 psi (172 kPa) for supplying wall-hung siphon-jet or blowout-type water closets. For other types of water-supplied equipment, the minimum flow pressure required should be obtained from the manufacturer.

Provision of Necessary Information on Plans

Information necessary for establishing a proper basis for designing sizes of water supply piping should be provided on plans of the water supply system when submitted to plumbing plan examiners for proposed installations. Provision of such information permits the examiner to check easily and efficiently the adequacy of sizes proposed for the various parts of the building water supply system.

FRICTION LOSSES IN THE PIPING SYSTEM

Friction in the building water supply system must be limited so that the highest water outlets on the system will have available during periods of peak demand at least the minimum pressure required at such outlets for satisfactory water supply conditions.

Maximum Permissible Friction Loss

The limit to which pressure loss due to friction may be permitted to occur in the main water lines and risers supplying the highest water outlets during peak demand periods is the amount of static pressure available in excess of the minimum pressure required at such outlets when no-flow conditions exist. This may be calculated as the difference between the static pressure existing at the highest water outlets during no-flow conditions and the minimum pressure required at such outlets for satisfactory supply conditions.

To calculate the static pressure at the highest outlet, where water is supplied from a public main, deduct from the certified minimum pressure available in the public main the amount of static pressure loss corresponding to the height at which the outlet is located above the public main; i.e., deduct 0.433 psi pressure for each foot (or 9.79 kPa/m) of rise in elevation from the public main to the highest outlet.

Where water is supplied under pressure from a gravity water supply tank located at an elevation above the highest water outlet, the static pressure at that outlet is calculated as being equal to 0.433 psi for each foot (or 9.79 kPa/m) difference in elevation between the outlet and the water line in the tank. In this case, the minimum static pressure at the outlet should be determined as that corresponding to the level of the low-water line at which the tank is designed to operate.

Where water is supplied under pressure from a pressure-booster pump system, to calculate the static pressure at the highest outlet, deduct from the minimum pressure designed to be maintained at all times at the pump outlet the amount of static pressure loss corresponding to the height at which the highest outlet is located above the level of the pump outlet, i.e., deduct 0.433 psi pressure for each foot (or 9.79 kPa/m) of rise in elevation from the pump outlet to the highest water outlet.

Friction Loss in Equipment

Where a water meter, water filter, water softener, fish trap or strainer, or instantaneous or tankless hot-water heating coil is provided in the basic design circuit, the friction loss corresponding to the peak demand through such equipment must be determined and included in pressure loss calculations. Manufacturers' charts and data sheets on their products provide such information generally, and should be used as a guide in selecting the most appropriate type and size of equipment to use with consideration for the limit to which pressure loss due to friction may be permitted to occur in the basic design circuit. The rated pressure loss through such equipment should be deducted from the friction loss limit so as to establish the amount of pressure which may be permitted to be dissipated by friction in pipe, valves, and fittings of the basic design circuit.

Pressure Loss in Displacement-Type Cold-Water Meters

The American Water Works Association standard for cold-water meters of the displacement type is designated AWWA C700-71. It covers displacement meters known as nutating- or oscillating-piston or disk meters, which are practically positive in action. This standard establishes maximum capacity for each meter size and also the maximum pressure losses corresponding to the stated maximum capacities. These values are given in Table 7.1.

TABLE 7.1 Maximum Capacities of Displacement-Type Cold-Water Meters and Corresponding Maximum Pressure Losses*

Meter size, in (cm)	Maximum capacity, gpm (L/s)	Maximum pressure loss, psi (kPa)
⅝ (1.59)	20 (1.3)	15 (103)
¾ (1.9)	30 (1.9)	15 (103)
1 (2.54)	50 (3.1)	15 (103)
1½ (3.81)	100 (6.3)	20 (138)
2 (5.0)	160 (10.1)	20 (138)
3 (7.5)	300 (18.9)	20 (138)
4 (10.0)	500 (31.5)	20 (138)
6 (15.0)	1000 (63)	20 (138)

*Standard AWWA C700-71, American Water Works Association, Denver, CO 80235.

Minimum Size of Fixture Supply Pipes

The diameters of fixture supply pipes should not be less than sizes shown in Table 7.2. The fixture supply pipe should terminate not more than 30 in (762 mm) from the point of connection to the fixture; in every case it must extend into the room through the floor or wall adjacent to the fixture.

Basic Design Circuit

Of the highest water outlets on a system, the one at which the least available pressure will prevail during periods of peak demand is that outlet which is supplied through the longest run of piping extending from the pressure source of water supply, as a general rule. As pipe friction loss is directly proportional to length of piping, the most extreme run of piping from the pressure source of water sup-

TABLE 7.2 Minimum Size of Fixture Supply Pipes

Fixture or device	Size in	Size cm
Bathtub	½	1.27
Combination sink and laundry tray	½	1.27
Drinking fountain	⅜	0.95
Dishwashing machine (domestic)	½	1.27
Kitchen sink (domestic)	½	1.27
Kitchen sink (commercial)	¾	1.90
Lavatory	⅜	0.95
Laundry tray (1, 2, or 3 compartments)	½	1.27
Shower (single head)	½	1.27
Sink (service, slop)	½	1.27
Sink (flushing rim)	¾	1.90
Urinal [1 in (2.54 cm) flush valve]	1	2.54
Urinal [¾ in (1.9 cm) flush valve]	¾	1.90
Urinal (flush tank)	½	1.27
Water closet (flush tank)	⅜	0.95
Water closet (flush valve)	1	2.54
Hose bib	½	1.27
Wall hydrant or sill cock	½	1.27

Note: For fixtures not listed in the above table, the minimum size of fixture supply pipes shall be the same as given in the table for comparable fixtures.

ply to the highest outlets on the system should be designated as the "basic design circuit" (BDC) for sizing the main water lines and risers in accordance with the limit to which pressure loss due to friction may be permitted to occur therein. In most systems, the basic design circuit may consist of the run of cold-water supply piping extending from the pressure source of water supply to the domestic hot-water heating unit, and the run of hot-water supply piping therefrom to the highest and most remote hot-water outlet on the system. However, in systems having flush valve (flushometer) supplied water closets at the topmost floor, the basic design circuit may be found to be the run of cold-water supply piping extending from the pressure source of water supply to the highest and most remote flush valve on the system.

Equivalent Length of Piping

The total equivalent length of piping is its developed length plus the equivalent pipe length corresponding to the frictional resistance of all fittings and valves in the piping run. When sizes of fittings are known or have been established by sizing based upon appropriate limitation of velocity, corresponding equivalent lengths may be determined directly from available tables. In general, the equivalent length for fittings and valves is approximately 50 percent of the developed length of the basic design circuit in the case of copper water-tube systems and approximately 85 percent for standard threaded-pipe systems.

LIMITATION OF VELOCITY

Consideration of Velocity in Design

Velocity of flow through water supply piping during periods of peak demand is an important factor to consider in the design of building water supply systems. Limitation of water velocity should be observed in order to avoid objectionable noise effects in systems; shock damage to piping, equipment, tanks, coils, and joints; and accelerated deterioration and eventual failure of piping from erosion-corrosion.

Good Engineering Practice

In accordance with good engineering practice, it is recommended that maximum velocity in water supply piping be limited to no more than 8 ft/s (2.4 m/s). This is deemed essential in order to avoid such objectionable effects as the production of whistling line noise, the occurrence of cavitation, and associated excessive noise in fittings and valves.

It is also recommended that maximum velocity be limited to no more than 4 ft/s (1.2 m/s) in branch piping from mains, headers, and risers to water outlets at which the supply is controlled by means of quick-closing devices such as an automatic flush valve, solenoid valve, or pneumatic valve, or a quick-closing valve or faucet of the self-closing, push-pull, push-button, or other similar type. This limitation is deemed necessary in order to avoid development of excessive and damaging shock pressures in the piping and equipment when flow is suddenly shut off. Many items of plumbing equipment and systems are not designed to withstand the very high shock pressures which may occur as the result of sudden cessation of high-velocity flow in piping.

Manufacturers' Recommendations for Avoiding Erosion-Corrosion

Velocity limits recommended by pipe manufacturers to avoid accelerated deterioration of their piping materials due to erosion-corrosion should be observed. Recent research studies have shown that extreme turbulence accompanying high flow velocities is an important factor in causing erosion-corrosion, and that this is especially prone to occur where the water supply has a high carbon dioxide content (i.e., in excess of 10 ppm) and where it has been softened to zero hardness. Another important factor is very high water temperature [i.e., in excess of 150°F (66°C)].

To control erosion-corrosion effects in copper water tube and copper and brass pipe, pipe manufacturers' recommendations are as follows:

1. Where the water supply has a pH value higher than 6.9 and a positive scale-forming tendency, such as may be shown by a positive Langelier index, velocity should be limited to no more than 8 ft/s (2.4 m/s).
2. Where the water supply has a pH value lower than 6.9 and may be classified as aggressively corrosive or where the water supply has been softened to zero hardness by passage through a water softener, velocity should be limited to no more than 4 ft/s (1.2 m/s).
3. The 4 ft/s (1.2 m/s) velocity limit should be applied to all hot-water supply piping conveying water at a temperature above 150°F (65.6°C) because of the accelerated rate of corrosion at such higher temperature.

Recommendations for Minimizing Cost of Pumping

Velocity limitation is generally advisable and recommended in the sizing of inlet and outlet piping for water supply pumps. Frictional losses in such piping affect the cost of pumping, and consequently should be reduced to a reasonable minimum. The general recommendation in this instance is to limit velocity in both inlet and outlet piping for water supply pumps to no more than 4 ft/s (1.2 m/s). This may also be applied advantageously in the case of constant-pressure booster-pump water supply systems.

SIMPLIFIED METHOD FOR SIZING SYSTEMS IN LOW BUILDINGS

The following simplified method for sizing building water supply systems in accordance with demand load, in terms of water supply fixture units, can be applied to at least 95 percent of all residential buildings and a significant percentage of buildings of other types.

In this category are all buildings supplied from a source at which the minimum available water pressure is more than adequate for supplying the highest and most remote fixtures satisfactorily during peak demand, provided the water supply system is sized in accordance with the velocity limitations which should be observed. Included are almost all one- and two-family dwellings, most multiple dwellings up to at least 3 stories in height, and a considerable proportion of commercial and industrial buildings of limited height and area, where supplied from a source at which the minimum available pressure is no less than 40 psi (276 kPa). Under such conditions, the available pressure generally is more than enough for overcoming static head and ordinary pipe friction losses, and pipe friction is not an additional factor to consider in sizing.

Simplified Method Based on Velocity Limitation

This method is based solely on the application of velocity limitations that are (*a*) recognized as good engineering practice; (*b*) authoritative recommendations issued by manufacturers of piping materials regarding proper use of their products in order to achieve durable performance and avoid failure in service, especially in water areas where the supply is aggressively corrosive; and (*c*) general recommendations for minimizing the cost of pumping where water supply pumps are provided.

Step-by-Step Procedure, Simplified Sizing Method

The procedure consists of the following steps.

1. Obtain the following information:
   a. Design basis for sizing
   b. Materials for system
   c. Characteristics of the water supply
   d. Location and size of water supply source
   e. Developed length of system
   f. Pressure data relative to source of supply
   g. Elevations
   h. Minimum pressure required at highest water outlets
2. Provide a schematic elevation of the complete water supply system. Show all piping connections in proper sequence and all fixture supplies. Identify all fixtures and risers by means of appropriate letters, numbers, or combinations thereof. Specially identify all piping conveying water at a temperature above 150°F (66°C), and all branch piping to such water outlets as automatic flush valves, solenoid valves, pneumatic valves, or quick-closing valves or faucets. Provide on the schematic elevation all the necessary information obtained as per Step 1.
3. Mark on the schematic elevation, for each section of the complete system, the hot- and cold-water loads conveyed thereby in terms of water supply fixture units in accordance with Table 2.2.
4. Mark on the schematic elevation, adjacent to all fixture unit notations, the demand in gallons per minute or liters per second corresponding to the various fixture unit loads in accordance with Table 2.3.
5. Mark on the schematic elevation, for appropriate sections of the system, the demand in gallons per minute or liters per second for outlets at which demand is deemed continuous, such as outlets for watering gardens, irrigating lawns, air-conditioning apparatus, refrigeration machines, and other similar equipment using water at a relatively continuous rate during peak demand periods. Add the continuous demand to the demand for intermittently used fixtures, and show the total demand at those sections where both types of demand occur.
6. Size all individual fixture supply pipes to water outlets in accordance with the minimum sizes permitted by regulations. Minimum fixture supply pipe sizes for common plumbing fixtures are given in Table 7.2.
7. Size all other parts of the water supply system in accordance with velocity limitations recognized as good engineering practice, with velocity limitations recommended by pipe manufacturers for avoiding accelerated deterioration and failure of their products under various conditions of service, and with velocity limitations generally recommended for minimizing the cost of pumping where water supply pumps are provided. [Sizing tables (Tables 7.3 to 7.8) based on such velocity limitations and showing permissible loads in terms of

TABLE 7.3a Sizing Table Based on Velocity Limitation—U.S. Customary Units

Galvanized iron and steel pipe, standard pipe size

		Velocity = 4 ft/s				Velocity = 8 ft/s			
Nominal size, in	Actual ID, in	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡
½	0.622	3.8	1.5		8.2	7.6	3.7		31.0
¾	0.824	6.7	3.0		6.0	13.4	8.4		22.5
1	1.049	10.8	6.1		4.6	21.6	25.3	7.7	17.2
1¼	1.380	18.6	17.5	6.0	3.4	37.2	77.3	23.7	12.8
1½	1.610	25.4	37.0	9.3	2.9	50.8	132.3	52.0	10.8
2	2.067	41.8	93.0	29.8	2.2	83.6	293.0	171.6	8.4
2½	2.469	59.8	174.0	75.6	1.8	119.6	477.0	361.0	6.8
3	3.068	92.0	335.0	209.0	1.4	184.0	842.0	806.0	5.4
4	4.026	158.6	688.0	615.0	1.1	317.0	1930.0	1930.0	4.1

*Col. A applies to piping which does not supply flush valves.

†Col. B. applies to piping which supplies flush valves.

‡Friction loss p, corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.3b Sizing Table Based on Velocity Limitation—SI Units

Galvanized iron and steel pipe, standard pipe size

		Velocity = 1.2 m/s				Velocity = 2.4 m/s			
Nominal size, cm	Actual ID, cm	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡
1.27	1.58	0.23	1.5		172.3	0.47	3.7		651.5
1.90	2.09	0.42	3.0		126.1	0.84	8.4		472.8
2.54	2.66	0.68	6.1		96.7	1.36	25.3	7.7	361.5
3.18	3.51	1.17	17.5	6.0	71.5	2.34	77.3	23.7	269.0
3.81	4.09	1.60	37.0	9.3	60.9	3.20	132.3	52.0	227.0
5.08	5.25	2.63	93.0	29.8	46.2	5.27	293.0	171.6	176.5
6.35	6.27	3.77	174.0	75.6	37.8	7.54	477.0	361.0	142.9
7.62	7.77	5.80	335.0	209.0	29.4	11.60	842.0	806.0	113.5
10.20	10.23	10.00	688.0	615.0	23.1	20.01	1930.0	1930.0	86.2

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p, corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.4*a* Sizing Table Based on Velocity Limitation—U.S. Customary Units

Copper and brass pipe, standard pipe size

		Velocity = 4 ft/s				Velocity = 8 ft/s			
Nominal size, in	Actual ID, in	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡
½	0.625	3.8	1.5		6.8	7.0	3.7		24.2
¾	0.822	6.6	3.0		5.1	3.2	8.4		18.0
1	1.062	11.0	6.3		3.7	22.0	26.4	8.0	13.3
1¼	1.368	18.3	16.8	6.4	2.8	36.6	75.0	22.7	10.0
1½	1.600	25.2	36.3	9.3	2.3	50.4	130.0	51.0	8.4
2	2.062	41.6	92.0	29.5	1.7	83.2	291.0	170.0	6.2
2½	2.500	61.2	181.0	80.0	1.4	122.4	492.0	376.0	4.9
3	3.062	92.0	335.0	209.0	1.1	184.0	842.0	807.0	3.9
4	4.000	158.0	685.0	611.0	0.8	316.0	1920.0	1920.0	2.9

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.4*b* Sizing Table Based on Velocity Limitation—SI Units

Copper and brass pipe, standard pipe size

		Velocity = 1.2 m/s				Velocity = 2.4 m/s			
Nominal size, cm	Actual ID, cm	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡
1.27	1.59	0.24	1.5		143.0	0.48	3.7		508.6
1.90	2.09	0.42	3.0		107.2	0.83	8.4		378.3
2.54	2.70	0.69	6.3		71.8	1.39	26.4	8.0	279.5
3.18	3.47	1.15	16.8	6.4	58.8	2.31	75.0	22.7	210.2
3.81	4.06	1.59	36.3	9.3	48.3	3.18	130.0	51.0	176.5
5.08	5.24	2.62	92.0	29.0	35.7	5.25	291.0	170.0	130.3
6.35	6.35	3.86	181.0	80.0	29.4	7.72	492.0	376.0	103.0
7.62	7.78	5.80	335.0	209.0	23.1	11.61	842.0	807.0	82.0
10.20	10.16	9.97	685.0	611.0	16.8	19.94	1920.0	1920.0	61.0

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.5a Sizing Table Based on Velocity Limitation—U.S. Customary Units

Threadless copper and red brass pipe (TP)

		Velocity = 4 ft/s				Velocity = 8 ft/s			
Nominal size, in	Actual ID, in	Flow *q*, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction *p*, psi/100 ft‡	Flow *q*, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction *p*, psi/100 ft‡
½	0.710	4.9	2.0		5.9	9.8	5.3		20.8
¾	0.920	8.3	4.2		4.4	16.6	13.2	5.7	15.5
1	1.185	13.7	9.0		3.3	27.4	44.0	10.5	11.7
1¼	1.530	22.9	28.9	8.3	2.4	45.8	110.0	40.0	8.5
1½	1.770	30.6	55.0	14.5	2.1	61.2	181.0	80.0	7.2
2	2.245	49.4	126.0	48.5	1.6	98.8	369.0	240.0	5.6
2½	2.745	74.0	245.0	125.0	1.3	148.0	631.0	537.0	4.4
3	3.334	109.0	421.0	305.0	1.0	218.0	1081.0	1081.0	3.5
4	4.286	180.0	816.0	774.0	0.8	360.0	2318.0	2318.0	2.6

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss *p* corresponding to flow rate *q*, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.5b Sizing Table Based on Velocity Limitation—SI Units

Threadless copper and red brass pipe (TP)

		Velocity = 1.2 m/s				Velocity = 2.4 m/s			
Nominal size, cm	Actual ID, cm	Flow *q*, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction *p*, Pa/m‡	Flow *q*, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction *p*, Pa/m‡
1.27	1.80	0.31	2.0		124.0	0.62	5.3		437.1
1.90	2.34	0.52	4.2		92.5	1.05	13.2	5.7	325.7
2.54	3.01	0.86	9.0		69.4	1.73	44.0	10.5	245.9
3.18	3.89	1.44	28.9	8.3	50.4	2.89	110.0	40.0	178.6
3.81	4.70	1.91	55.0	14.5	44.1	3.86	181.0	80.0	151.3
5.08	5.70	3.11	126.0	48.5	33.6	6.23	369.0	240.0	117.7
6.35	6.97	4.6	245.0	125.0	27.3	9.34	631.0	537.0	92.5
7.62	8.47	6.8	421.0	305.0	21.0	13.75	1081.0	1081.0	73.6
10.20	10.89	11.4	816.0	774.0	16.8	22.71	2318.0	2318.0	54.6

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss *p* corresponding to flow rate *q*, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.6a Sizing Table Based on Velocity Limitation—U.S. Customary Units

Copper water tube, type K

		Velocity = 4 ft/s				Velocity = 8 ft/s			
Nominal size, in	Actual ID, in	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡
½	0.527	2.7	0.75		8.5	5.4	2.3		31.0
¾	0.745	5.5	2.3		5.6	11.0	6.3		20.2
1	0.995	9.7	5.3		4.1	19.4	19.5	5.8	14.4
1¼	1.245	15.2	10.8	5.0	3.1	30.4	54.0	14.0	11.1
1½	1.481	21.5	25.0	7.8	2.6	43.0	98.0	34.0	9.2
2	1.959	37.6	78.0	24.0	1.8	75.2	251.0	130.0	6.5
2½	2.435	58.2	166.0	69.0	1.4	116.4	460.0	340.0	5.2
3	2.907	82.8	289.0	161.0	1.2	165.6	725.0	663.0	4.2
4	3.857	146.0	609.0	528.0	0.8	292.0	1705.0	1705.0	3.0

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.6b Sizing Table Based on Velocity Limitation—SI Units

Copper water tube, type K

		Velocity = 1.2 m/s				Velocity = 2.4 m/s			
Nominal size, cm	Actual ID, cm	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡
1.27	1.34	0.17	0.75		178.6	0.34	2.3		651.5
1.90	1.89	0.34	2.3		117.7	0.69	6.3		424.5
2.54	2.53	0.61	5.3		86.2	1.22	19.5	5.8	302.6
3.18	3.16	0.95	10.8	5.0	65.1	1.91	54.0	14.0	233.3
3.81	3.76	1.35	25.0	7.8	54.6	2.71	98.0	34.0	193.3
5.08	4.98	2.37	78.0	24.0	37.8	4.74	251.0	130.0	136.6
6.33	6.18	3.67	166.0	69.0	29.4	7.34	460.0	340.0	109.3
7.62	7.38	5.22	289.0	161.0	25.2	10.44	725.0	663.0	88.3
10.20	9.80	9.21	609.0	528.0	16.8	18.42	1705.0	1705.0	63.0

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.7a Sizing Table Based on Velocity Limitation—U.S. Customary Units

Copper water tube, type L

		Velocity = 4 ft/s				Velocity = 8 ft/s			
Nominal size, in	Actual ID, in	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡
½	0.545	2.9	1.0		8.2	5.8	2.5		29.0
¾	0.785	6.0	2.5		5.2	12.0	7.3		18.7
1	1.025	10.3	5.5		3.9	20.6	22.5	7.0	13.7
1¼	1.265	15.7	11.5	5.0	3.0	31.4	58.0	15.5	10.7
1½	1.505	22.8	28.5	8.0	2.5	45.6	109.0	38.0	8.7
2	1.985	38.6	82.0	26.0	1.8	77.2	261.0	138.0	6.3
2½	2.465	59.5	172.0	75.0	1.4	119.0	474.0	356.0	4.9
3	2.945	85.0	300.0	178.0	1.1	170.0	750.0	692.0	4.0
4	3.905	149.0	636.0	544.0	0.8	298.0	1759.0	1759.0	2.8

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.7b Sizing Table Based on Velocity Limitation—SI Units

Copper water tube, type L

		Velocity = 1.2 m/s				Velocity = 2.4 m/s			
Nominal size, cm	Actual ID, cm	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡
1.27	1.38	0.18	1.0		172.3	0.36	2.5		609.4
1.90	1.99	0.37	2.5		109.3	0.75	7.3		392.9
2.54	2.60	0.64	5.5		80.7	1.29	22.5	7.0	287.9
3.18	3.11	0.99	11.5	5.0	63.0	1.98	58.0	15.5	224.9
3.81	3.82	1.43	28.5	8.0	52.5	2.87	109.0	38.0	182.8
5.08	5.04	2.43	82.0	26.0	37.8	4.87	261.0	138.0	132.4
6.35	6.26	3.75	172.0	75.0	29.4	7.50	474.0	356.0	102.9
7.62	7.48	5.36	300.0	178.0	23.1	10.72	750.0	692.0	84.0
10.20	9.92	9.40	636.0	544.0	16.8	18.80	1759.0	1759.0	58.8

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.8a Sizing Table Based on Velocity Limitation—U.S. Customary Units

Schedule 40 plastic pipe (PE, PVC, and ABS)

		Velocity = 4 ft/s				Velocity = 8 ft/s			
Nominal size, in	Actual ID, in	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡	Flow q, gpm	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, psi/100 ft‡
½	0.622	3.8	1.5		6.8	7.6	3.7		24.2
¾	0.824	6.7	3.0		5.1	13.4	8.4		18.0
1	1.049	10.8	6.1		3.7	21.6	25.3	7.7	13.2
1¼	1.380	18.6	17.5	6.0	2.8	37.2	77.3	23.7	9.6
1½	1.610	25.4	37.0	9.3	2.3	50.8	132.3	52.0	8.2
2	2.067	41.8	93.0	29.8	1.7	83.6	293.0	171.6	6.1
2½	2.469	59.8	174.0	75.6	1.4	119.6	477.0	361.0	4.8
3	3.068	92.0	335.0	209.0	1.1	184.0	842.0	806.0	3.8
4	4.026	158.6	688.0	615.0	0.8	317.2	1930.0	1930.0	2.8

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

TABLE 7.8b Sizing Table Based on Velocity Limitation—SI Units

Schedule 40 plastic pipe (PE, PVC, and ABS)

		Velocity = 1.2 m/s				Velocity = 2.4 m/s			
Nominal size, cm	Actual ID, cm	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡	Flow q, L/s	Load WSFU (col. A)*	Load WSFU (col. B)†	Friction p, Pa/m‡
1.27	1.58	0.23	1.5		142.9	0.47	3.7		508.6
1.90	2.09	0.42	3.0		107.2	0.84	8.4		378.3
2.54	2.66	0.68	6.1		77.8	1.36	25.3	7.7	277.4
3.18	3.51	1.17	17.5	6.0	58.8	2.34	77.3	23.7	201.7
3.81	4.09	1.60	37.0	9.3	48.3	3.20	132.3	52.0	172.3
5.08	5.25	2.63	93.0	29.8	35.7	5.27	293.0	171.6	128.2
6.35	6.27	3.77	174.0	75.6	29.4	7.54	477.0	361.0	100.9
7.62	7.77	5.80	335.0	209.0	23.1	11.60	842.0	806.0	79.9
10.20	10.23	10.00	688.0	615.0	16.8	20.01	1930.0	1930.0	58.8

*Col. A applies to piping which does not supply flush valves.

†Col. B applies to piping which supplies flush valves.

‡Friction loss p corresponding to flow rate q, for piping having fairly smooth surface condition after extended service, from the formula

$$q = 4.57p^{0.546}d^{2.64}$$

kind of piping material have been provided and may be applied advantageously in this step.]

APPLICATION OF SIMPLIFIED METHOD

Problem 7.1

Draw a schematic elevation, and size the piping of the following water distributing system using the simplified sizing method:

A one-family dwelling, 2 stories and cellar in height, is to be supplied by direct pressure from an 8-in (20.3-cm) public water main in which the certified minimum pressure available is 50 psi (345 kPa). Top-floor fixture outlets are 20 ft (6.1 m) above the public main and require 8 psi (55 kPa) flow pressure for satisfactory operation.

Authoritative reports indicate that the public water supply has a pH of 7.2, carbon dioxide content of 7 ppm, and a solids content of 90 ppm. Records show no significant corrosion of copper by the water up to 150°F (65.6°C).

Copper water tube with wrought copper fittings has been selected, and is to be of type K for the water service and of type L for inside the building.

Water supply for the premises is to be metered at the point of entry by a disk-type meter. The system is to be of the upfeed riser type. A 52-gal (197-L) automatic hot-water storage heater, having a rated pressure loss of 1.5 psi (10.3 kPa) at peak demand, is to provide 140°F (60°C) tank-controlled hot-water supply.

The most extreme run of piping from the public main to the highest and most remote outlet is 180 ft (54.9 m) in developed length, consisting of the following: 100 ft (30.5 m) of water service, 45 ft (13.7 m) of cold-water piping from the water service valve to the hot-water storage heater, and 35 ft (10.7 m) therefrom to the top-floor hot-water outlet at the shower. Plans of the entire water supply system are available.

Fixtures provided on the system are as follows:

Cellar. An automatic laundry washing machine, two hose bib outlets (only one to be used at any one time) at the outside of the building for lawn watering, and one valved outlet for supplying the house heating boiler

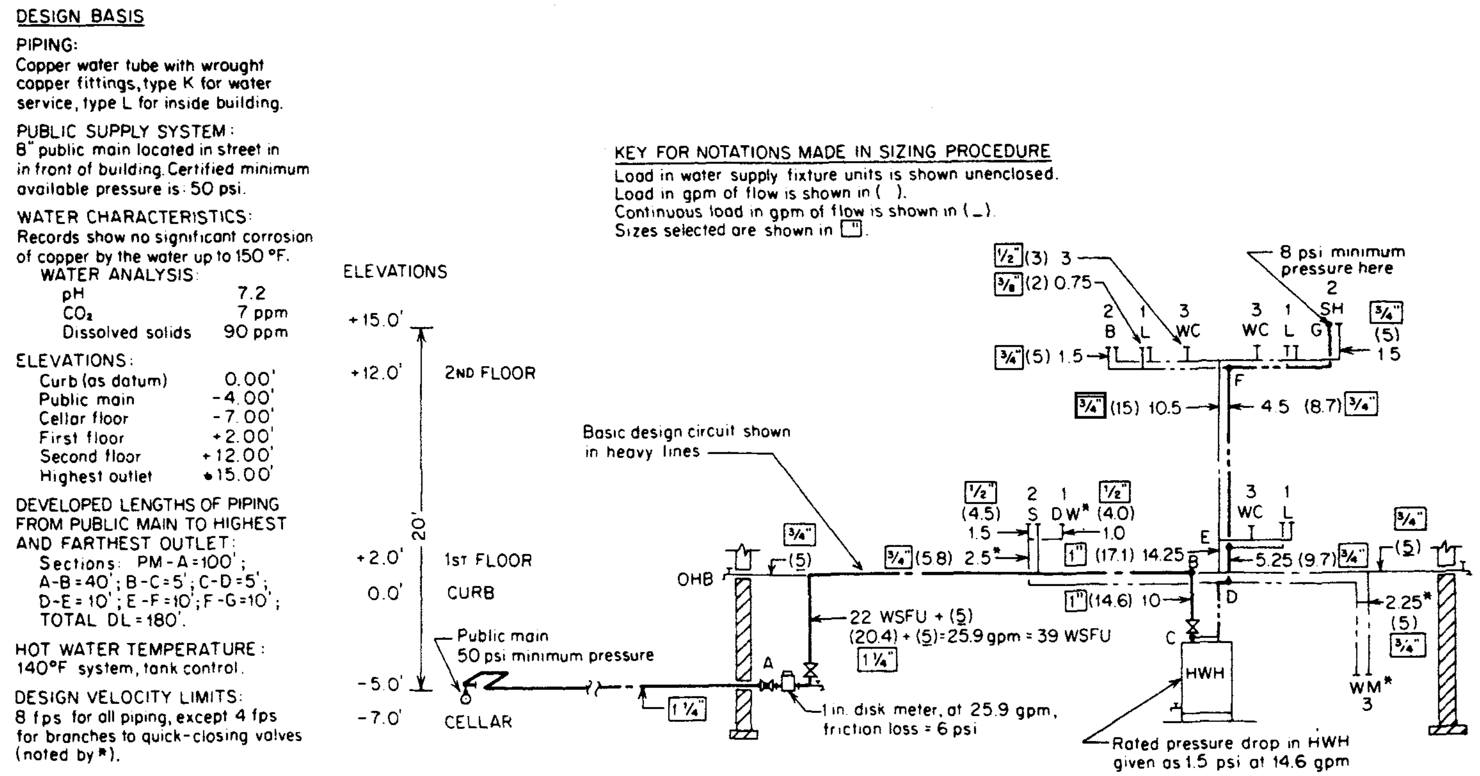
First floor. A kitchen equipped with a sink and a domestic dishwasher, and a powder room containing one lavatory and one water closet with flush tank

Second floor. Two bathroom groups, one containing a lavatory, bathtub with shower above, and a water closet with flush tank, and a second containing a lavatory, shower stall, and a water closet with flush tank

Solution

Step 1 All the required information is tabulated in the left column of the design sheet, Fig. 7.1.

Step 2 A schematic elevation of the building water supply system is shown in Fig. 7.1. This drawing is based on plans of the system. All piping connections



DESIGN BASIS

PIPING:
Copper water tube with wrought copper fittings, type K for water service, type L for inside building.

PUBLIC SUPPLY SYSTEM:
8" public main located in street in in front of building. Certified minimum available pressure is: 50 psi.

WATER CHARACTERISTICS:
Records show no significant corrosion of copper by the water up to 150 °F.

WATER ANALYSIS:

pH	7.2
CO_2	7 ppm
Dissolved solids	90 ppm

ELEVATIONS:

Curb (as datum)	0.00'
Public main	-4.00'
Cellar floor	-7.00'
First floor	+2.00'
Second floor	+12.00'
Highest outlet	+15.00'

DEVELOPED LENGTHS OF PIPING FROM PUBLIC MAIN TO HIGHEST AND FARTHEST OUTLET:
Sections: PM-A = 100'; A-B = 40'; B-C = 5'; C-D = 5'; D-E = 10'; E-F = 10'; F-G = 10';
TOTAL DL = 180'.

HOT WATER TEMPERATURE:
140°F system, tank control.

DESIGN VELOCITY LIMITS:
8 fps for all piping, except 4 fps for branches to quick-closing valves (noted by *).

KEY FOR NOTATIONS MADE IN SIZING PROCEDURE

Load in water supply fixture units is shown unenclosed.
Load in gpm of flow is shown in ( ).
Continuous load in gpm of flow is shown in (_).
Sizes selected are shown in ["].

FIG. 7.1 Water supply design sheet for Prob. 7.1.

are shown in proper sequence as per the plans, and the developed lengths of each section of the basic design circuit determined therefrom. Fixtures are identified by letters, and those fixtures and branches having quick-closing valve outlets are specially identified by an asterisk.

Step 3 For each section of the system, notations showing the hot- and cold-water loads in terms of water supply fixture units. Fixture unit values are shown unenclosed by parentheses.

Step 4 Adjacent to fixture unit load notations, the demand in gallons per minute corresponding to such loads is shown in parentheses. The demand was determined from Table 2.3 by applying the values under the heading "Supply Systems Predominantly for Flush Tanks," since no flush valves (flushometers) are involved in this system.

Step 5 The continuous demand posed by the two outside hose bibs (only one of which is to be used at a time) is shown on the design sheet. The demand is underlined and is included in parentheses as gallons per minute where added to fixture units of load. The normal demand posed by a hose bib was obtained from Table 2.1.

Step 6 All individual fixture supply pipes to water outlets are sized on the design sheets in accordance with the minimum sizes shown in Table 7.2.

Step 7 All other parts of the system have been sized in accordance with the velocity limitations established for this system as the proper basis for design, i.e., 8 ft/s for all piping, except 4 ft/s for branches to quick-closing valves as noted by asterisks on the design sheet. Sizing was done in accordance with total fixture units of load corresponding to total demand in each section. For those sections of the cold-water header in the cellar which convey both demand of intermittently used fixtures and continuous demand of a hose bib, the total demand in gallons per minute was converted to equivalent water supply fixture units of load and proper sizes were determined therefor, although proper sizing could also have been done simply on the basis of demand rates in gallons per minute. Sizing was done using Tables 7.3 through 7.8 and specifically those tables dealing with copper water tube, type K, for sizing the water service pipe, and with copper water tube, type L, for sizing piping inside the building.

SIZING TABLES BASED ON VELOCITY LIMITATION

Tables 7.3 through 7.8 show, for velocity limits of 4 ft/s (1.2 m/s) and 8 ft/s (2.4 m/s), the number of water supply fixture units of load permissible for each size and kind of pipe in common use. Hence, the tables may be used in much the same manner as tables applied for sizing drainage and vent systems. There are two tables for each kind of pipe, customary U.S. units and SI units. As an example, in Table 7.6*a* the first column lists the nominal pipe sizes, and the second column shows the actual internal pipe diameter as stated in the applicable ASTM standard for the pipe. Under the heading "Velocity = 4 ft/s" the column headed "Flow" shows the rate of flow, in gallons per minute, calculated for a velocity of 4 ft/s for each size of pipe based on the actual internal diameter. The column headed "Friction" shows the amount of pipe friction calculated for that rate of flow by applying the formula noted beneath the table. Between these two columns are columns A and B, which show load values in terms of water supply fixture units. Column A applies to piping which does not supply flush valves (flushometers). The load values in this column were determined for the calculated flow rates from the values in Table 2.3 for "Supply systems predominantly for flush tanks." Column B applies to piping which supplies flush valves. The load values shown therein were similarly determined for the same calculated flow rates, using the same table, but from values for "Supply systems predominantly for flushometer valves."

ACCURATE PIPE FRICTION CHARTS FOR VARIOUS SERVICE CONDITIONS

In this section, pipe friction charts for various service conditions are given for each of the standard piping materials used for water supply systems in buildings. The charts were developed using actual internal pipe diameters given in applicable standards for each of the different kinds of materials.

Flow rates corresponding to any given uniform pipe friction loss may be determined for each nominal size of the kind of pipe selected for the system. The appropriate chart to apply in any given case depends on the kind of piping to be used and the effect that the water to be conveyed will produce within the piping after extended service. Accordingly, one can select the proper chart to use in determining flow rates through various sizes of a given kind of piping for a specific uniform pipe friction loss, knowing the quality and characteristics of the water to be conveyed and the effects that the water will have upon the internal pipe surface in extended service.

For Red Brass and Copper Pipe and Copper Water Tube

Where the water supply is relatively noncorrosive to the pipe material and is not scale-forming, apply the charts applicable to the "fairly smooth" surface condition. Where the water supply is moderately scale-forming, apply the charts applicable to the "fairly rough" surface condition. Where the water has an appreciable scale-forming tendency and would otherwise result in clogging of small-diameter pipes and in reducing the effective diameter of other piping in the system, allow one standard pipe size larger than would be determined applying the "fairly smooth" chart. (See Figs. 7.2–7.5.)

For Galvanized Iron and Steel Pipe

Where the water supply is relatively noncorrosive to the pipe material and is not scale-forming, apply the chart applicable to the "fairly rough" surface condition. Where the water supply is moderately corrosive or moderately scale-forming, apply the chart applicable to the "rough" surface condition. Where the water supply is significantly corrosive to iron or steel or has an appreciable scale-forming tendency and would otherwise result in clogging of small-diameter pipes and in

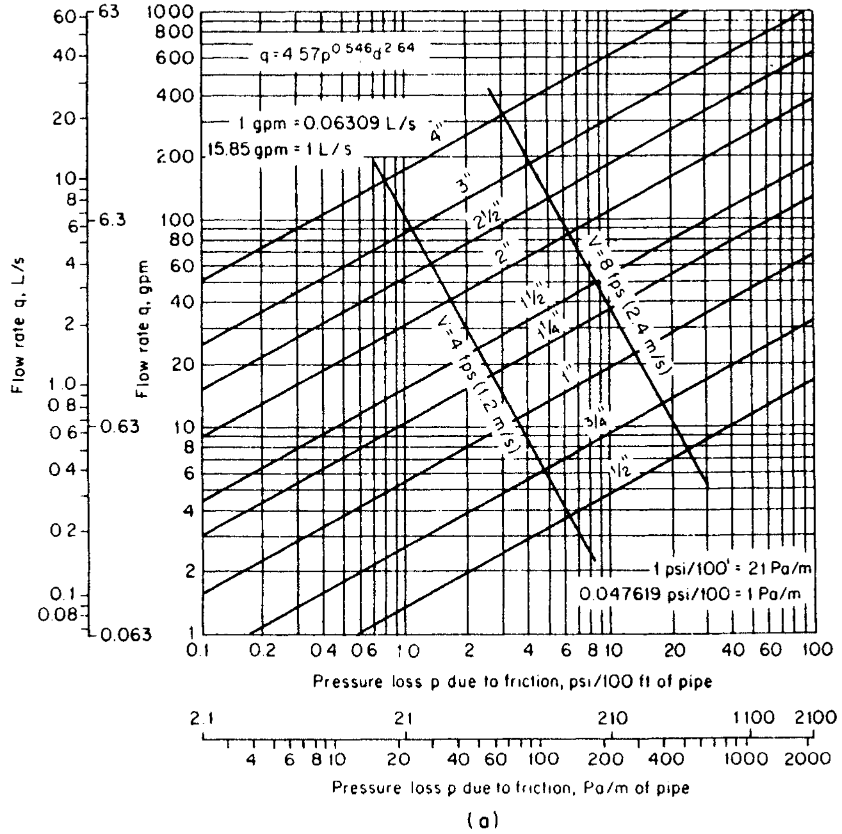


FIG. 7.2 Pipe friction chart for copper and brass pipe, standard pipe size (SPS)—ASTM B42, B43. (*a*) Fairly smooth surface condition; (*b*) fairly rough surface condition.

reducing the effective diameter of other piping in the system, allow one standard pipe size larger than would be determined applying the "fairly rough" chart. (See Fig. 7.6.)

For Plastic Pipe (PE, ABS, and PVC)

Where the water supply is relatively not scale-forming, apply the chart applicable to the "fairly smooth" surface condition. Where the water supply is moderately scale-forming, apply the chart applicable to the "fairly rough" surface condition. Where the water has an appreciable scale-forming tendency and would otherwise result in clogging of small-diameter pipes and in reducing the effective diameter of other piping in the system, allow one standard pipe size larger than would be determined applying the "fairly smooth" chart. (See Fig. 7.7.)

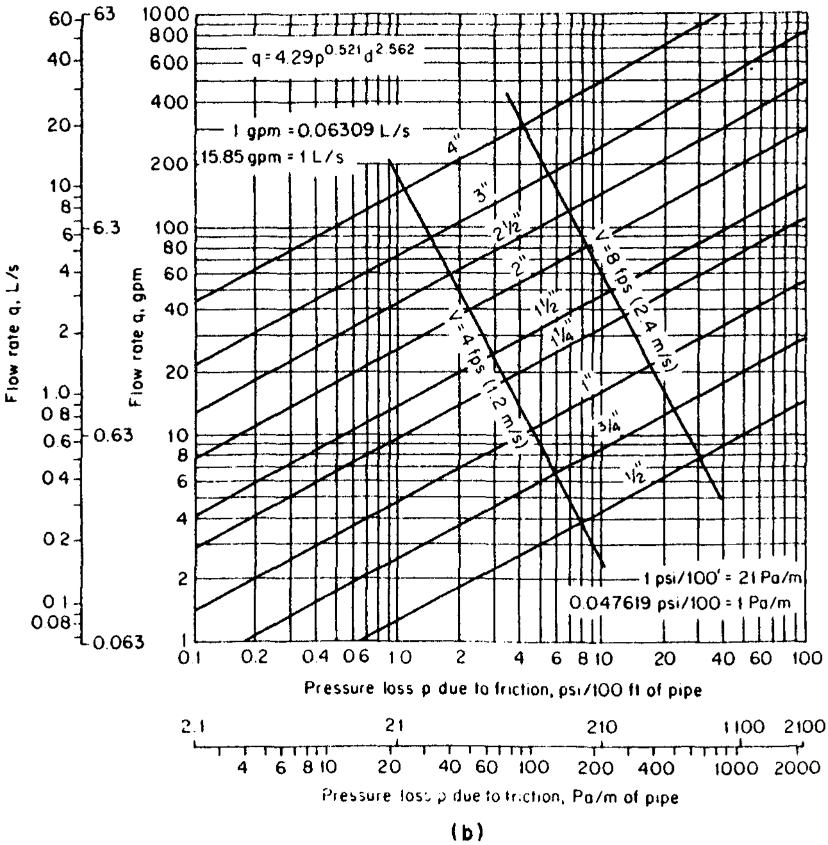
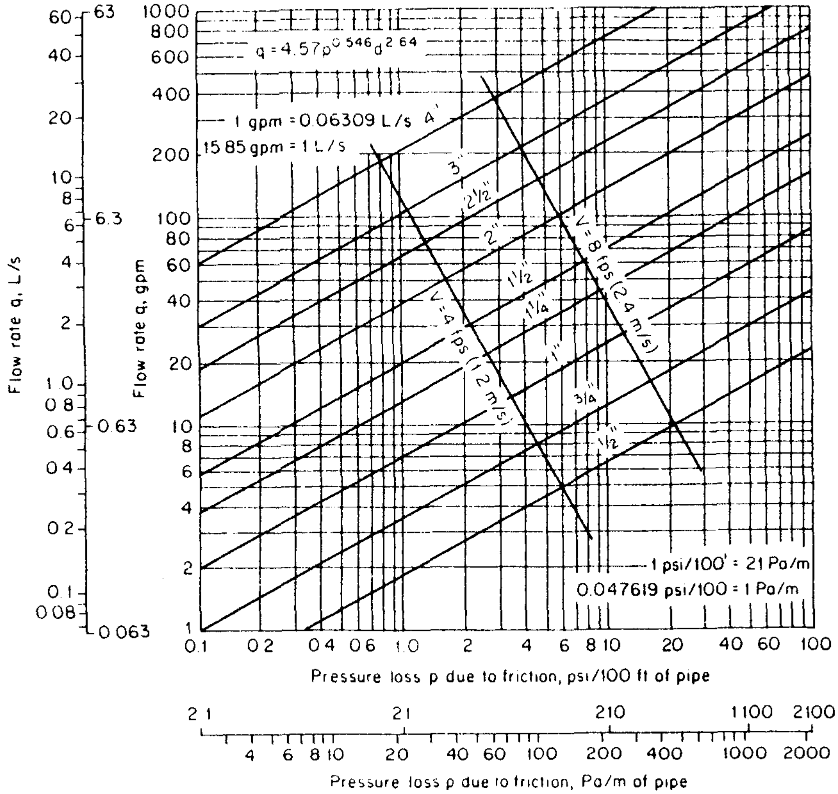


FIG. 7.2 *Continued.*

DETAILED METHOD FOR SIZING SYSTEMS IN BUILDINGS OF ANY HEIGHT

For sizing water supply systems in buildings of any height, a detailed method has been developed in a step-by-step procedure which may be applied in the design of modern buildings. The procedure consists of 16 steps. They are as follows:

1. Obtain all information necessary for establishing a proper basis for sizing the system. Properness of the basis for sizing is contingent upon accuracy and reliability of the information applied. Such information should be obtained from responsible parties and appropriate local authorities recognized as sources of the necessary information. See Step 1 under "Step-by-Step Procedure, Simplified Sizing Method."
2. Provide a schematic elevation of the complete water supply system. Show all piping connections in proper sequence and all fixture supplies. Identify all fixtures and risers by means of appropriate letters, numbers, or combinations thereof. Specially identify all piping conveying water at a temperature above



(a)

FIG. 7.3 Pipe friction chart for threadless red brass and copper pipe (ASTM B302). (*a*) Fairly smooth surface condition; (*b*) fairly rough surface condition.

150°F (66°C), and all branch piping to such water outlets as automatic flush valves, solenoid valves, pneumatic valves, or quick-closing valves or faucets. Provide on the schematic elevation all the necessary information obtained as per Step 1.

3. Mark on the schematic elevation, for each section of the complete system, the hot- and cold-water loads conveyed thereby in terms of water supply fixture units in accordance with Table 2.2.

4. Mark on the schematic elevation, adjacent to all fixture unit notations, the demand in gallons per minute or liters per second corresponding to the various fixture unit loads in accordance with Table 2.3.

5. Mark on the schematic elevation, for appropriate sections of the system, the demand in gallons per minute or liters per second for outlets at which demand is deemed continuous, such as outlets for watering gardens, irrigating lawns, air-conditioning apparatus, refrigeration machines, and other similar equipment using water at a relatively continuous rate during peak demand

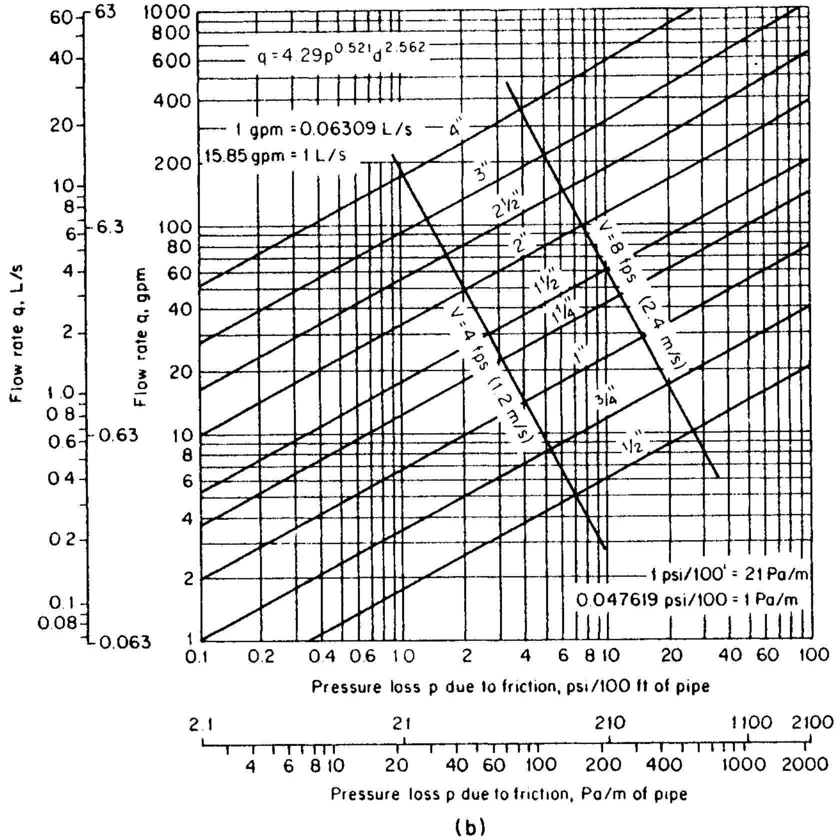
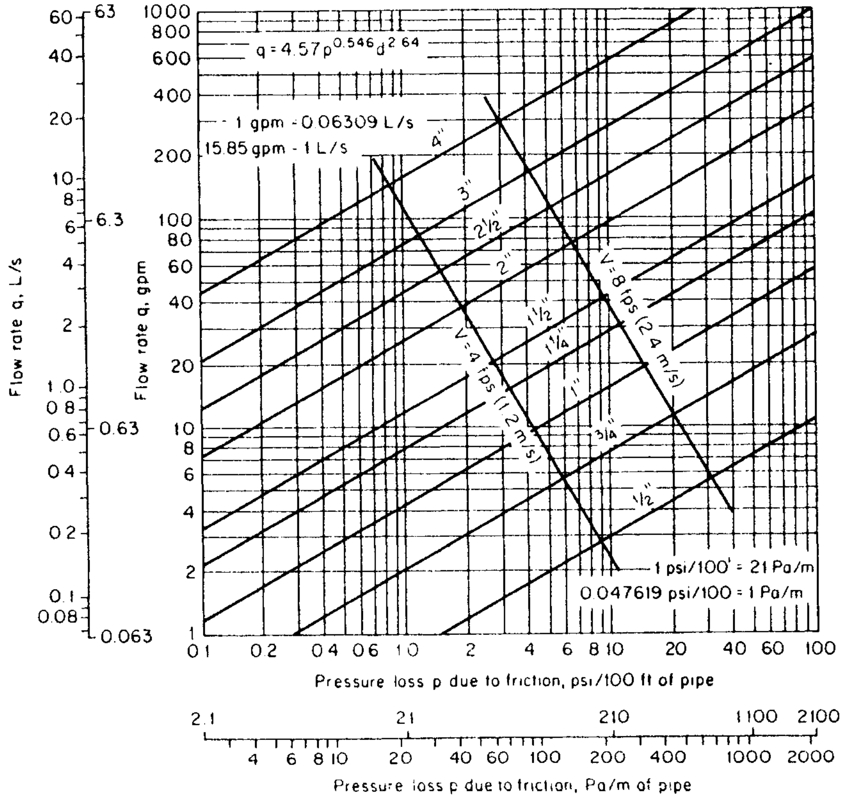


FIG. 7.3 *Continued.*

periods. Add the continuous demand to the demand for intermittently used fixtures, and show the total demand at those sections where both types of demand occur.

6. Size all individual fixture supply pipes to water outlets in accordance with the minimum sizes permitted by regulations. Minimum fixture supply pipe sizes for common plumbing fixtures are given in Table 7.2.
7. Size all other parts of the water supply system in accordance with velocity limitations recognized as good engineering practice, with velocity limitations recommended by pipe manufacturers for avoiding accelerated deterioration and failure of their products under various conditions of service, and with velocity limitations generally recommended for minimizing the cost of pumping where water supply pumps are provided. [Sizing tables based on such velocity limitations and showing permissible loads in terms of water supply fixture units for each size and kind of piping material have been provided (Tables 7.3 through 7.8) and may be applied advantageously in this step.]
8. Assuming conditions of no flow in the system, calculate the amount of pres-

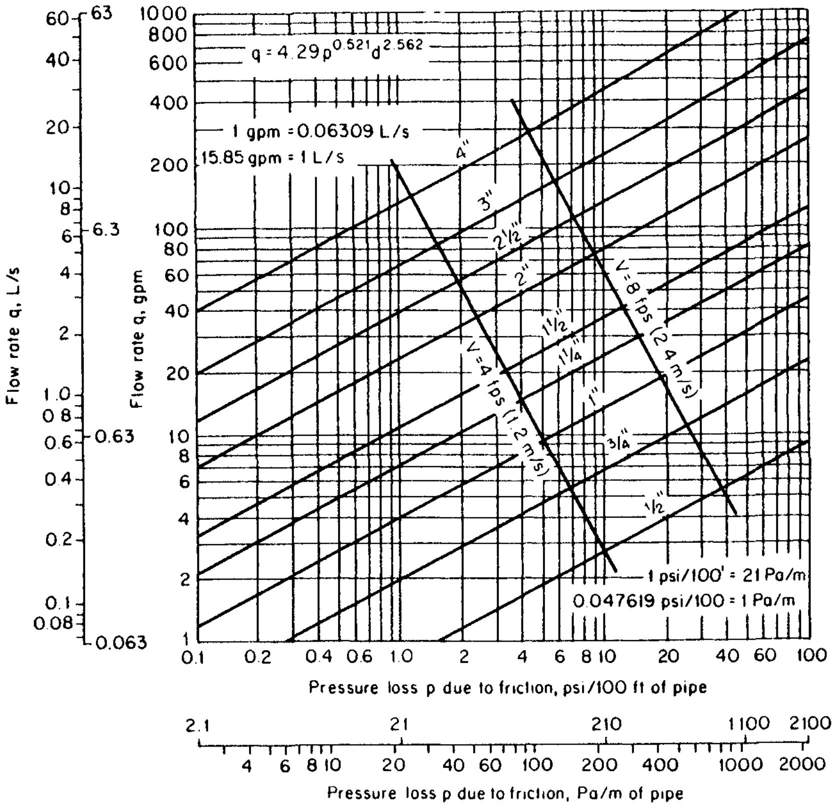


(a)

FIG. 7.4 Pipe friction chart for copper water tube, type K (ASTM B88). (*a*) Fairly smooth surface condition; (*b*) fairly rough surface condition.

sure available at the topmost fixture in excess of the minimum pressure required at such fixture for satisfactory supply conditions. The calculated excess pressure is the limit to which friction losses may be permitted for flow during peak demand in the system. (1 ft of water column = 0.433 psi pressure, and 1 m of water column = 9.795 kPa pressure.)

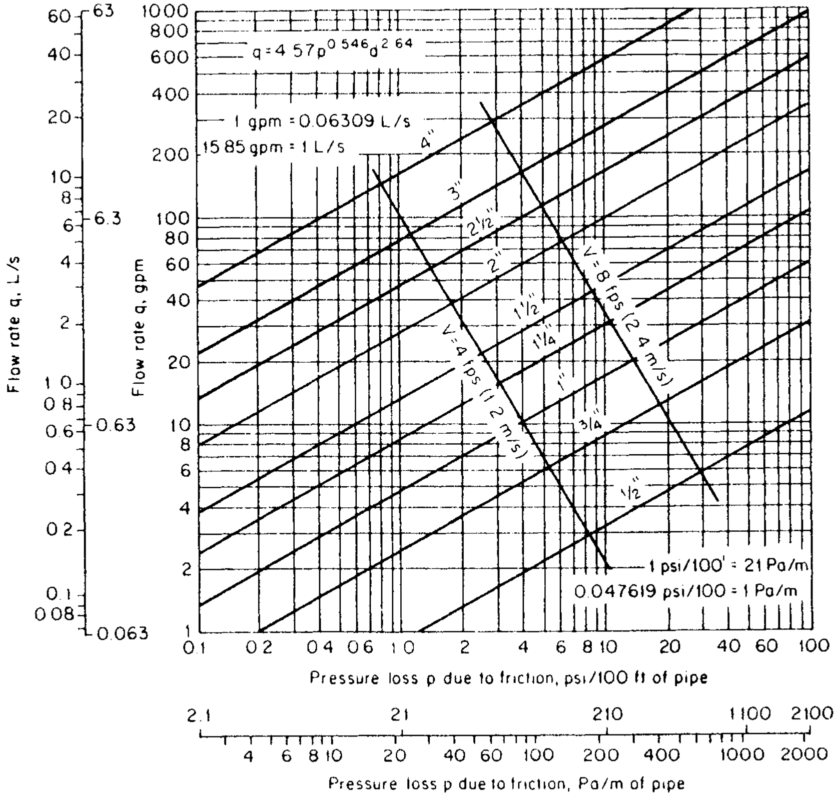
9. Determine which piping circuit of the system is the basic design circuit for which pipe sizes in main lines and risers should be designed in accordance with friction loss limits. This circuit is the most extreme run of piping through which water flows from the public main, or other pressure source of supply, to the highest and most distant water outlet. The basic design circuit should be specially identified on the schematic elevation of the system.
10. Mark on the schematic elevation the rated pressure loss due to friction corresponding to the demand through any water meter, water softener, or instantaneous or tankless hot-water heating coil that may be provided in the basic design circuit.



(b)

FIG. 7.4 *Continued.*

11. Calculate the amount of pressure remaining and available for dissipation as friction loss during peak demand through the pipe, valves, and fittings in the basic design circuit. Deduct from the excess static pressure available at the topmost fixture (determined in Step 8) the rated friction losses for any water meters, water softeners, or instantaneous or tankless hot-water heating coils provided in the basic design circuit (determined in Step 10).
12. Calculate the total equivalent length of the basic design circuit. Pipe sizes established on the basis of velocity limitations in Step 7 for main lines and risers must be considered just tentative at this stage but may be deemed appropriate for determining corresponding equivalent lengths of fittings and valves in this step.
13. Calculate the permissible uniform pressure loss for friction in piping of the basic design circuit. The amount of pressure available for dissipation as friction loss due to pipe, fittings, and valves in the circuit (determined in Step 11) should be divided by the total equivalent length of the circuit (determined in Step 12). This establishes the pipe friction limit for the circuit in terms of



(a)

FIG. 7.5 Pipe friction chart for copper water tube, type L (ASTM B88). (*a*) Fairly smooth surface condition; (*b*) fairly rough surface condition.

pressure loss, in pounds per square inch per foot (pascals per meter) [psi/ft (Pa/m)] for the total equivalent pipe length. Multiply this value by 100 in order to express the pipe friction limit in terms of psi per 100 ft of length.

14. Set up a sizing table showing the rates of flow, for various sizes of the kind of piping to be used, corresponding to the permissible uniform pressure loss for pipe friction calculated for the basic design circuit (determined in Step 13). Such rates may be determined from an accurate pipe friction chart appropriate for the kind of piping to be used and for the effects upon the piping of the quality of water to be conveyed thereby for extended service.

15. Size all parts of the basic design circuit, and all other main lines and risers which supply water upward to the highest water outlets on the system, in accordance with the sizing table set up in Step 14. Where sizes determined in

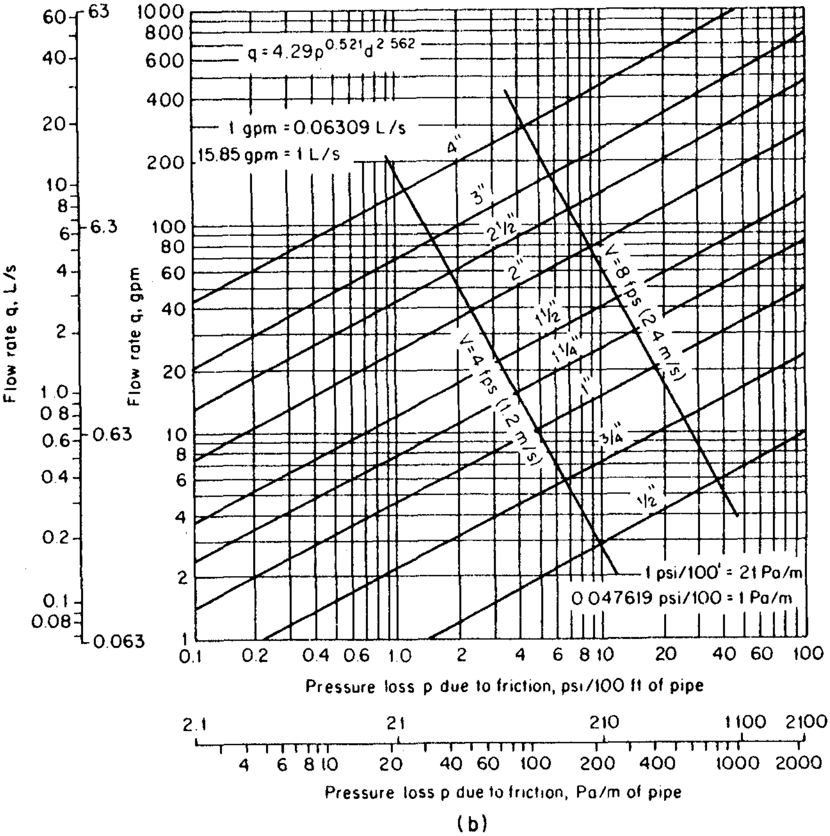


FIG. 7.5 *Continued.*

this step are larger than those previously established in Step 7 (based just on velocity limitations), the increased size is applicable for limitation of friction.

16. Due consideration must be given to the action of the water on the interior of the piping, and proper allowance must be made where necessary as a design consideration, such as where the kind of piping selected and the characteristics of the water conveyed are such that an appreciable buildup of corrosion products or hard-water scale may be anticipated to cause a significant reduction in bore of the piping system and inadequate capacity for satisfactory supply conditions during the normal service life of the system. A reasonable allowance in such cases may be considered to be provision of at least one standard pipe size larger than the sizes determined in the preceding steps. Where the water supply is treated in such manner as to avoid buildup of corrosion products or hard-water scale, no allowance need be made in sizing piping conveying such treated water.

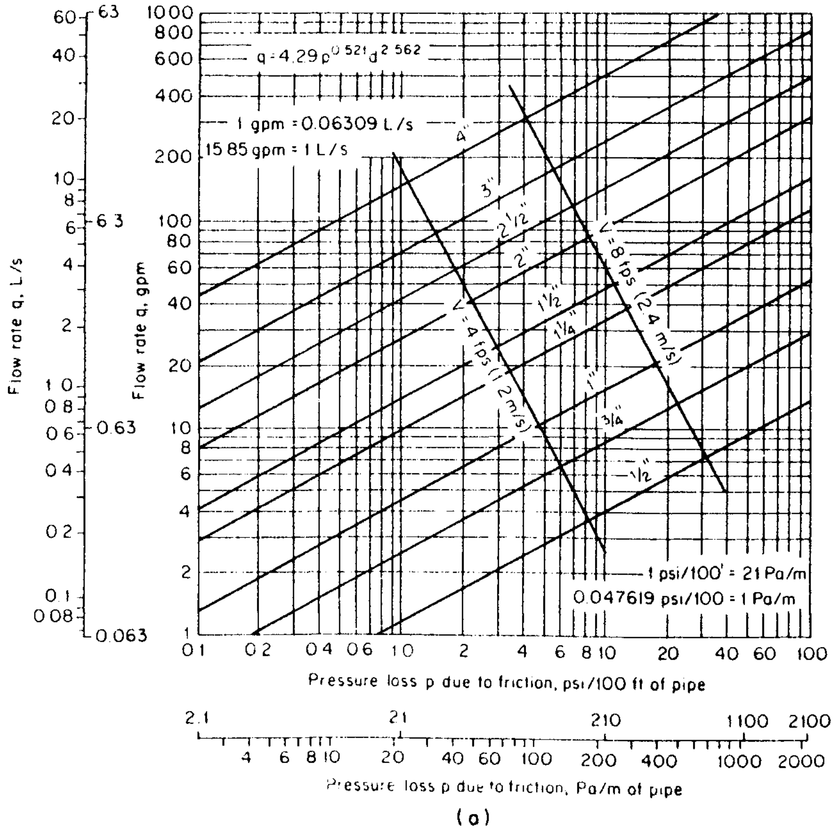


FIG. 7.6 Pipe friction chart for galvanized iron and steel standard weight pipe (ASTM A72, A120). (*a*) Fairly rough surface condition; (*b*) rough surface condition.

APPLICATION OF DETAILED METHOD TO ILLUSTRATIVE PROBLEMS

Problem 7.2

Draw a schematic elevation, and size the piping of the following water distributing system using the detailed sizing method:

A 102-family multiple dwelling, 7 stories and basement in height, fronts on a public street and is to be supplied by direct street pressure from an 8-in public water main located beneath the street in front of the building. The public system is of cast iron and a hydrant flow test indicates a certified minimum available pressure of 75 psi. Top floor fixture outlets are 65 ft 8 in above the public main and require 8 psi flow pressure for satisfactory operation.

Authoritative water analysis reports show that the public water supply has a pH of 6.9, carbon dioxide content of 3 ppm, dissolved solids content of 40 ppm, and is supersaturated with air. Reports show that the public water supply has no significant corrosion effect on red brass for temperatures up to 150°F.

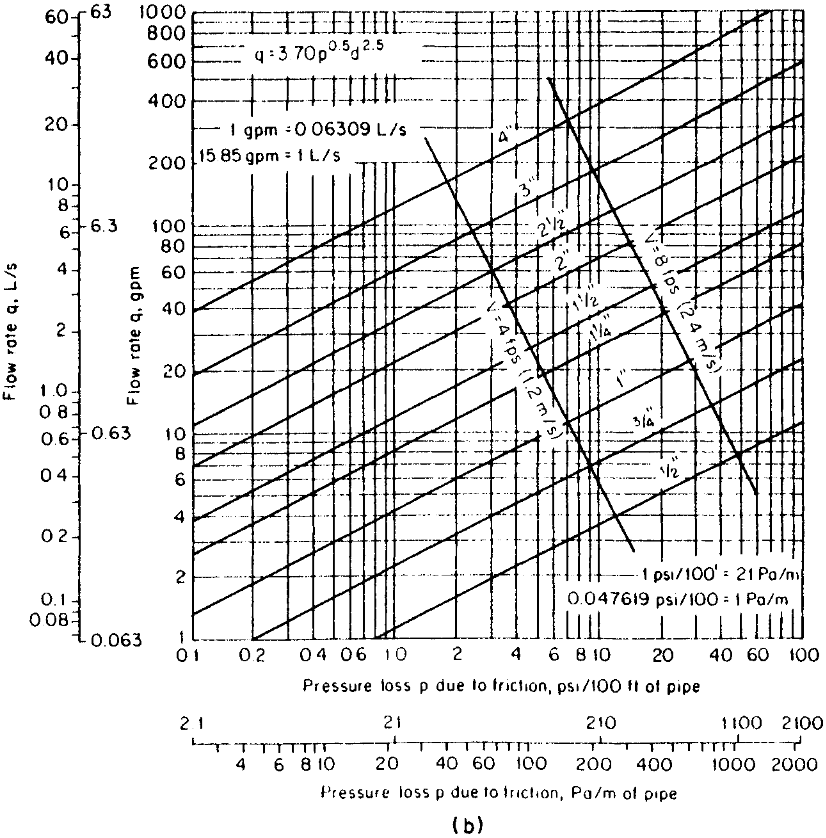


FIG. 7.6 *Continued.*

Cement-lined cast iron, class B, corporation water pipe, valves, and fittings have been selected for the water service pipe. Red brass pipe, standard pipe size, has been selected for the water distributing system inside the building.

Water supply for the building is to be metered at the point of entry by a compound meter installed in the basement. The system is to be of the upfeed riser type. A horizontal hot-water storage tank is to provide hot water to the entire building and is to be equipped with automatic tank control of water temperature set for 140°F. The tank is to have a submerged heat exchanger.

The most extreme run of piping from the public main to the highest and most remote outlet is 420 ft in developed length, consisting of the following: 83 ft of water service, 110 ft of cold-water piping from the water service valve to the hot-water storage tank, and 227 ft of hot-water piping from the tank to the top floor hot-water outlet at the kitchen sink. Plans of the entire water supply system are available.

The building has a basement and 7 above-grade stories. The basement floor is 3 ft 8 in below curb level, the first floor is 5.0 ft above curb level, and the public water main is 5.0 ft below curb level. Each of the above-grade stories is 9 ft 4 in in height from floor to floor. The highest fixture outlet is 3 ft above floor level.

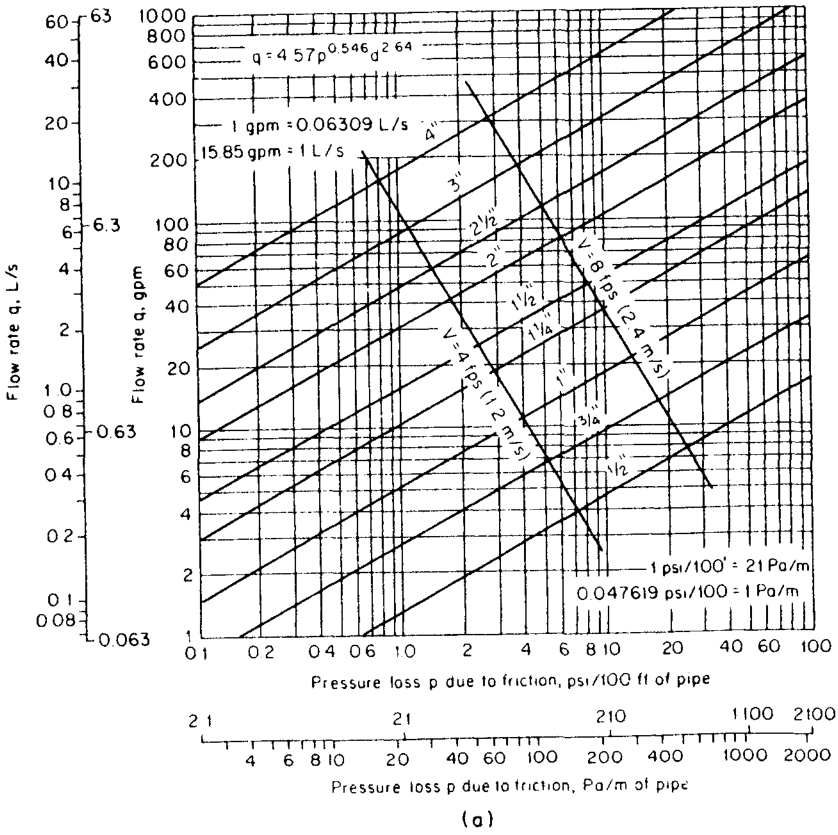


FIG. 7.7 Pipe friction chart for Schedule 40 plastic pipe: PE (ASTM D2104), ABS (ASTM D1527), PVC (ASTM D1785). (*a*) Fairly smooth surface condition; (*b*) fairly rough surface condition.

Fixtures provided on the system for the occupancies are as follows:

1. There are 17 dwelling units on each of the second, third, fourth, fifth, sixth, and seventh floors, and each dwelling unit is provided with a sink and domestic dishwashing machine in the kitchen and a close-coupled water closet and flush tank combination, a lavatory, and a bathtub with shower head above in a private bathroom.
2. The first floor is occupied for administrative and general purposes, and has the following provisions for such occupancy: one flush-valve-supplied water closet and one lavatory in an office toilet room; one flush-valve-supplied water closet, one flush-valve-supplied urinal, and one lavatory in a men's toilet room; two flush-valve-supplied water closets and one lavatory in each of two women's toilet rooms; a sink and domestic dishwashing machine in a demonstration kitchen; one sink in an office kitchen; one sink in a craft room; and two drinking fountains in the public hall.
3. The basement is occupied for building equipment rooms, storage, utility, laun-

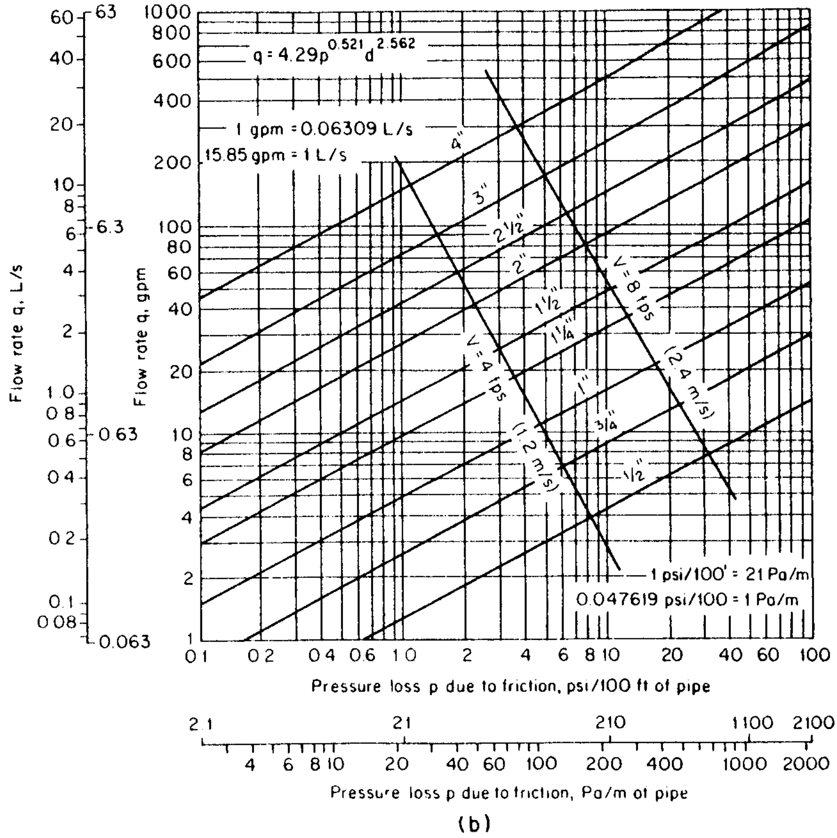
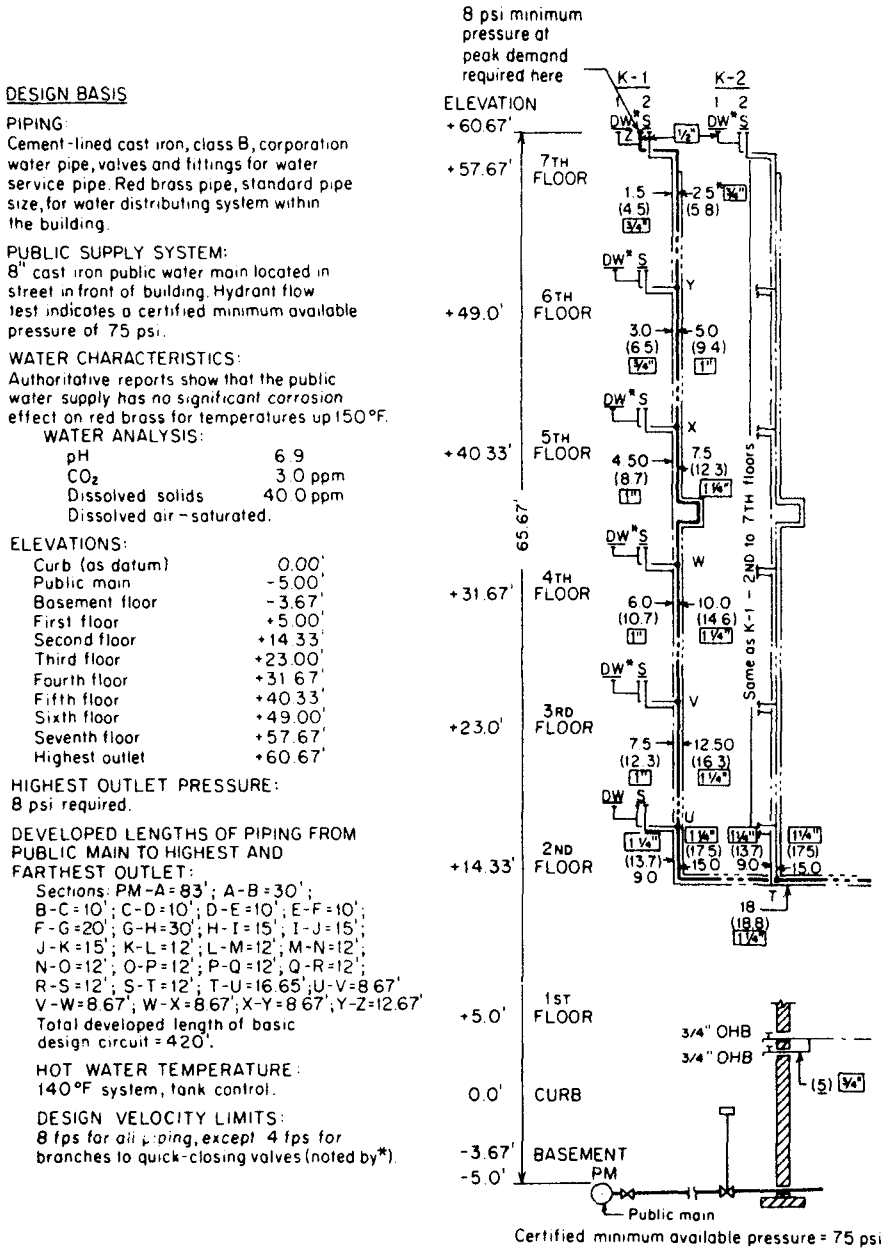


Fig. 7.7 *Continued.*

dry, and general purposes and has the following provisions for such occupancy: one flush-valve-supplied water closet and one lavatory in a women's toilet room; one flush-valve-supplied water closet, one lavatory, and one shower stall in a men's toilet room; one service sink and six automatic laundry washing machines in a general laundry room; one faucet above a floor drain in the boiler room; and one valve-controlled primary water supply connection to the building heating system.

4. At each story and in the basement, a service sink is provided in a janitor's closet in the public hall.
5. Four outside hose bibs (only two to be used at any time) are provided for lawn watering at appropriate locations on the exterior of the building.

Fixture arrangements are typical on the six upper floors of the building, and 24 sets of risers are provided. Of these, 5 sets are for back-to-back bathrooms, 2 sets are for back-to-back kitchens, 4 sets are for back-to-back kitchen and bathroom groups, 9 sets are for separate kitchens, 3 sets are for separate bathrooms, and one set is for a service sink on each floor above the basement. Fixtures on the



DESIGN BASIS

PIPING:
Cement-lined cast iron, class B, corporation water pipe, valves and fittings for water service pipe. Red brass pipe, standard pipe size, for water distributing system within the building.

PUBLIC SUPPLY SYSTEM:
8" cast iron public water main located in street in front of building. Hydrant flow test indicates a certified minimum available pressure of 75 psi.

WATER CHARACTERISTICS:
Authoritative reports show that the public water supply has no *significant corrosion* effect on red brass for temperatures up 150°F.

WATER ANALYSIS:

pH	6.9
CO_2	3.0 ppm
Dissolved solids	40.0 ppm

Dissolved air – saturated.

ELEVATIONS:

Curb (as datum)	0.00'
Public main	-5.00'
Basement floor	-3.67'
First floor	+5.00'
Second floor	+14.33'
Third floor	+23.00'
Fourth floor	+31.67'
Fifth floor	+40.33'
Sixth floor	+49.00'
Seventh floor	+57.67'
Highest outlet	+60.67'

HIGHEST OUTLET PRESSURE:
8 psi required.

DEVELOPED LENGTHS OF PIPING FROM PUBLIC MAIN TO HIGHEST AND FARTHEST OUTLET:
Sections: PM-A = 83'; A-B = 30'; B-C = 10'; C-D = 10'; D-E = 10'; E-F = 10'; F-G = 20'; G-H = 30'; H-I = 15'; I-J = 15'; J-K = 15'; K-L = 12'; L-M = 12'; M-N = 12'; N-O = 12'; O-P = 12'; P-Q = 12'; Q-R = 12'; R-S = 12'; S-T = 12'; T-U = 16.65'; U-V = 8.67' V-W = 8.67'; W-X = 8.67'; X-Y = 8.67'; Y-Z = 12.67'
Total developed length of basic design circuit = 420'.

HOT WATER TEMPERATURE:
140°F system, tank control.

DESIGN VELOCITY LIMITS:
8 fps for all piping, except 4 fps for branches to quick-closing valves (noted by*).

Certified minimum available pressure = 75 psi

FIG. 7.8 Water supply system design sheet for Prob. 7.2.

first floor are connected to adjacent risers. Basement fixtures are connected to overhead mains, which also supply directly the four outside hose bibs.

Solution

Step 1 All information required for establishing a proper design basis has been obtained from appropriate sources.

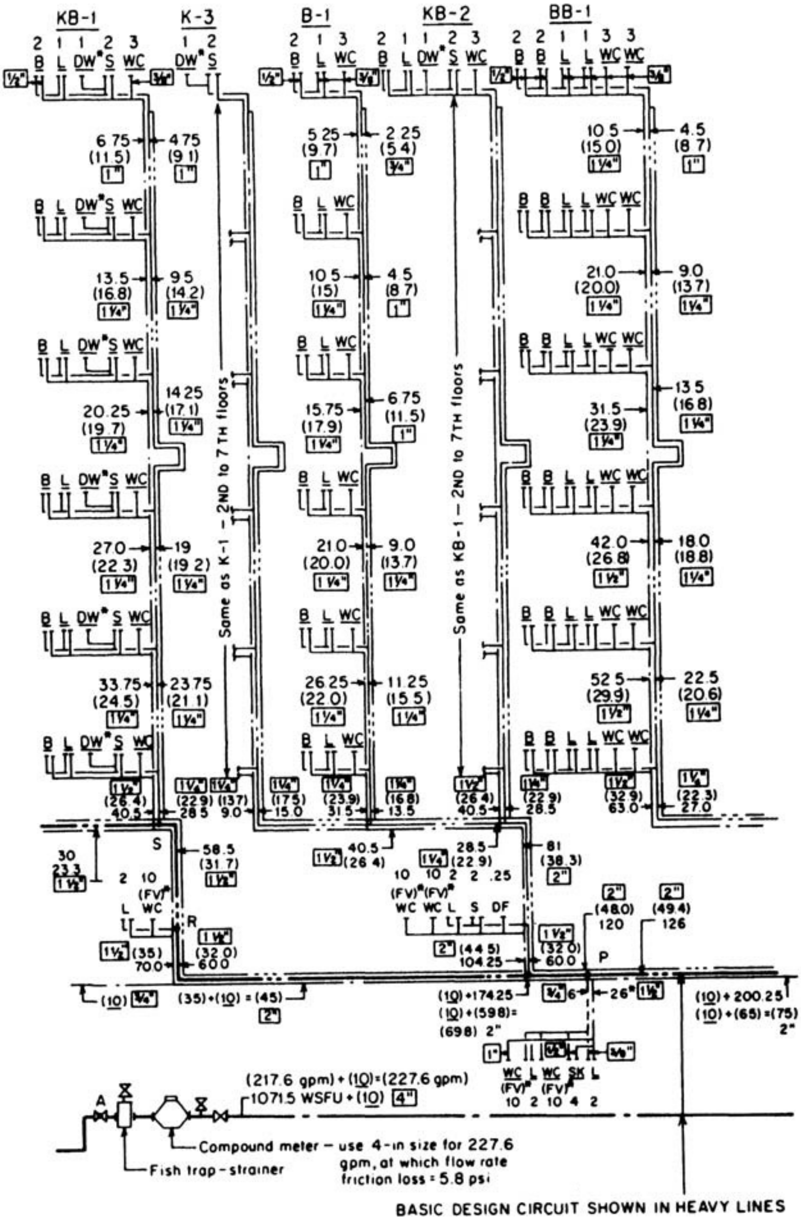


FIG. 7.8 *Continued.*

Step 2 A schematic elevation of the building water supply system is provided in Fig. 7.8. This drawing was developed from the plans of the system. All piping connections have been shown in proper sequence as per the plans, and the developed lengths of each section of the basic design circuit have been determined therefrom. Fixtures and risers have been identified by combinations of letters and numbers, and those fixtures and branches having quick-closing valve outlets have been specially identified by means of an asterisk. All information required for es-

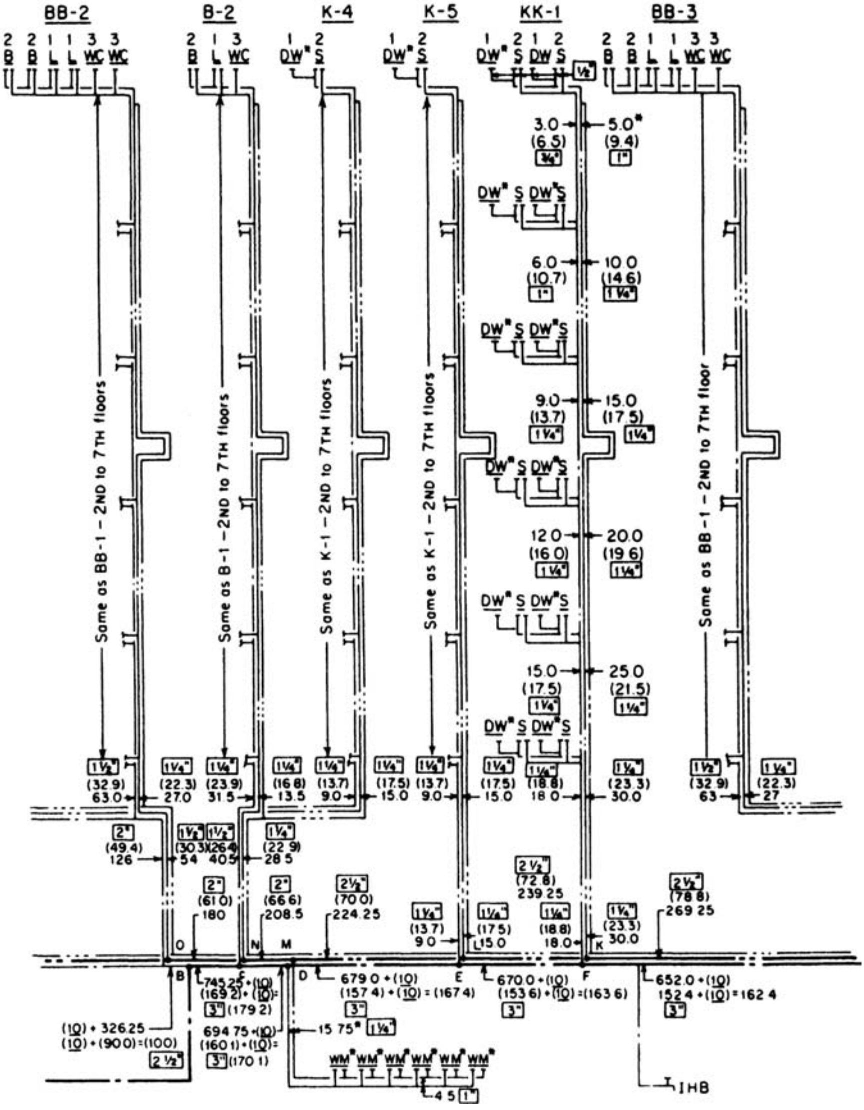


FIG. 7.8 *Continued.*

tablishing a proper design basis has been shown on the left side of the design sheet.

Step 3 For each section of the system, notations have been made showing the hot- and cold-water loads conveyed thereby in terms of water supply fixture units. Fixture unit values have been shown unenclosed by parentheses.

Step 4 Adjacent to fixture unit load notations, the demand in gallons per minute corresponding to such loads has been shown in parentheses. The demand in gal-

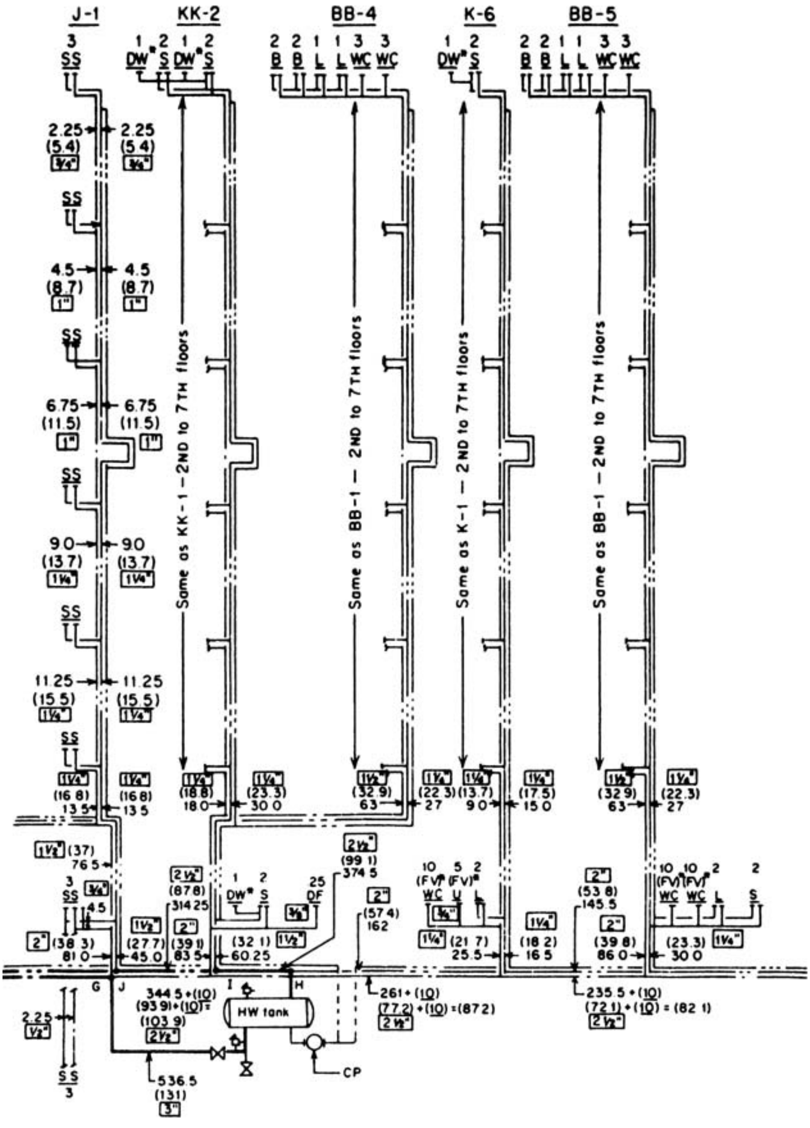


FIG.7.8 *Continued.*

lons per minute was determined from Table 2.3 by applying the values shown therein under the heading "Supply systems predominantly for flush tanks" for all piping except for short branch piping which supplies water to water closets and urinals equipped with flush valves on the first floor and in the basement.

Step 5 The continuous demand posed by the four outside hose bibs, only two of which are to be used at any time, has been shown on the design sheet. This demand has been specially underlined and included in parentheses as gallons per

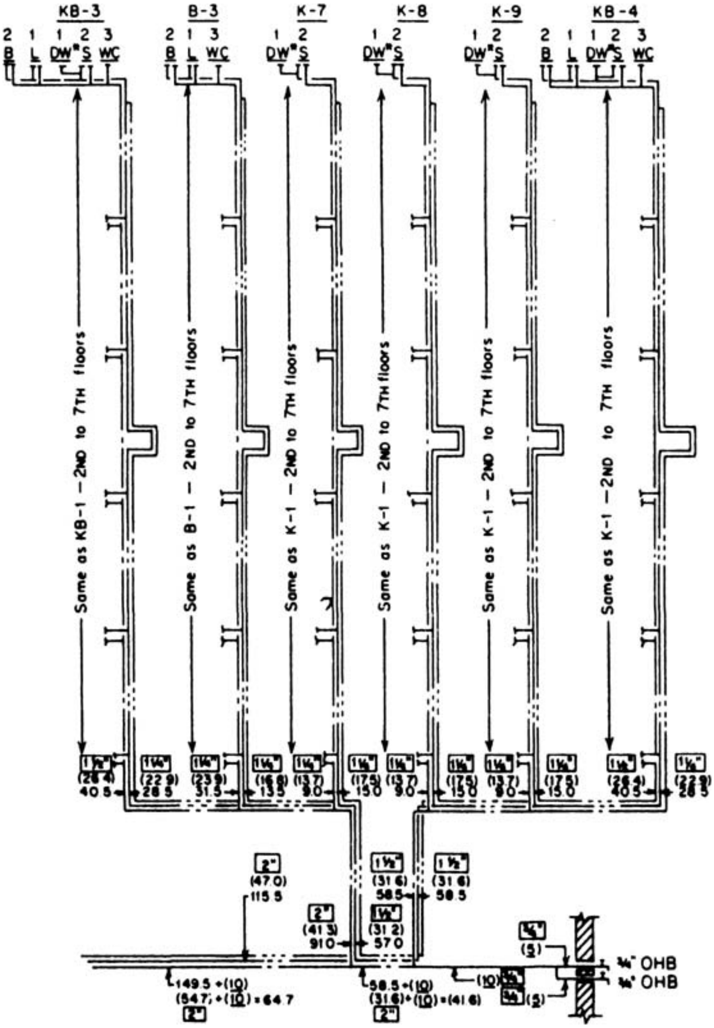


FIG. 7.8 *Continued.*

minute, or otherwise designated CL, where added to fixture units of load. The normal demand posed by a hose bib was obtained from Table 2.1.

Step 6 All individual fixture supply pipes to water outlets have been sized on the design sheet in accordance with the minimum sizes shown in Table 7.2.

Step 7 All other parts of the system have been sized in this step in accordance with the velocity limitations established for this system as the proper basis for design, i.e., 8 ft/s for all piping, except 4 ft/s for branches to quick-closing valves as noted by asterisks on the design sheet. Sizing was done in accordance with total fixture units of load corresponding to total demand in each section. For those sections of the cold-water header in the basement which convey both demand of intermittently used fixtures and continuous demand of hose bibs, the total demand in gallons per minute was converted to equivalent water supply fixture units of load and proper sizes were determined therefor, although proper sizing could also have been done simply on the basis of demand rates in gallons per minutes. Sizing was done using Tables 7.3 through 7.8, specifically Tables 7.4*a* and 7.4*b*, for sizing piping inside the building.

Step 8 Assuming conditions of no flow in the system, the amount of excess pressure available at the topmost fixture in excess of the minimum pressure required at the fixture for satisfactory supply conditions was determined as follows (see Table 7.9):

$$\text{Excess pressure available} = 75 \text{ psi} - 8 \text{ psi} - (65.67 \times 0.433) = 38.6 \text{ psi}$$

Step 9 The basic design circuit of the water supply system for the building was specially identified and shown in heavy lines on the schematic elevation provided in Step 2. For each of the 26 sections of the circuit, the developed length was given on the design sheet as determined from the plans of the system.

Step 10 The rated pressure loss through the compound water meter selected for this system was determined from appropriate meter data to be 5.8 psi for peak demand flow rate of 227.6 gpm. This has been noted on the design sheet. The rated pressure loss for flow through the horizontal hot-water storage tank, i.e., entrance and exit losses, may be assumed to be approximately 1.6 ft head or 0.7 psi.

TABLE 7.9 Pressure Calculations for Basic Design Circuit

Minimum at public main	75.0 psi
Loss in rise to top outlet (65.67 ft × 0.433)	−28.4 psi
Static pressure at top outlet	46.6 psi
Minimum pressure at top outlet	− 8.0 psi
Excess static pressure at top outlet available for friction loss	38.6 psi
Friction loss through 4-in compound meter at 227 gpm flow rate (manufacturer's charts)	− 5.8 psi
	32.8 psi
Friction loss through horizontal hot-water storage tank assumed for rated flow at 8 ft/s	− 0.7 psi
Maximum pressure remaining for friction in pipe, valves, and fittings	32.1 psi
Developed length of circuit from public main to top outlet	420 ft
Equivalent length for valves and fittings in circuit (based on sizes established on velocity limitation basis)	363 ft
Total equivalent length of circuit	783 ft
Maximum uniform pressure loss for friction in basic design circuit (32.1 psi/783 ft)	0.04 psi/ft or 4.0 psi/100 ft

Step 11 The amount of pressure available for dissipation as friction loss during peak demand through pipe, valves, and fittings in the basic design circuit is (from Table 7.9)

$$38.6 - 5.8 - 0.7 = 32.1 \text{ psi}$$

Step 12 In Step 7, tentative pipe sizes for the main lines and risers were established on the basis of velocity limitations. Using such tentative sizes for the basic design circuit, corresponding equivalent lengths for valves and fittings were determined and added to the developed length to calculate the total equivalent length of the circuit. The equivalent length for valves and fittings was found to be 363.2 ft, which when added to the 420 ft developed length resulted in a total equivalent length for the basic design circuit of 783.2 ft (as calculated in Table 7.9).

Step 13 The maximum uniform pressure loss for friction in the basic design circuit is

$$32.1 \text{ psi}/783.2 \text{ ft} = 0.04 \text{ psi/ft or } 4.0 \text{ psi}/100 \text{ ft}$$

This is the pipe friction limit for the basic design circuit. It is to be applied for sizing all the main lines and risers supplying water to fixtures on upper floors of the building.

Step 14 In Table 7.10, flow rates have been tabulated, through various standard sizes of red brass pipe, that correspond to the velocity limits of 4 and 8 ft/s and to the friction limit of 4.0 psi/100 ft of total equivalent piping length. The values shown therein for velocity limitations were taken from the tables cited in Step 7.

TABLE 7.10 Sizing Table for System in Problem 7.2

Red brass pipe, standard pipe size

Nominal pipe size, in	Velocity limit flow rate at $V = 4$ ft/s WSFU (col. A)	$V = 4$ ft/s gpm	$V = 8$ ft/s WSFU (col. A)	$V = 8$ ft/s gpm	Friction limit flow rate at 4.0 psi/100 ft, gpm
½	1.5	3.8	3.7	7.6	2.8
¾	3.0	6.6	8.4	13.2	5.8
1	6.3	11.1	26.4	22.0	11.7
1¼	16.8	18.3	75.0	36.6	22.5
1½	36.3	25.2	130.0	50.4	33.0
2	92.0	41.6	291.0	83.2	66.0
2½	181.0	61.2	492.0	122.4	112.0
3	335.0	92.0	842.0	184.0	288.0
4	685.0	158.0	1920.0	316.0	380.0

Note: Apply the column headed "Velocity limit, $V = 4$ ft/s" to size branches to quick-closing valves. Apply the column headed "Velocity limit, $V = 8$ ft/s" to all piping other than individual fixture supplies. Apply the column headed "Friction limit" just for sizing piping that conveys water to top floor outlets. Where two columns apply and two different sizes are indicated, select the larger size.

The values shown therein for friction limitation were taken directly from Fig. 7.2*a*, one of the accurate pipe friction charts presented earlier in this chapter. The chart applied to red brass pipe of standard pipe size and was appropriate in view of the water supply conditions and surface condition, "fairly smooth."

Step 15 All the main lines and risers on the design sheet have been subjected to sizing in accordance with the friction limitation for the basic design circuit. Where sizes determined in this step were larger than those previously determined in Step 7 (based on velocity limitation), the increased size was noted directly on the design sheet. Increased sizes were made in all risers and in some parts of the main lines in this system. As an example, in the basic design circuit the sizes of many sections were increased and may be specifically cited as follows: sections J–K, K–L, and L–M were increased from 2 in to 2½ in; sections O–P and P–Q were increased from 1½ in to 2 in; sections Q–R, R–S, and S–T were increased from 1¼ in to 1½ in; sections T–U, U–V, and V–W were increased from 1 in to 1¼ in; section W–X was increased from ¾ in to 1¼ in; and section X–Y was increased from ¾ in to 1 in.

Step 16 From the characteristics of the water supply stated in the problem, it is recognized that the water is relatively noncorrosive and nonscaling. Consequently, there is no need for additional allowance in sizing in this case.

CHAPTER 8

PIPING INSULATION

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INTRODUCTION

This chapter describes the various types of material used as thermal insulation in piping systems and provides information concerning their physical characteristics. The selection of an appropriate choice of insulation material is discussed, and methods of determining a thickness which is cost-effective are described. Other subjects include the control of condensation on the walls of piping; the temperature drop, as a result of heat transfer, in piping carrying warm water; thermal insulation of pipes as a protection against freezing; jackets as a covering for thermal insulation around pipes; insulation for noise control in piping systems; code considerations in selecting a material and applying thermal insulation on piping; and the installation of piping insulation.

TYPES AND CHARACTERISTICS OF PIPING INSULATION

Table 8.1 lists types of insulation widely used on water supply and steam piping systems in residential and commercial buildings and tabulates their key properties and characteristics.[1] (None of the piping insulation types referenced here contain asbestos fibers. Manufacture of insulation of this type has been discontinued in the U.S.A. because of the health hazard such fibers create.) The following materials are widely used in piping insulations:

Calcium silicate, which is composed principally of hydrous calcium silicate and reinforcing fibers processed into a rigid structure. It is used on piping where a fire or explosion hazard exists and where the insulation must provide some fire protection to the piping. It is generally not used in residential or commercial steam or hot-water services.

TABLE 8.1 Useful Temperature Ranges and Thermal Conductivities of Common Types of Thermal Insulation Used on Plumbing Systems and Steam Lines

Type of insulation	Applicable ASTM standard	Forms of insulation	Service temperature range, °F (°C)	Thermal conductivity,* Btu·in/(h·ft^2·°F) [Watts/(m·°C)] at 75°F (23.9 °C) mean temperature	Common application
Calcium silicate	C-533, type I	Pipe, block	Above ambient to 1200 (649)	0.41 [0.059]	High-pressure steam, hot water, condensate; load bearing
Cellular glass	C-552	Pipe, block	−450 to 800 (−268 to 427)	0.38 [0.055]	Dual temperature, cold water, brine; load bearing
Cellular elastomer, flexible	C-534	Pipe, sheet	−40 to 200 (−40 to 93)	0.27 [0.039]	Dual temperature to 200°F, cold water, runouts, non-load-bearing
Cellular polystyrene	C-578, type I	Board (pipe)	−65 to 165 (−53 to 74)	0.25 [0.036]	Dual temperature to 165°F, cold water, hot water to 165°F; limited load bearing
Cellular polyurethane	C-591, type 1	Board (pipe)	−40 to 225 (−40 to 107)	0.16 [0.023]	Dual temperature to 200°F, cold water, hot water to 225°F; limited load bearing
Mineral fiber: fiberglass	C-547, class 1	Pipe	−20 to 450 (−29 to 232)	0.23 [0.033]	Dual temperature to 450°F, steam, condensate, hot and cold water; non-load-bearing
Mineral fiber: rock or slag	C-547, class 3	Pipe	Above ambient to 1200 (649)	0.23 [0.033]	Steam, condensate, hot and cold water; non-load-bearing

*The ASTM standards listed give maximum thermal conductivity values, which are approximately 10 percent higher than the nominal values given by most insulation manufacturers.

Cellular elastomeric, which is composed principally of natural or synthetic elastomers (or both), processed into a flexible foam which has a predominately closed-cell structure.*

Cellular glass, which is composed of glass processed to form a rigid foam having a predominately closed-cell structure.

Cellular polystyrene, which is composed principally of polymerized styrene resin processed to form a rigid foam having a predominately closed-cell structure. It must be fabricated into the piping insulation form from blocks or boards.

Cellular polyurethane, which is composed principally of the reaction product of polyisocyanate or polyisocyanurate and polyhydroxy compounds, processed usually with fluorocarbon gas to form a rigid foam having a predominately closed-cell structure. It must be fabricated into the piping insulation form from blocks or boards.

Diatomaceous silica, which is composed principally of diatomaceous earth with binders and which usually contains reinforcing fibers processed to form a rigid structure.

Mineral fiber, which is composed principally of mineral fibers manufactured from glass, rock, or slag with binders processed to form a semirigid or rigid structure.

Most manufacturers of piping insulations have adopted dimensional standards for the inner and outer diameters of rigid and semirigid piping insulations for pipes and tubing. This is (*a*) to ensure satisfactory fit of the insulation on standard piping sizes, (*b*) to accommodate radial expansion of tubing and piping that are heated after they are insulated, (*c*) to permit application of one layer of insulation over another layer (nesting), and (*d*) to minimize the number of preformed pipe insulation sizes and wall thicknesses to be manufactured and stocked. Most manufacturers follow ASTM Standard C-585,[1] on recommended sizes of insulation.

Rigid piping insulation is supplied in semicylindrical sections. The two half-sections are joined to enclose the pipe. Semirigid insulation is usually fabricated in full sections with a seam to allow a separation that is sufficient to fit over the piping or tubing during installation. Flexible piping insulation is usually available with no seam for installation on flexible tubing before a fitting is installed, or with a seam for installation on the finished piping system. The rigid and semirigid piping insulation types are usually supplied with a factory-applied vapor retarder jacket; the flexible types are not.

Piping insulation can be divided into two major categories:

A *reflective type of insulation* is an insulation whose performance depends upon the reduction of radiant heat transfer across air spaces by use of one or more surfaces of high reflectance and low emittance.[2]

A *mass type of insulation* is an insulation whose performance depends upon reduction of heat transfer by conduction, convection, and radiation through its thickness. Insulations of this type (vs. reflective type) are most widely used for piping insulation in residential and commercial buildings.

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* A *closed cell* is one of the many air spaces (cells), in a material such as foam plastic, that is totally enclosed by its walls and hence does not interconnect with other cells. If the cell interconnects with others, it is called an *open cell*.

THERMAL CONDUCTIVITY AND THERMAL RESISTANCE

The *thermal conductivity* (represented by the letter k) of a homogeneous insulation material is the rate of heat flow through a unit area and unit thickness of the material, in a direction perpendicular to the surface, when a unit temperature gradient is maintained in a direction perpendicular to the area. It is a measure of the insulation value of the material—the lower the value of k, the higher the insulation the material provides. In English (U.S. Customary System) units, thermal conductivity is measured in units of Btu · in/(h · ft^2 · °F); in the International System of units, it is measured in units of W/(m · K). Typical values of k for piping insulation are given in Table 8.1.

Thermal resistance (represented by the letter R) is given by:

$$R = \frac{T}{k} \tag{8.1}$$

where T is the thickness and k is the thermal conductivity. For example, according to Table 8.1 the k value for cellular polystyrene at 75°F (23.9°C) mean temperature is 0.25 Btu · in/(h · ft^2 · °F). Therefore, from Eq. (8.1) the R value for a 3-in (7.6-cm) thickness is 3/0.25 = 12 h · ft^2 · °F/Btu at 75°F (23.9°C) mean temperature.

Thermal conductance (represented by the letter c) is the reciprocal of thermal resistance.

Conversion factors are

k (thermal conductivity): 1 Btu · in/(h · ft^2 · °F) = 519.22 W/(m · K)
c (thermal conductance): 1 Btu/(h · ft^2 · °F) = 5.682 W/(m^2 · K)
Temperature: °F = (°C × $\frac{9}{5}$) + 32
K = °C + 273.15
Temperature difference: 1°C = 1 K = 1.8°F

SELECTION OF TYPE OF PIPING INSULATION

An appropriate selection of piping insulation usually can be made from the materials listed in Table 8.1 for both water and steam lines. The principal factors in making this selection are (*a*) the need to meet code requirements, (*b*) the operating temperature, (*c*) the conditions of the ambient air (temperature and humidity), (*d*) the requirement for a vapor barrier, (*e*) the cost-effectiveness of the insulation, (*f*) space availability, and (*g*) the need to provide satisfactory performance over a long service life.

The need for insulation to meet code requirements for noncombustibility[3] or fire hazard classification[4] must be identified. Any special requirements that depend on the occupancy of the building and its construction must be known. When insulated piping is located within a plenum (such as the space between a suspended ceiling and the floor above), the applicable building or mechanical code may require that the insulation be either noncombustible or that it have a flame spread index not exceeding 25 and a smoke developed index not exceeding 50.

There may be other restrictions on the use of types of piping insulation that have a fire hazard classification exceeding either of these ratings. This consideration may be important when piping insulation of the cellular elastomeric, cellular polystyrene, or cellular polyurethane types are to be used.

Operating temperature often is a determining factor in the selection process. For example, if a steam line has an operating temperature of 350°F (177°C), then an insulation that has a maximum service temperature limit of at least this value must be selected. Of the materials that can withstand this temperature, those having a lower thermal conductivity require a lesser thickness to meet performance requirements; therefore, they would be the preferred materials.

When the water service temperature is below the ambient temperature, the upper temperature limit is not so important. In this case, the performance of a factory-applied vapor barrier may be significant in providing a satisfactory long-term service life for the insulation. As indicated in a following section, "Condensation and Its Control," water vapor in the air surrounding piping can condense on the surface of the insulation, degrading the thermal performance and damaging the material. Generally, water supply lines at temperatures of 20°F (− 6°C) and above may be insulated with the closed-cell types of piping insulation and with mineral fiber piping insulation made from glass fibers. For operating temperatures below this temperature, a closed-cell type of insulation usually is preferred.

When the piping is used for dual temperature service (service temperatures above ambient for part of the year and below ambient for another part of the year), the piping insulation selected must be suitable for service at both temperatures and it must also be provided with vapor retarder protection.

For some applications, there may be more than one type of piping insulation, commercially available, that can provide satisfactory long-term service and performance. Then, cost considerations heavily influence selection of the type of insulation.

DETERMINATION OF PIPING INSULATION THICKNESS

Insulation may be required on piping because of the need for (*a*) energy conservation, (*b*) condensation control, (*c*) personnel protection, (*d*) temperature control, and (*e*) noise control. For each of these needs, a different thickness may be optimum. Then, the critical insulation thickness should be identified.

Critical Insulation Thickness

When insulation is needed to satisfy more than one requirement, the insulation thickness required for each must be determined. The *critical thickness*, the largest of the individual thickness solutions, is the only thickness that will satisfy all the design parameters. For example, if the economic thickness is 2 in (5.1 cm) and personnel protection thickness is 1½ in (3.8 cm), the economic thickness is critical and should be specified. This thickness, being greater than that needed for personnel protection, will still meet the design parameters for personnel protection.

A computer program[5] may be used to estimate (*a*) heat losses or heat gains for insulated pipes and equipment and (*b*) the surface temperature of insulation. Such a program may be used to determine the thickness of an insulation that will meet a specified heat flow or a specified surface temperature for a given set of conditions. It may also be used to help determine the appropriate insulation thickness for energy conservation, condensation control, or for personnel protection.

Economic Thickness and Energy Considerations

In determining the economic thickness of insulation to be applied to piping, one must consider not only the initial cost of the insulation and its installation, but also many other factors such as return on investment, maintenance, cost of the equipment, operating conditions, the insulation type, and the savings in energy resulting from the application of the insulation. All of these factors are needed to determine the costs related to insulation ownership and the heat-loss (heat-gain) related costs. All of these costs can be converted to an equivalent annual cost by a method described in Ref. 6. The results are illustrated in Fig. 8.1, which shows cost as a function of the thickness of the insulation. The cost of the piping insulation increases with thickness. In contrast, heat-loss-related costs decrease with the thickness of insulation. The *economic thickness* is that thickness which yields the minimum total of these costs per year.

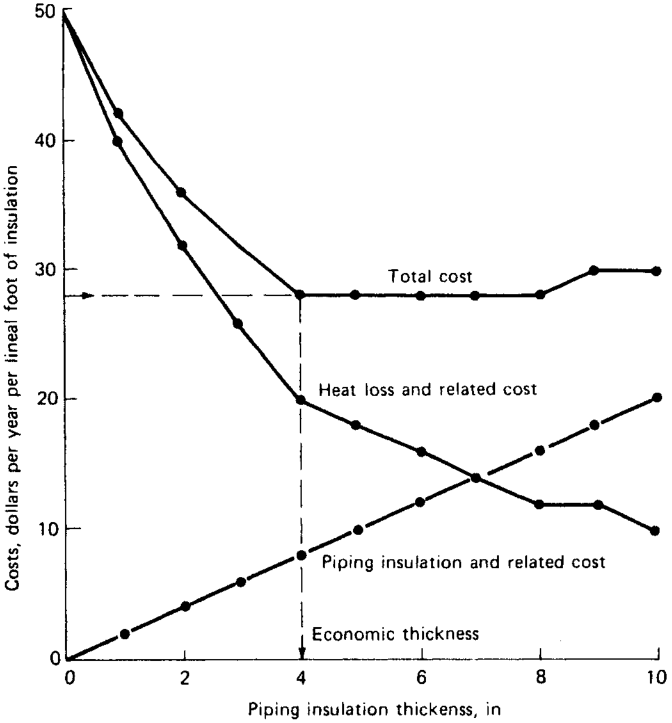

FIG. 8.1 The relationship, as a function of frequency, of (*a*) piping insulation and related costs and (*b*) heat loss and related costs. The total cost is the sum of (*a*) and (*b*). The least thickness which yields the minimum total cost is defined as the *economic thickness*.

The calculation of economic thickness is complex, but computer programs are available for making such calculations quickly and easily. Many insulation manufacturers offer this calculation service to designers and specifiers. Because the operating conditions connected with piping for building services (such as domestic hot water and chilled drinking water) are not critical, the use of the economic thickness calculation is usually not necessary provided an energy conservation code is followed and minimum insulation thicknesses are specified.

When a building must comply with an energy conservation code or a standard such as ASHRAE 90[7] (or BOCA,[8] ICBO,[9] or SBCCI[10]), minimum insulation thicknesses are mandated by the local authority having jurisdiction for (*a*) steam piping, (*b*) steam condensate, (*c*) domestic and service hot water, (*d*) chilled water, and (*e*) brine. These minimum thicknesses depend on the pipe size and the operating temperature of the fluid in the pipe. Generally, they have been selected on a basis of average economic considerations. For a particular building, it may be economically justifiable to select an insulation thickness greater than the minimum specified by the governing code or standard. For example, the energy conservation code may not require insulation for domestic and service hot water and chilled drinking water with temperatures in the range of 55 to 105°F (13 to 41°C). Table 8.2 provides recommended insulation thicknesses for piping in this temperature range. The thicknesses are calculated to meet an energy conservation objective of not more than 12 Btu/(h · ft^2) [68.1 W/(m^2 · K)], where ft^2 and m^2 refer to the insulation outer surface area, for an insulation having a thermal conductivity in the range of 0.22 to 0.25 Btu · in/(h · ft^2 · °F) [0.032 to 0.037 W/(m · K)] at 75°F (24°C) mean temperature.

TABLE 8.2 Minimum Piping Insulation Thickness

For an energy conservation objective of not more than 12 Btu/(h · ft^2 of outer insulation surface) [68.1 W/(m^2 · K)] where energy conservation codes may exempt need for insulation

		Insulation thickness,* in (cm), for nominal pipe size of		
System†	Water temperature, °F (°C)	Up to 2½ in (6.4 cm)	3 to 6 in (8 to 15 cm)	8 in (20 cm) and above
Domestic hot water, general purpose	95 (35)	½ (1.3)	½ (1.3)	1 (2.5)
Domestic hot water, general purpose	110 (43)	½ (1.3)	½ (1.3)	1 (2.5)
Domestic hot water, general purpose	120 (49)	½ (1.3)	1 (2.5)	1 (2.5)
Domestic hot water, utility systems	140 (60)	1 (2.5)	1 (2.5)	1 (2.5)
Sanitizing systems	180 (82)	1½ (3.8)	1½ (3.8)	2 (5.1)
Chilled water‡	45 to 55 (7 to 13)	½ (1.3)	½ (1.3)	1 (2.5)

*Table based on use of insulation having a thermal conductivity in the range of 0.22 to 0.25 Btu · in/(h · ft^2 · °F) at 75°F mean temperature.

†Thickness selected to have heat transfer rate not exceeding 12 Btu/(h · ft^2 of outer surface) for energy conservation. Thicknesses for other insulations having thermal conductivities outside the range in the note above must be determined to meet this limit.

‡Condensation control required. If relative humidity exceeds 75 percent, additional thickness may be required to prevent condensation on the outer surface of the insulation.

CONDENSATION AND ITS CONTROL

Condensation (also called *sweating*) is the formation of water on the exterior surfaces of cold pipes when the temperature of the air falls below its dew point (i.e., the temperature at which the air is fully saturated). Water vapor in the air is changed to moisture on the surface of the pipes by the extraction of heat. Condensation may be prevented by the covering the outer surface of an insulated pipe with a membrane called a *vapor barrier* to prevent moisture from penetrating the insulation and reaching the cold pipe; the term *vapor retarder* also is used, since such barriers are not 100 percent effective and the membrane simply retards the flow of water vapor. The membrane may be factory-applied on the insulation or be of a type recommended by the manufacturer for use with the insulating material. It is very important that the membrane be sealed at seams, joints, fittings, hangers, supports, and all other penetrations of the insulation. Otherwise the effectiveness of the vapor barrier will be greatly reduced.

Energy conservation codes do not consider the control of condensation moisture on the surface of cold piping in determining the required insulation thickness. Therefore, to avoid condensation on cold piping, a greater thickness may be required than is necessary for energy conservation purposes. Table 8.3 shows the thicknesses needed to prevent condensation if the ambient air is 100°F (38°C) at relative humidities from 50 to 90 percent, for glass-fiber insulation covering a pipe in which the water temperature is 45°F (7°C). The thickness necessary to prevent condensation on the surface of a cold pipe can also be determined by the following procedure.

First, the dew point temperature of the ambient air must be determined from the dry-bulb temperature and relative humidity. The psychrometric chart shown in Fig. 8.2 is used to determine the humidity ratio at the ambient air conditions, which in turn establishes the saturation temperature (dew point temperature). Condensation will not occur on the vapor barrier jacket of the piping insulation if its temperature is kept above this dew point temperature by thermal insulation. Equation (8.2) shows how the temperature drops across the outside air film and across the insulation are proportional to the thermal resistances of the outside air film and the insulation resistance.

$$\frac{T_a - T_{\text{dew point}}}{T_{\text{dew point}} - T_{\text{pipe}}} = \frac{R_{\text{air film}}}{R_{\text{insulation}}} \tag{8.2}$$

For most cases, the thermal resistance of the outside air film is about 0.62 h · ft^2 · °F/Btu for still air and a nonreflective jacket. The thermal resistance of the insulation is:

$$R_{\text{insulation}} = \frac{\ln (r_o/r_i)(12)}{6.28Lk} \tag{8.3}$$

where ln = natural logarithm
r_o = outside radius of the pipe insulation, in
r_i = inside radius of the pipe insulation, in
k = thermal conductivity of the insulation
L = pipe length, ft

TABLE 8.3 Minimum Piping Insulation Thickness on Copper Tubing to Prevent Surface Condensation

For an insulation having a thermal conductivity in the range of 0.22 to 0.25 Btu · in/(h · ft² · °F) [0.032 to 0.037 W/(m · K)] at 75 °F (24 °C) mean temperature

Ambient air conditions				Minimum insulation thickness,* in (cm), for nominal tube size of					
Dry-bulb temperature, °F (°C)	Relative humidity, %	Dew point temperature, °F (°C)	Water temperature in tube, °F (°C)	Less than 1 in (2.5 cm)	1 to 2 in (2.5 to 5 cm)	2½ to 3 in (6.4 to 8 cm)	3½ to 4 in (9 to 10 cm)	5 in (12.7 cm)	6 in (15.2 cm)
80 (26.7)	50	59.7 (15.4)	45 (7.2)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	55	62.4 (16.9)		½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	60	64.9 (18.3)		½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	65	67.2 (19.6)		½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	70	69.3 (20.8)		½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	75	71.4 (21.9)		½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	80	73.3 (22.9)		½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)	½ (1.3)
	85	75.1 (23.9)		½ (1.9)	1 (2.5)	1 (2.5)	1 (2.5)	1 (2.5)	1 (2.5)
	90	76.8 (24.9)		1 (2.5)	1½ (3.8)	1½ (3.8)	1½ (3.8)	1½ (3.8)	1½ (3.8)
	95	78.4 (25.8)	1½ (3.8)	2 (5.1)	2 (5.1)	2 (5.1)	2 (5.1)	2 (5.1)	

*For insulations having thermal conductivity outside this range, calculate the minimum thickness using Ref. 7. For insulations used on piping, calculate the minimum thickness using Ref. 7.

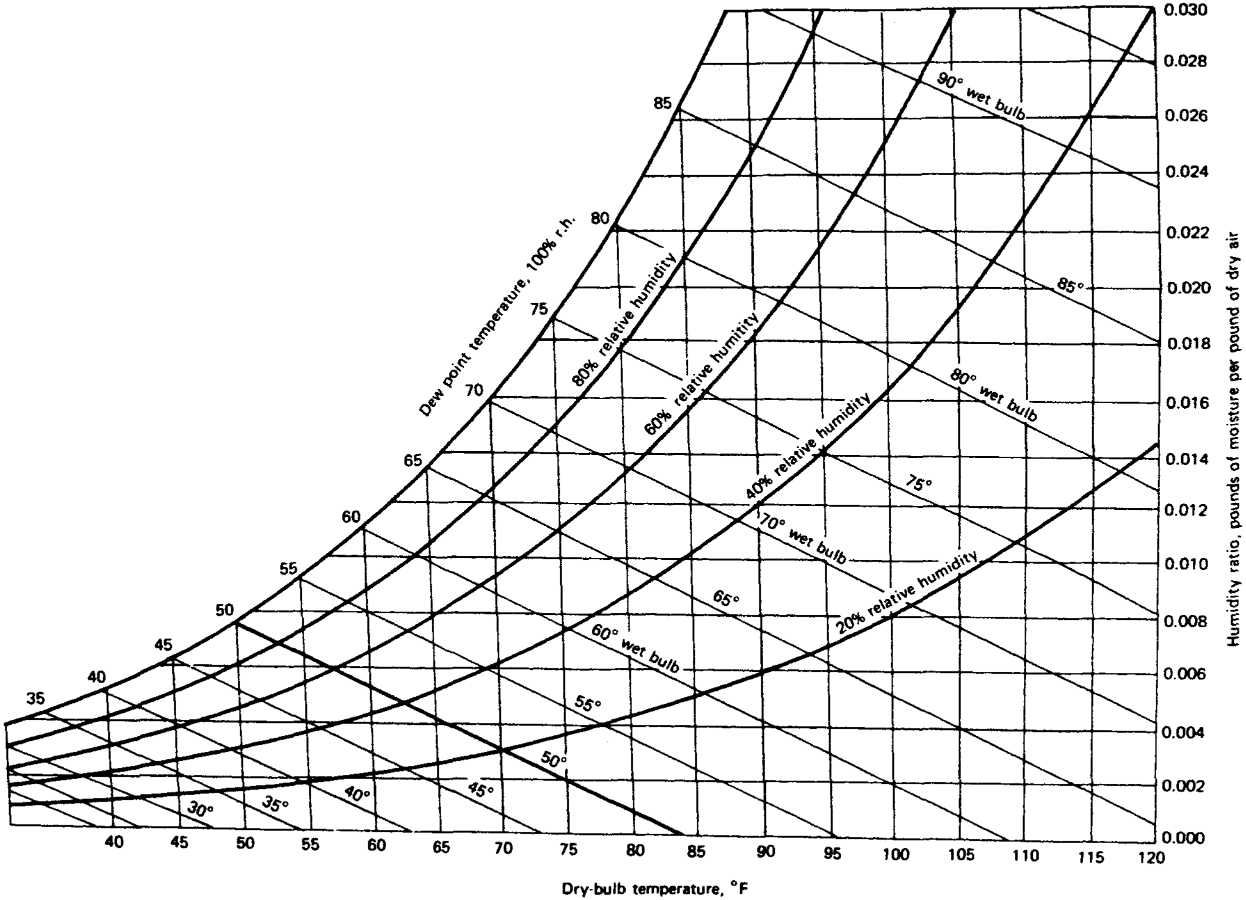

FIG. 8.2 Psychrometric chart. When air is saturated with moisture, the relative humidity is 100 percent and the air is said to be at its *dew point*; under these conditions, the wet-bulb and dry-bulb temperatures are equal. (The wet-bulb temperature is measured with a sling psychrometer; the dry-bulb temperature is measured with an ordinary thermometer.) This chart shows the relationship between the dry-bulb temperature, wet-bulb temperature, humidity ratio, and the temperature of the dew point. For example, if the wet-bulb temperature is 75°F and the dry-bulb temperature is 95°F, the lines corresponding to these two values intersect at a humidity ratio of 0.014. Then, a horizontal line through this intersection crosses the dew point curve, along the left side of the illustration, at 66°F. Therefore, the temperature of the dew point is 66°F. (*Adapted with permission from the* ASHRAE Handbook.[11])

Solving Eq. (8.2) for $R_{\text{insulation}}$,

$$R_{\text{insulation}} = \frac{0.62(T_{\text{dew point}} - T_{\text{pipe}})}{T_a - T_{\text{dew point}}} \tag{8.4}$$

Then, for the given pipe or copper tube size, the value of r_i is obtained, and values of r_o at various wall thicknesses are used in Eq. (8.3) until the value of $R_{\text{insulation}}$ meets or exceeds that calculated from Eq. (8.4).

For example, suppose the ambient air dry-bulb temperature is 80°F (27°C), the relative humidity is 60 percent, and the fluid in the pipe is at 35°F (2°C). What thickness of fiberglass pipe insulation is needed on a 3-in (7.6-cm) iron pipe to prevent condensation?

The dew point temperature from the psychrometric chart, Fig. 8.2, is 66°F (18.9°C). From Eq. (8.4), the r value of the pipe insulation may be not less than (0.62) (66 − 35)/(80 − 66), or 1.37. From ASTM C-585, the inside radius of the insulation is 1.77 in (4.5 cm). The outside radius is 2.78 in (7.1 cm) for a 1-in (2.5-cm) nominal wall thickness. When these values are used in Eq. (8.3), $R_{\text{insulation}}$ is 3.75, which indicates that condensation will not occur on the jacket. For this condition, the 0.5-in-thick (1.27-cm) wall yields an $R_{\text{insulation}}$ value of 1.99 and will prevent condensation at a lower cost. It therefore is the thickness of choice.

TEMPERATURE DROP RESULTING FROM HEAT TRANSFER

When water flows in a pipe, heat is transferred between the water and the ambient air. The direction of this heat transfer is from the water to the air (heat loss) when the water temperature exceeds the ambient air temperature, or from the ambient air to the water (heat gain) when the water temperature is below the ambient air temperature. The amount of heat transferred is a function of the temperature difference, the pipe size, the pipe length, the thermal resistance between the water and the ambient air, and the rate of flow of the water. Under no-flow or low-flow conditions, the temperature of the water can be changed significantly. This is particularly apparent for uninsulated pipes in which the velocity of the water fluctuates. Hot water is wasted when a user must wait for it to reach the tap. In long piping systems, operators often raise the temperature of the water so that the desired temperature can be delivered at outlets. This also adds to energy waste. The magnitude of water temperature drop per 100 ft (30.8 m) of length of selected pipe sizes at different flow rates, for ambient air at 70°F (21°C) and for fiberglass insulation, is given in Table 8.4.

PROTECTION AGAINST FREEZING

In some buildings, the water supply piping passes through spaces in which the temperature may drop below freezing. Under no-flow conditions, and for small-diameter pipes, the time for the water temperature to fall to the freezing point may be less than 1 h—even with insulation on the pipes. With flow in the pipes, and with an increase in pipe diameter, the time required for the pipes to freeze is

TABLE 8.4 Water Temperature Drop in Pipes per 100 ft (30.5 m)

For indoor ambient air at 70°F (21 °C) and fiberglass piping insulation

Nominal pipe diameter, in (cm)	Water temperature at source, °F (°C)	Insulation thickness, in (cm)	Water flow rate, gpm (L/min)	Water temperature drop per 100 ft (30.5 m), °F (°C)
½ (1.37)	80 (26.7)	½ (1.27)	1 (3.8)	0.27 (0.15)
	95 (35)	½ (1.27)	1 (3.8)	0.68 (0.38)
	110 (43.3)	½ (1.27)	1 (3.8)	1.12 (0.62)
	120 (48.9)	½ (1.27)	1 (3.8)	1.42 (0.79)
	140 (60)	1 (2.54)	1 (3.8)	1.50 (0.83)
	180 (82.2)	1½ (3.81)	1 (3.8)	2.12 (1.18)
½ (1.37)	80 (26.7)	½ (1.27)	3 (11.4)	0.09 (0.05)
	95 (35)	½ (1.27)	3 (11.4)	0.23 (0.12)
	110 (43.3)	½ (1.27)	3 (11.4)	0.38 (1.21)
	120 (48.9)	½ (1.27)	3 (11.4)	0.48 (0.23)
	140 (60)	1 (2.54)	3 (11.4)	0.50 (0.28)
	180 (82.2)	1½ (3.81)	3 (11.4)	0.71 (0.39)
½ (1.37)	80 (26.7)	½ (1.27)	10 (37.9)	.03 (0.02)
	95 (35)	½ (1.27)	10 (37.9)	.07 (0.04)
	110 (43.3)	½ (1.27)	10 (37.9)	.11 (0.06)
	120 (48.9)	½ (1.27)	10 (37.9)	.14 (0.08)
	140 (60)	1 (2.54)	10 (37.9)	.15 (0.08)
	180 (82.2)	1½ (3.81)	10 (37.9)	.21 (0.12)

increased. Table 8.5 shows the time required for water pipes to freeze for pipes of various diameters, under no-flow conditions, if they are covered with fiberglass insulation of different thicknesses. The table also gives values of the minimum rate of flow required to prevent freezing under the same conditions. For example, suppose a ½-in (1.27-cm) pipe is insulated with a ½-in (1.27-cm) thickness of fiberglass insulation, the ambient air temperature is 0°F (−17.8°C), and the water temperature in the pipe initially is 45°F (7.2°C). From Table 8.5, the time to freezing under no-flow conditions is 0.3 h (18 min). Table 8.5 also shows that freezing will not occur if the rate of water flow is not less than 0.47 lb/(h · ft) of pipe [0.7

TABLE 8.4 Water Temperature Drop in Pipes per 100 ft (30.5 m) *(Continued)*

3 (7.62)	80 (26.7)	½ (1.27)	1 (3.8)	0.81 (0.45)
	95 (35)	½ (1.27)	1 (3.8)	2.07 (1.15)
	110 (43.3)	½ (1.27)	1 (3.8)	3.38 (1.88)
	120 (48.9)	1 (1.27)	1 (3.8)	2.74 (1.52)
	140 (60)	1 (2.54)	1 (3.8)	3.95 (2.59)
	180 (82.2)	1½ (3.81)	1 (3.8)	5.11 (2.84)
3 (7.62)	80 (26.7)	½ (1.27)	3 (11.4)	0.28 (0.16)
	95 (35)	½ (1.27)	3 (11.4)	0.71 (0.39)
	110 (43.3)	½ (1.27)	3 (11.4)	1.16 (0.64)
	120 (48.9)	1 (1.27)	3 (11.4)	0.96 (0.53)
	140 (60)	1 (2.54)	3 (11.4)	1.35 (0.75)
	180 (82.2)	1½ (3.81)	3 (11.4)	1.74 (0.90)
3 (7.62)	80 (26.7)	½ (1.27)	10 (37.9)	.08 (0.04)
	95 (35)	½ (1.27)	10 (37.9)	.22 (0.12)
	110 (43.3)	½ (1.27)	10 (37.9)	.35 (0.19)
	120 (48.9)	1 (1.27)	10 (37.9)	.28 (0.16)
	140 (60)	1 (2.54)	10 (37.9)	.41 (0.23)
	180 (82.2)	1½ (3.81)	10 (37.9)	.52 (0.29)

Note: To account for losses due to joints, fittings, hangers, and supports, the heat loss due to piping is increased by 15 percent.

kgm/(h · m)]. Another method of preventing freezing is to wrap the pipe with electrical heating tape before the insulation is applied. Table 8.5 also indicates the supplemental heating required to prevent freezing under no-flow conditions. If the building use is seasonal, protection may be provided by draining the piping system.

PERSONNEL PROTECTION

Thermal insulation can be used to reduce the surface temperature of hot pipes and equipment so that people will not be burned by coming in contact with the

TABLE 8.5 Time to Freezing under No-Flow Conditions, Minimum Piping Supplemental Heating to Prevent Freezing under No-Flow Conditions, and Minimum Water Flow Rate to Prevent Freezing

For selected piping sizes and piping insulation thicknesses; initial water temperature 45°F (7.2°C) and ambient air temperature 0°F (−17.8°C).

Nominal pipe size, in (cm)	Nominal insulation thickness, in (cm)	Time* to freezing, min	Minimum water flow rate,† lb/(h · ft) [kg/(h · m)]	Minimum supplemental heat required,‡ Btu/(h · ft) (W/m)
½ (1.3)	½ (1.27)	0.3	0.47 [0.70]	11.5 (11.1)
½ (1.3)	1 (2.54)	0.5	0.30 [0.45]	5.0 (4.8)
½ (1.3)	1½ (3.81)	0.6	0.24 [0.36]	2.9 (2.8)
½ (1.3)	2 (5.08)	0.7	0.21 [0.31]	2.0 (1.9)
3 (7.6)	½ (1.27)	2.3	1.83 [2.82]	15.7 (15.1)
3 (7.6)	1 (2.54)	4.1	0.87 [1.29]	6.9 (6.6)
3 (7.6)	1½ (3.81)	5.7	0.61 [0.91]	4.2 (4.0)
3 (7.6)	2 (5.08)	7.0	0.49 [0.73]	3.0 (2.9)
8 (20.3)	1 (2.54)	13.3	2.18 [3.24]	7.5 (7.2)
8 (20.3)	1½ (3.81)	18.7	1.40 [2.08]	4.9 (4.7)
8 (20.3)	2 (5.08)	23.7	1.06 [1.58]	3.6 (3.5)

*Calculated time for the water in the pipe to reach 32°F (0°C) with no flow and no supplemental heat.

†Calculated minimum flow rate of water needed to keep the water from freezing with no supplemental heat.

‡Calculated supplemental heat needed to maintain the water temperature above 32°F (0°C) with no flow.

hot surfaces.[12] Contact with metallic surfaces at temperatures of 130°F (54°C) for more than a few seconds can cause skin damage. Piping insulation used for building service water and steam has a laminated protective outer jacket. If the insulation is sufficiently thick so that the surface temperature of the jacket does not exceed 130°F (54°C), burn protection is provided. If the jacket on the piping insulation has a metallic protective surface outer jacket, then the insulation should be sufficiently thick to ensure that the surface temperature of the jacket does not exceed 120°F (49°C) if burn protection is to be provided.

For ambient air temperature at 100°F (38°C), Table 8.6 provides approximate values of the surface temperature for pipes having different thicknesses of insulation. This table shows that, in general, an insulation thickness based on economics or energy conservation criteria also will provide personnel protection.

TABLE 8.6 Calculated Surface Temperature of Fiberglass Piping Insulation with Laminated Jacketing to Yield a Temperature below 130°F (54°C) to Protect Personnel from Burns on Contact when the Ambient Air is 100°F (37.8°C)

Nominal pipe size, in (cm)	Insulation thickness, in (cm)	Water temperature in pipe, °F (°C)	Surface temperature, °F (°C)
½ (1.3)	½ (1.3)	140 (60)	105 (40.6)
		180 (82.2)	112 (44.4)
	1 (2.5)	140 (60)	102 (38.9)
		180 (82.2)	106 (41.1)
	1½ (3.8)	140 (60)	101 (38.3)
		180 (82.2)	103 (39.4)
2½ (6.4)	½ (1.3)	140 (60)	107 (41.7)
		180 (82.2)	115 (46.1)
	1 (2.5)	140 (60)	103 (39.4)
		180 (82.2)	108 (42.2)
	1½ (3.8)	140 (60)	102 (38.9)
		180 (82.2)	104 (40)
3 (7.6)	½ (1.3)	140 (60)	108 (42.2)
		180 (82.2)	117 (47.2)
	1 (2.5)	140 (60)	104 (40)
		180 (82.2)	108 (42.2)
	1½ (3.8)	140 (60)	102 (38.9)
		180 (82.2)	105 (40.6)
6 (15.2)	½ (1.3)	140 (60)	102 (38.9)
		180 (82.2)	118 (47.8)

TABLE 8.6 Calculated Surface Temperature of Fiberglass Piping Insulation with Laminated Jacketing *(Continued)*

	1 (2.5)	140 (60)	104 (40)
		180 (82.2)	110 (43.3)
	1½ (3.8)	140 (60)	103 (39.4)
		180 (82.2)	106 (41)
8 (20.3)	1 (2.5)	140 (60)	104 (40)
		180 (82.2)	109
	1½ (3.8)	140 (60)	103 (39.4)
		180 (82.2)	106 (41.1)
	2 (5.1)	140 (60)	102 (38.9)
		180 (82.2)	105 (40.6)

PIPING INSULATION JACKETS

Surface treatment for piping insulation provides (*a*) protection for the insulation, (*b*) an attractive appearance for piping that may be visible, and (*c*) a vapor barrier covering insulation on cold piping, as described earlier in the section "Condensation and Its Control." The requirements for protection performance of jackets are the same for both hot and cold service. Therefore, rigid and semirigid piping insulation usually is available with factory-applied jacketing which acts as a vapor barrier. During the installation of such insulation, the integrity of the vapor retarder must be maintained. A jacket is not furnished on flexible piping insulation. The outer surface of flexible insulation provides sufficient protection and vapor-retarder performance for most applications.

Materials used as vapor barriers on pipe insulations must have a low water vapor permeance to retard the collection of water within the insulation system. *Permeance* is a measure of a material's resistance to water-vapor transmission, expressed in *perms*. It is the time rate of water vapor transmission through a unit area of a flat jacket material induced by unit vapor pressure difference between its two surfaces under specified temperature and humidity conditions. Vapor barriers have permeance values of 1 perm or less. In English units, one *perm* equals one grain of water vapor transmitted per one square foot per hour per inch of mercury pressure difference. In International System units, 1 perm = 0.0000000572 $g/(Pa \cdot s \cdot m^2)$. For piping operating at temperatures of −20°F (−28.9°C) and higher, the permeance of the vapor barrier should not be higher than 0.02 perms.

Code requirements regarding the surface burning characteristics of the insulation and/or jacket material may apply.[4] Standard practice requires that the fire hazard classification of the jacket material have a flame spread index of not more than 25 and smoke developed index of not more than 50. Some types of piping insulation with factory-applied jackets meet these requirements.

An important consideration in selecting a surface treatment for piping is the location of the piping. When the piping is outdoors, in addition to other requirements, piping insulation must also be protected from the elements and abuse. In this case, the weather protection materials are field-applied after the piping insulation has been installed. For cold piping, the protection is field-applied after installation of a vapor barrier.

Table 8.7 shows the properties and minimum requirements for jacketing materials commonly used as surface finishings on piping insulation. These values have been established for rigid and semirigid insulation in ASTM Standard C-921.[13] For water supply and steam piping systems, jacket materials having these minimum properties should be adequate to provide long and satisfactory service.

The following materials are commonly used on rigid and semirigid piping insulation located indoors:

Laminated Jackets. Laminated jacketing manufactured from white kraft paper, reinforcing scrim and adhesive, and aluminum foil is factory-applied on the piping insulation. There is an overlap that must be sealed along an open seam of the insulation. Strips of this material are supplied in each carton to cover the butt joints between sections during installation. See Sec. 5.3.1 of Ref. 13.

Plastic Sheets. Plastic sheets (usually manufactured from polyvinyl chloride) are field-applied over rigid and semirigid piping insulation having the standard jacketing. This is common when the piping must be washed or steam-cleaned, or when the piping systems must have high visual appeal. This material is also furnished in preformed shapes to act as a surface finish over the piping insulation at fittings such as els, tees, and valves. It is common to use such covers on fittings and to use a laminated jacket on straight piping. See Sec. 5.3.3 of Ref. 12.

Aluminum Sheets. Aluminum sheets and preformed fitting covers usually have a thickness of 0.016 in (0.4 mm). They are field-applied over rigid or semirigid piping insulation. The integrity of the vapor-retarder membrane for cold piping must be provided before this material is applied. The sheets are furnished either plain or corrugated. Aluminum jacketing is used to provide additional protection for piping insulations that may be exposed to physical abuse in service or when the exposed piping must have high visual appeal. This material is a reflective-type insulation. For a given thickness of the piping insulation, the surface temperature of the aluminum will be higher on hot piping and lower on cold piping than on surfaces that are not reflective. This may affect the selection of the insulation thickness when personnel protection or condensation control must be provided. See Sec. 5.2.2 of Ref. 13.

The following materials are commonly used on rigid and semirigid piping insulations located outdoors:

Aluminum sheets and preformed fitting covers. See Secs. 5.2.1 and 5.2.2 of Ref. 13.

TABLE 8.7 Properties and Minimum Requirements for Jacketing Materials Commonly Used as Surface Finishings on Piping Insulations for Steam and Hot and Cold Water

Property	Requirement	Test method	Jacketing materials
Fire hazard classification:		ASTM E-84	All types
Max. flame spread index	25		
Max. smoke developed index	50		
Leachability resistance:			Only those containing paper
Max. % increase in char length	20	ASTM C-921, Sec. 9.1.5	
Mold and mildew resistance:			All types
Mold growth sustenance	None	ASTM C-921, Sec. 9.1.6	
Dimensional stability:			All types
Max. % length change	0.25	ASTM C-921, Sec. 9.1.8	
Low-temperature resistance:		ASTM C-921, Sec. 9.1.9	All types
Remains flexible, no delamination	Pass	ASTM C-921, Sec. 9.1.11	
High-temperature resistance:		ASTM C-921, Sec. 9.1.10	All types
Remains flexible, no delamination	Pass	ASTM C-921, Sec. 9.1.11	
Max. water vapor permeance, perms	0.02	ASTM E-96, Procedure A	Only those used as vapor retarders
Min. puncture resistance (beach units)	50	ASTM D-781	Nonmetallic jacketings factory-applied
Min. tensile strength, lb/in of width	35	ASTM D-828	Nonmetallic jacketings factory-applied

Steel sheets and preformed fitting covers. See Secs. 5.2.1 and 5.2.2 of Ref. 13.

Stainless-steel sheets and preformed fitting covers. See Secs. 5.2.1 and 5.2.3 of Ref. 13.

Plastic sheets and preformed fitting covers. These are made of materials such as polyvinyl chloride. See Sec. 5.3.3 of Ref. 13.

Bitumen-saturated organic (rag) felts. When this treatment is used, fittings are protected by mastic and fabric or with preformed fitting covers of another material. See Sec. 5.3.4 of Ref. 13.

Mastic and Fabric. The recommendations of the mastic manufacturer should be followed as to the materials used and how they are applied.

USE OF PIPING INSULATION IN NOISE CONTROL

Various methods for controlling noise in water piping are described in other chapters of the handbook. The discussion here considers how insulation can be used for this purpose. There are two principal ways in which it can be applied beneficially.

1. Piping insulation can be used to create a physical separation of the piping system from the building structure, thereby impeding the transmission of solidborne noise from the piping to the building structure.
2. Piping insulation can be used, with a jacketing material, to reduce the noise radiated by piping.

Reduction of Solidborne Noise Transmission

Vibration in a piping system is generated within the piping by such noise sources as turbulent flow, cavitation, and water hammer. The piping, and the water within it, also transmit solidborne noise generated by equipment in the system such as pumps. The solidborne noise can be transmitted through the building structure with very little attenuation. Such noise can be reduced significantly by a physical break in the transmission path.[14] Piping insulation can be used for this purpose.

One of the most significant sources of noise caused by piping systems in buildings is physical contact between the piping and the building structure where the piping penetrates walls or floors. Figure 8.3 shows how this source of noise can be controlled by piping insulation. Where the penetration occurs, the space surrounding the pipe is filled with insulation and caulked on both sides of the partition. Before this is done, it is important to field-inspect the penetration to ensure that the piping is nowhere in contact with the partition.

Figure 8.4 shows an insulated pipe supported by a ring-type hanger. Here, vibration in the piping is transmitted by the hanger to the building structure. In this case, no noise control benefit is provided by the insulation. In contrast, Fig. 8.5 shows an insulated pipe supported by a clevis hanger. Here the piping insulation provides a physical break between the piping and the hanger, thereby impeding the transmission of solidborne noise. It is important to ensure that the insulation can support the weight of the piping. In this illustration, a sheet of metal is inserted between the insulation and the clevis hanger to distribute the weight of the insulated pipe over a larger area.

Noise Reduction of Sound Radiated by Piping (Also see Chap. 20)

Where piping radiates noise directly to the air, piping insulation covered with a jacket can provide a reduction in noise level. To be effective, the insulation

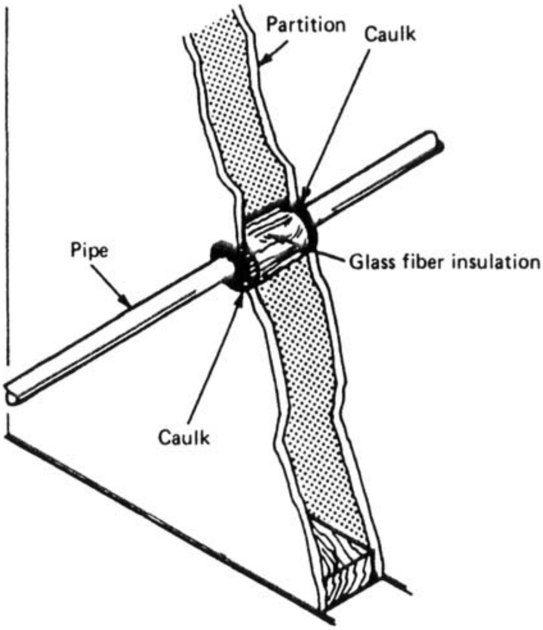

FIG. 8.3 The use of insulation to control the transmission of noise where a pipe penetrates a wall. The space surrounding the pipe is filled with insulation. Then caulking is applied on both sides of the wall.

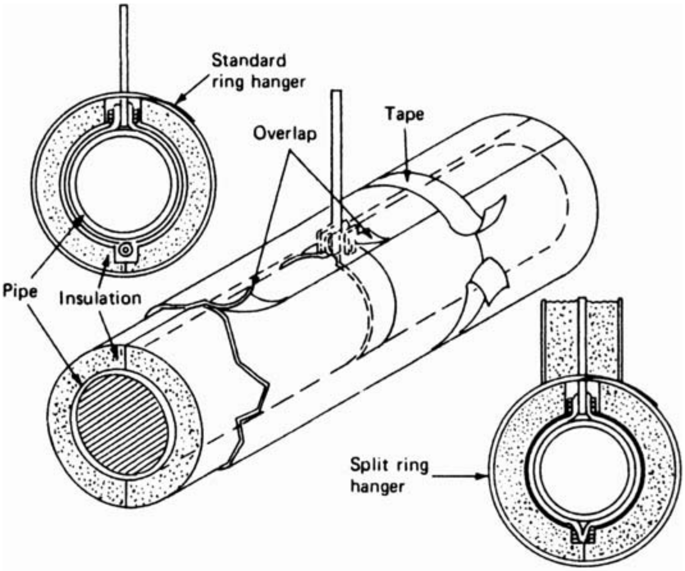

FIG. 8.4 An insulated pipe supported by a ring-type hanger. The insulation reduces the transmission of noise to the hanger and therefore to the structure.

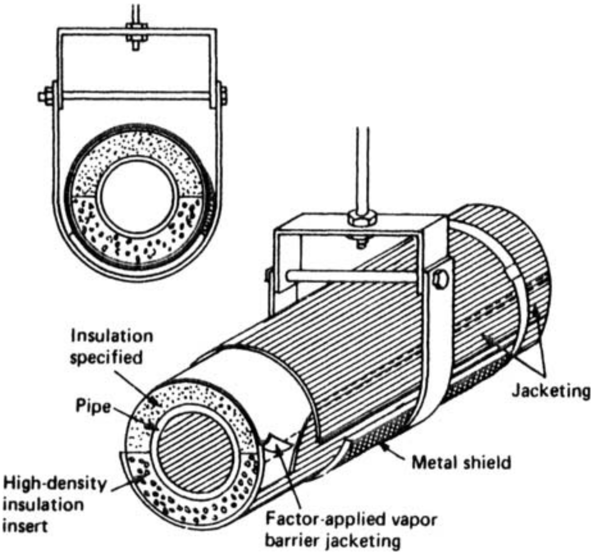

FIG. 8.5 An insulated pipe supported by a clevis hanger. The insulation reduces the transmission of noise to the hanger and therefore to the structure.

should be porous and resilient and the outer surface (jacket) should be sealed. Such a covering (*a*) provides some sound absorption within the insulation, (*b*) provides some mechanical damping of the pipe, and (*c*) reduces the amplitude of vibration of the exposed surface. Figure 8.6 shows the noise insulation provided by a jacket weight of 1 lb/ft^2 (5 kg/m^2) over medium-density fiberglass. These data show that the noise reduction increases with the thickness of insulation, and it increases significantly with frequency.

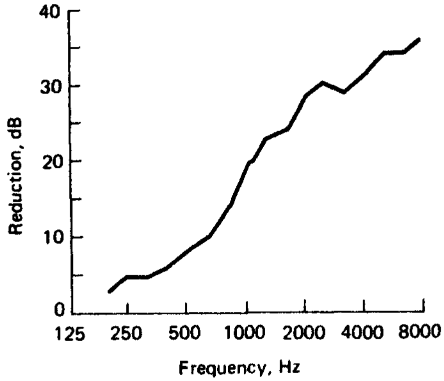

FIG. 8.6 The reduction in radiated noise, in decibels, provided by jacket-covered insulation surrounding a pipe. The reduction increases significantly with increasing frequency.

CODE CONSIDERATIONS

Energy conservation codes have been adopted by many state and local governments. Such codes establish minimum requirements for thermal performance of building services including steam, domestic hot water, and chilled drinking water. These energy conservation code requirements may be separate from those of the building code, mechanical code, plumbing code, gas code, and fire code. There are often cross references between them.[8,9,10,15] A working knowledge of all the codes which apply to buildings in the specific jurisdiction is useful in planning construction projects.

Water pipes usually penetrate walls, floors, ceilings, or roofs required to have a fire resistance rating.[16] Building codes and mechanical codes specify the requirements for piping that penetrates floor-ceiling, roof-ceiling, and wall or partition assemblies that must have a fire resistance rating. The space around such a pipe could transfer flames, heat, and smoke unless it is protected by an acceptable method. For vertical piping, a common protection practice is to enclose the piping within a shaft which has a fire resistance rating. Penetration of walls, partitions, shaft walls, and vertical piping through floors or roofs not protected by shaft enclosure requires the space to be firestopped.

When the piping is insulated with a material not specifically approved for use as a firestop by the authority having jurisdiction, the piping insulation should be terminated on both sides of the penetration; it should not be applied on that portion of the piping within the penetration. This does not apply to piping insulation in penetrations where assemblies (floor-ceiling, roof-ceiling, walls, partitions) are not required to have a fire resistance rating.

If piping is located in the space between a suspended ceiling and the floor or roof above that serves as a plenum for an air-conditioning system, code requirements for the plenum apply to the piping. Then, the piping insulation, including its jacketing, usually must have a surface-burning flame spread index of not more than 25 and a smoke developed index of not more than 50 as defined in ASTM Standard E-84.[4] Any penetrations of this plenum by piping must be firestopped. In this laboratory test for surface burning characteristics, cement-asbestos board has a flame spread index of zero and a smoke developed index of zero. Red oak has been arbitrarily assigned a flame spread index of 100 and a smoke developed index of 100.

INSTALLATION OF PIPING INSULATION

Long-term satisfactory performance of piping insulation depends on proper installation. The installation should be performed by skilled mechanics regularly engaged in the insulation trade under the supervision of qualified insulation contractors. Before piping insulation is installed, the piping system should be tested, inspected, and approved (as outlined in Chap. 12). The insulation should be clean, dry, and free of defects in quality when installed, and should be protected against moisture, weather, and abuse during shipment, storage, and installation. After installation, it must be properly maintained.

In most cases for water supply and steam systems, the required thickness of piping insulation is available in a single layer. If the required thickness is not available, then multiple-layer installation is necessary. It is recommended that the first layer be unjacketed and secured in place before the second layer is installed with seams and joints staggered from the first layer. The installation recommendations of the insulation manufacturers are important and should be followed.

Installation procedures are not alike for all types of piping insulation. For example, the procedures for installing cold service piping are different from hot service piping, and the procedures for installing indoor piping are different from those for outdoor piping. Insulation contractors have adopted Ref. 17 as a guide for the installation of piping insulations. Most of the piping insulation manufacturers have endorsed the use of Ref. 17 for their products. This applies to the installation on straight piping lengths and to the fabrication in the field of insulation around fittings, hangers and supports, joint and seam closures, and vapor barrier treatments. Section IV of Ref. 17 describes general installation methods for each of the commonly used piping insulation types for the following piping systems: ammonia and brine; boiler makeup water, chilled water, cold water, condensate return, domestic water, domestic hot water, drain, dual temperature, glycol, heating hot water, high-temperature hot water, makeup water, refrigerant suction, steam, tracing, utility, and well water.

In installation, consideration should be given to the fact that the coefficients of linear expansion of piping insulation materials differ from the coefficients for piping on which the insulation is applied. In service, at elevated temperatures, the piping undergoes positive linear displacement while the insulation undergoes negative linear displacement. Thus the total length of the piping will be longer at elevated temperature than the total length of the insulation. This difference does not occur at a fixed point in the piping system. As a result, some joints between sections of piping insulation may open. This is not a serious problem for piping operated at elevated temperatures, or for piping operated only at temperatures below ambient where the effect of expansion is small. It may be a problem for long lengths of piping in dual-temperature service where the difference in expansion can result in a rupture of the vapor barrier and a consequent degradation of the performance of the vapor barrier.

The densities of different types of piping insulation vary widely. The value of the density is important in estimating the total weight of the insulation and determining how much load the hangers must support. In general, in making such a determination, the maximum value of the density for a given type of material is used. Where water condensation on the hanger is not a problem, a standard hanger of the type shown in Fig. 8.4 is used and the insulation is applied after the pipe has been hung. Where noise control or water condensation control is an important factor, a clevis hanger of the type shown in Fig. 8.5 is used. There is a complete physical separation between the pipe and the hanger, which provides reduction of solidborne noise and eliminates the problem of condensation from the hanger. It is essential that vapor barriers be sealed at all connections, joints, and hangers to maintain the integrity of the vapor seal. It is essential that jackets on piping insulation used to reduce noise radiation be sealed as for vapor barriers.

MAINTENANCE

In general, commercial thermal insulations require little maintenance when the insulation material is suitable for the intended service, has the proper thickness for the intended service, and is installed in the proper manner, and the system is operated within the design parameters. However, there may be special cases where maintenance is required to provide long-term satisfactory performance of piping insulations:

1. *Where the insulation and/or its protective surface is physically damaged.* Such damage should be repaired to maintain the intended thermal performance.
2. *Where the vapor barrier membrane is torn or punctured.* The maintenance of the vapor barrier membrane on pipe insulations on cold pipes is necessary to retard the migration of water vapor from the ambient air into the insulated spaces where the vapor can condense. Insulation that becomes wet from ineffective vapor-retarder membranes, weather exposure, or leaks in the system loses its insulation properties, and shortens the service life.
3. *Where the insulation becomes wet.* Wet insulation should be removed and scrapped. The sources of water penetration should be eliminated by repair or removal, and the piping insulation and the surface treatment should be replaced.

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CHAPTER 9

SEISMIC PROTECTION

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INTRODUCTION

There is a significant need for methods of engineering design and for devices that make it possible to support water distribution systems, electrical distribution systems, and associated components so that they are able to provide essential services in buildings both during and after earthquakes.

This chapter first discusses methods of rating earthquakes and seismic protection requirements. It then considers the results of damage to water distribution systems from the great Alaska earthquake of 1964. This is followed by recommendations for installation based on the information provided by the Alaska earthquake. Next, various types of braces and vibration isolators are described that provide support for their load even if subject to an earthquake. For example, vibration isolators of this type function in the usual way under normal operating conditions but limit the motion of the support when it is subject to an earthquake. Finally, codes and regulations that govern seismic protection for water and electrical distribution systems, and associated equipment, are discussed.

METHODS OF RATING EARTHQUAKES AND SEISMIC PROTECTION REQUIREMENTS

Several methods of rating earthquakes are used in the design of mechanical and electrical systems to meet seismic code requirements.

Earthquake Magnitude

The *earthquake magnitude* scale is related to the energy emitted at the source of the earthquake. It is a function of the logarithm of this energy; therefore, an increase of one unit in magnitude indicates an increase in energy of 10 times. Thus a single earthquake has a fixed magnitude, but the intensity of the earthquake at a given location depends on a number of factors, including distance from the center of the disturbance and the geological foundation of the area. The earthquake magnitude scale is determined from measurements of ground motion recorded by seismographs. Events with magnitudes of about 4.5 or greater (there are several thousand shocks of this magnitude in the world each year) are strong enough to be recorded by sensitive seismographs at vast distances from the center of the disturbance. Major earthquakes, such as the 1906 San Francisco earthquake and the 1964 Alaskan earthquake, have magnitudes of 7.8 or higher. On the average, one earthquake with a magnitude larger than 7.8 occurs somewhere in the world each year. Although the earthquake magnitude has no theoretical upper limit, the largest known shocks have had magnitudes in the range from 8.8 to 9.2.

UBC Design for Total Lateral Seismic Force

According to the *Uniform Building Code* (UBC),[1] each element or component and its connection to a structure shall be designed to resist a ***total lateral seismic force*** F_p given by Eq. (12–10) of Sec. 2312 of the code:

$$F_p = ZIC_pW_p \tag{9.1}$$

where Z (*seismic zone factor*) is a dimensionless number. Its value is obtained in the following way: (*a*) first determine the seismic zone for the area in which the building is to be located from Fig. 9.1; then (*b*) find the value of Z corresponding to this zone as follows:

Areas of no earthquake damage	$Z = 0$
Zone 1 (areas of minor damage)	$Z = 0.075$
Zone 2A (areas of minor to moderate damage)	$Z = 0.15$
Zone 2B (areas of moderate to major damage)	$Z = 0.20$
Zone 3 (areas of major damage)	$Z = 0.30$
Zone 4 (areas near earthquake faults)	$Z = 0.40$

I (*importance factor* of the occupancy) has the following dimensionless values:

Nonessential facilities	$I = 1.0$
Essential facilities	$I = 1.25$
Life safety facilities	$I = 1.5$

C_p (numerical coefficient) = 0.75 for mechanical, plumbing, and electrical equipment; machinery; and associated piping

W_p = weight of an element or component

Design Response Spectrum

An alternative procedure for designing systems to meet seismic requirements is to use the *design response spectrum*. This procedure is described in Sec. 2312(f) of Ref. 1.

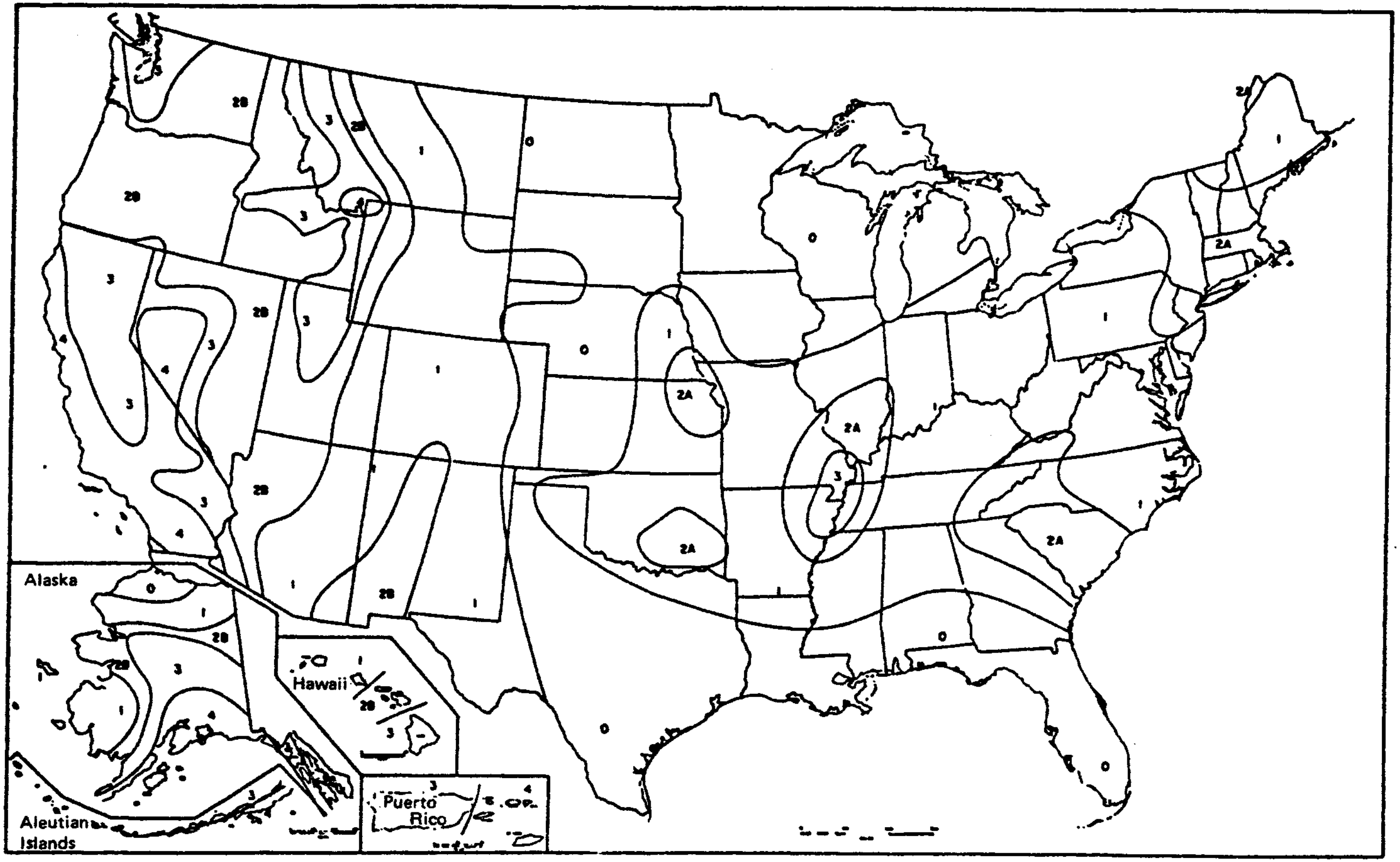

FIG. 9.1 Seismic zones in the U.S.A. Zone 0: no earthquake damage areas. Zone 1: minor damage areas. Zone 2A: minor to moderate damage areas. Zone 2B: moderate to major damage areas. Zone 3: major damage areas. Zone 4: areas near earthquake faults.[1]

A *response spectrum* is a plot of the maximum responses of an array of single-degree-of-freedom oscillators, as a function of oscillator frequency, in response to an applied transient motion (such as an earthquake). It may be used to describe the motion that an item of equipment is expected to experience at its mounting during a postulated seismic event. A *design response spectrum* is a response spectrum developed to yield design coefficients. Examples of its use are given in Ref. 2.

NFPA Guidelines

The National Fire Protection Association (NFPA) has suggested guidelines for use in the seismic protection of sprinkler systems based on the weight of the water-filled sprinkler piping.[3] This criterion has been included in NFPA standards for over 50 years; its use has established a good record of performance in resisting earthquakes. A survey after the San Fernando, California, earthquake of 1971 showed that sprinkler systems that followed these guidelines fared well if the building fared well.[4] These guidelines apply only to a sprinkler system that, according to the authority having jurisdiction, is subject to earthquakes.

DAMAGE TO WATER DISTRIBUTION SYSTEMS IN EARTHQUAKES

Surveys of nonstructural damage to buildings from earthquakes have provided information that has been important in establishing recommendations for the earthquake protection of water distribution systems in buildings. The following types of damage resulted from the great Alaskan earthquake of 1964[5]:

- *Water heaters.* Hundreds of small gas-fired and electric domestic water heaters fell over. Many of the legs on which heaters stood collapsed, and vent connectors were damaged.
- *Plumbing fixtures.* Some plumbing fixtures were damaged by falling debris.
- *Plumbing stacks.* Plumbing stacks in tall buildings were practically undamaged.
- *Joints.* Most pipe failures occurred at fittings. Most welded, brazed, or soldered joints were undamaged, many screwed joints failed, and a few caulked joints were pulled apart or twisted. Failures in screwed pipe joints occurred in many places where long unbraced horizontal runs of pipe joined short vertical risers or were connected to equipment.
- *Branch lines.* Small branch lines that were clamped tightly to the buildings were torn from large horizontal mains. Joints were loosened or pulled apart in long horizontal runs of unbraced cast-iron pipe; hanger rods were bent, shifted, or broken.
- *Seismic joints.* Pipes crossing seismic joints between buildings were damaged when they lacked provision for relative movement between buildings.
- *Thermal expansion.* Thermal expansion loops and joints in the piping system were damaged when the pipe expansion guides were not properly installed.
- *Fire sprinkler systems.* Fire sprinkler piping was practically undamaged because it was laterally braced.
- *Other equipment.* Sand filters, water softeners, domestic hot-water tanks, expansion tanks, and cold-water-storage tanks shifted, toppled, or rolled over if they were not firmly anchored to buildings.

RECOMMENDATIONS FOR INSTALLATION OF WATER DISTRIBUTION SYSTEMS

The following recommendations are based on observations of the damage to the distribution systems by earthquakes such as the great Alaskan earthquake of 1964:

- *Pipelines* should be tied to only one structural system (i.e., wall, floor, roof). However, where they are tied to more than one structural system, and relative deflections are anticipated, movable joints should be installed in the piping to allow for such deflections.
- *Pipelines* leading to thermal expansion loops or flexible pipe connections should be guided to confine the amplitude of pipe movement in the direction of expansion.
- *Pipelines* should not cross seismic joints between two buildings, if this can be avoided. Where they do cross such joints, appropriate allowance for differential movements must be provided. The crossing should be made at the lowest floor possible, and all pipe deflections and stresses induced by the deflections should be carefully evaluated.
- *Suspended piping systems* should have consistent freedom of movement throughout; for example, branch lines should not be anchored to structural elements if the main line is allowed to sway.
- *Pipe sleeves* through walls or floors should be large enough to allow for the anticipated pipe movement.
- *Movable joints* should be installed at equipment connections where relative deflections are anticipated.
- *Installation techniques* recommended by the National Fire Protection Association in NFPA Standard 13, for earthquake protection of fire-sprinkler systems, should be followed. This standard provides field-tested installation details that are applicable to any piping system.
- *Supports for heavy equipment and tanks* should be designed to withstand earthquakes, and should be anchored to the floor. Suspended tanks should be strapped to their hangers and provided with lateral bracing.
- *Domestic hot-water heaters* should be provided with legs that can withstand earthquakes. They should be anchored to the floor or strapped to a structural wall.
- *Earthquake-sensitive shutoff valves* in gas-service lines should be provided where maximum protection from gas leaks is required.
- *Vibrating and noisy equipment* should, if possible, be located far from occupied spaces so that the equipment can be anchored directly to the structure and the need for vibration isolation is eliminated.
- *Heavy mechanical equipment* should not be placed on the upper floors of tall buildings unless mounted on vibration isolators of an earthquake-resistant design.
- *Constraining devices* should be used in isolating equipment and piping from the building structure by vibration isolators (see Fig. 9.2).

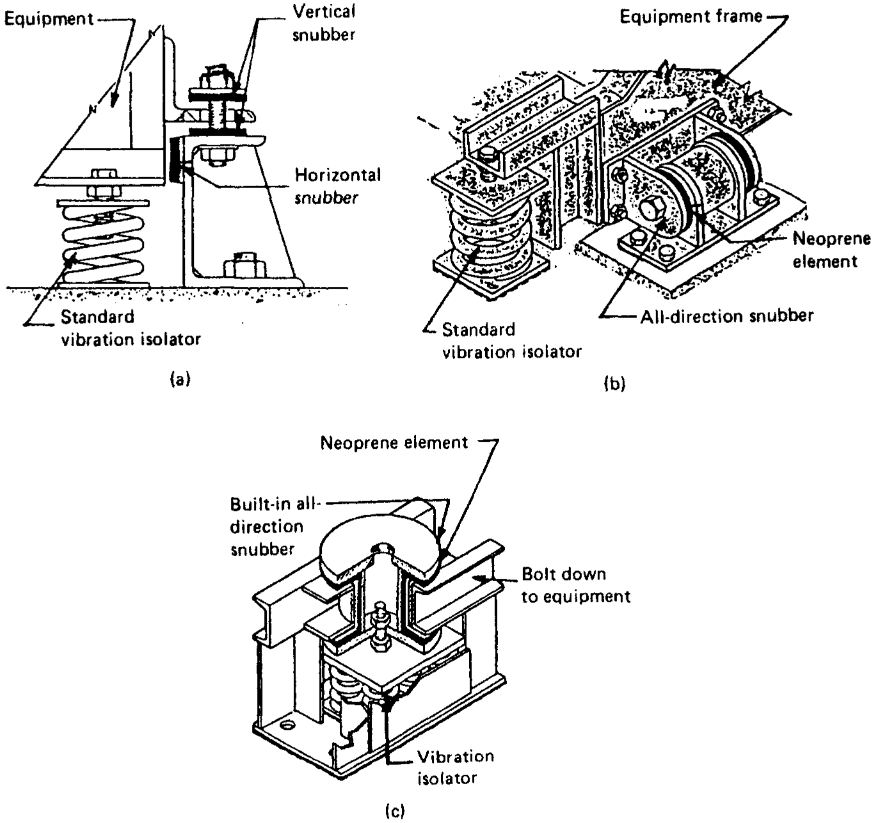

FIG. 9.2 Vibration isolators provided with various types of "snubbers" to limit the motion of the isolators. (*a*) One horizontal and one vertical snubber; (*b*) cylinder snubber; (*c*) built-in snubber to limit motion in all directions.

METHODS OF PROVIDING SEISMIC PROTECTION OF PIPING

Seismic protection design methods are, in part, based on data obtained from manufacturers of hangers and supports or product-related organizations. Guidelines and criteria for pipe installation are provided by the Plumbing and Piping Industry Council, Inc.[6] The guidelines are based on requirements of the *California Code of Regulations*, Title 24.[7] Many manufacturers have their seismic bracing systems tested by organizations such as Underwriters Laboratories, Inc., and Factory Mutual (Engineering and Research Corporations). The tests are performed with standard pipe and fittings normally used in commercial buildings, including roll-grooved pipe and fittings. Some manufacturers provide seismic pipe details using their own seismic bracing fittings. Hanger product manufacturers provide all the information needed for proper hanger installation.

A lateral or longitudinal brace prevents piping from moving back and forth in one direction; such a brace is called a *two-way brace*. A *four-way brace* prevents piping from moving in two directions. There are several methods of providing adequate lateral bracing. For example, Fig. 9.3*a* shows a clevis hanger properly selected for pipe size, a rod having a diameter that will support the load to which it is subjected, a rod coupling or turnbuckle, and an expansion anchor bolt of the same diameter as the rod. If the pipe must be seismically braced, a pipe sleeve in the clevis hanger and a bracing angle at the bolted section of the clevis hanger must be provided. Then the pipe can be seismically braced by one of the methods illustrated in Fig. 9.3*b, c,* and *d*. In Fig. 9.3*b*, angle bracing is used with a 2½-in (6.4-cm) angle iron bolted to the clevis hanger and installed at a 30 to 45° angle. The detail also shows another 2½-in (6.4-cm) angle iron welded to the pipe rod to limit the movement of the pipe in the vertical. In Fig. 9.3*c*, channel bracing is used with standard channels in lieu of an angle iron; the channel bracing is bolted to the clevis hanger and structure in the same manner as the angle iron, except that the channel at the vertical rod is not welded. The channel is bolted with special fittings manufactured by the same company that makes the channels. In Fig. 9.3*d*, cable bracing is used with ⅝-in (1.6-cm) aircraft cable for pipes up to 6 in (15 cm) and with 7⁄16-in (1.1-cm) aircraft cable for pipes larger than 6 in (15 cm). Cable bracing requires bracing on both sides of the clevis hanger and stiffening of the vertical rod.

The details shown in Fig. 9.4 are similar to the details in Fig. 9.3, except that the braces are installed in the longitudinal direction (i.e., longitudinal bracing is provided), and the clevis hanger is replaced with a seismic hanger.

No special seismic systems are required in geographic areas that are not near earthquake faults. In such areas, the use of normal pipe hangers and supports with the addition of the seismic bracing, as detailed in Figs. 9.3 and 9.4, is adequate. In piping installations in essential buildings in areas where the probability of a major earthquake is high, the design of piping supports and their spacing is critical. Usually such design requirements are covered by applicable codes and regulations. Data showing the rod sizes, bracing requirements, and hanger spacing that meet these regulations are given in Tables 9.1 and 9.2.

Other types of hanger and support systems may be used. The details in Fig. 9.5 apply to more than one pipe installed on a trapeze. The installation of such systems is economical for new construction when multiple pipes are installed on one supporting element. However, the installation is economical only when the channel construction strength is utilized in conjunction with the proper rod sizes. The trapeze method is not recommended for installation of large pipes. No more than two 8-in (20-cm) pipes, three 6-in (15-cm) pipes, or four 5-in (13-cm) pipes should be installed on one trapeze hanger. In addition, trapeze hangers should not be installed far from the supporting structure above [i.e., 24 in (60 cm) for ½-in (1.3-cm) rod, 30 in (76 cm) for ⅝-in (1.6-cm) rod, and 36 in (91 cm) for ¾-in (1.9-cm) rod]. The channels should be selected for proper application. Double horizontal channels and the single channels used for the seismic bracing requirement (i.e., rod stiffeners and lateral and longitudinal bracing) are preferred.

CODES AND REGULATIONS FOR MECHANICAL AND ELECTRICAL EQUIPMENT

Typical codes (e.g., *California Code of Regulations*[7]) require that working drawings and contract specifications be reviewed by the Department of General Services for Structural Safety, by the State Fire Marshal for Fire Safety, and by the Department for General Mechanical and Electrical Details, and that the following information be provided.

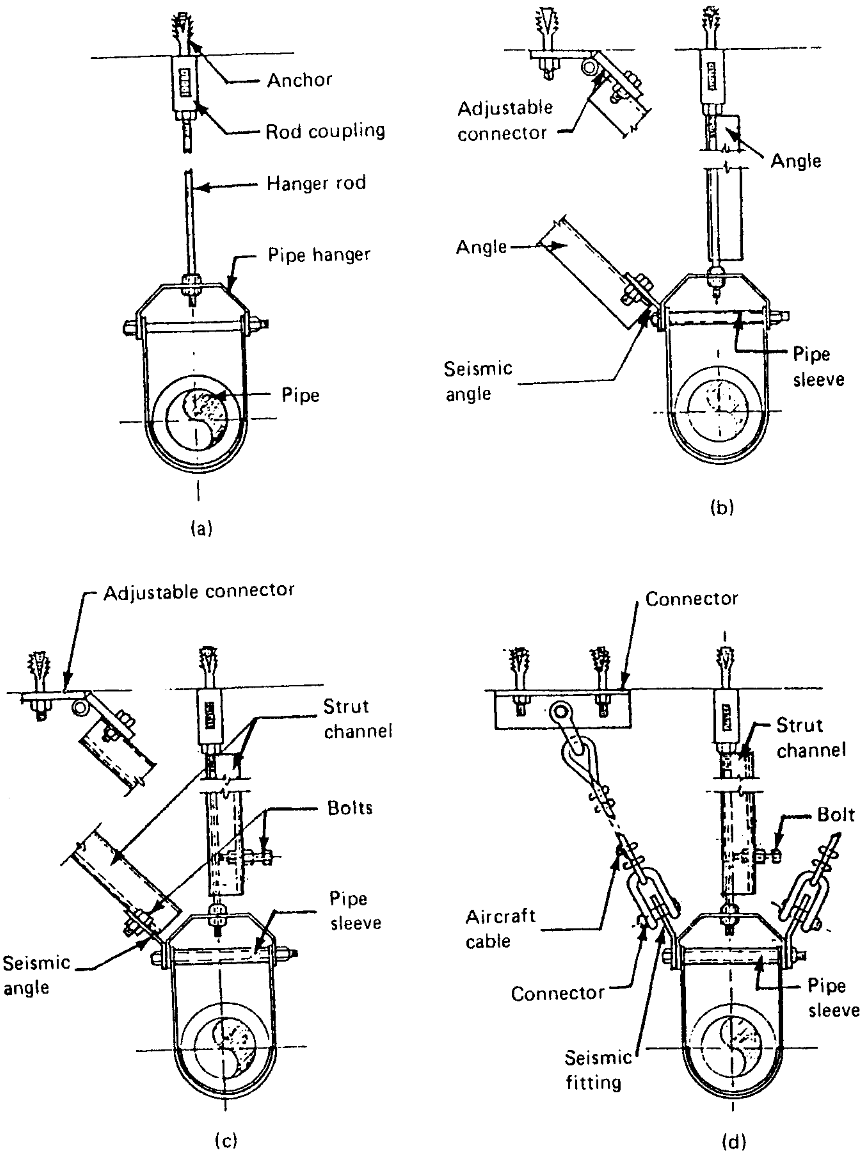

FIG. 9.3 Various types of lateral supports for piping hung from a clevis hanger. (*a*) Hanger with no support; (*b*) hanger with angle bracing; (*c*) hanger with channel bracing; (*d*) hanger with cable bracing.

General Requirements

All drawings and specifications must comply with the provisions of applicable regulations and provisions of applicable requirements of local authorities having jurisdiction. All such plans and specifications must bear the signature of the en-

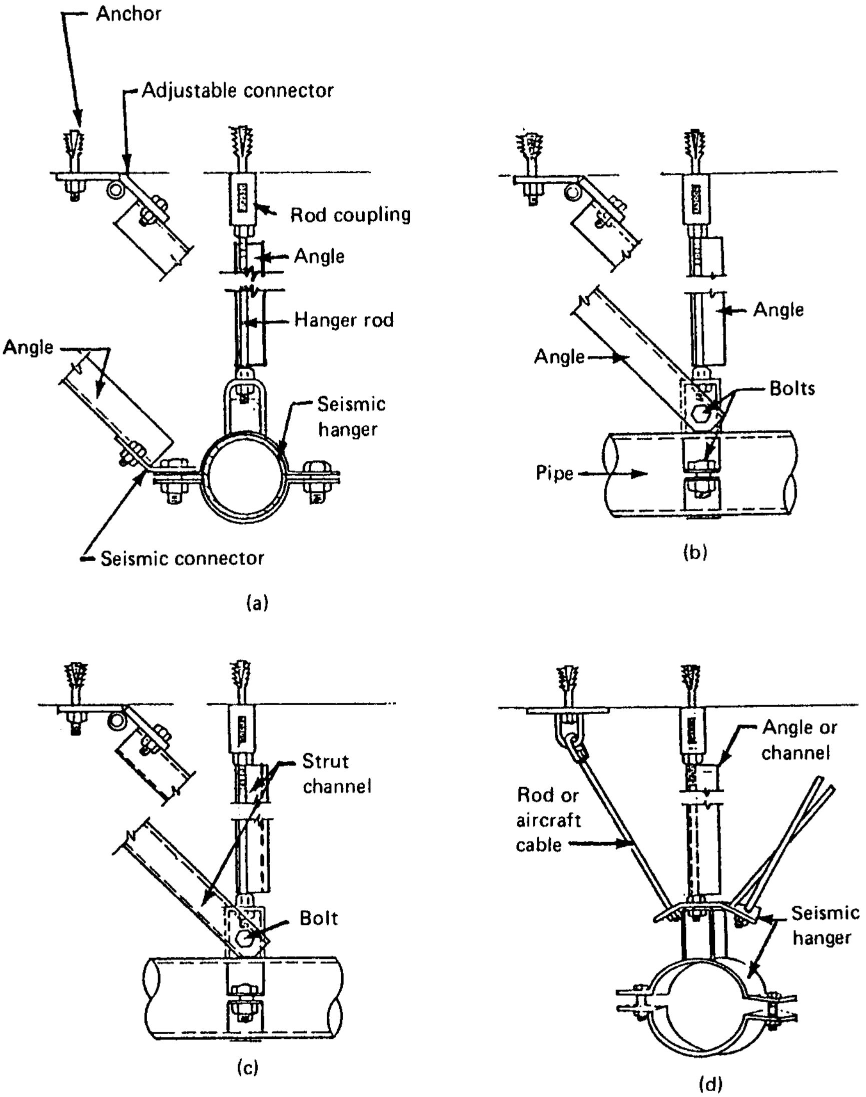

FIG. 9.4 Various types of longitudinal supports for piping. (*a*) Pipe hanger with lateral pipe support; (*b*) angle bracing; (*c*) channel bracing; (*d*) rod or aircraft cable bracing.

gineer in charge of design and the signature of any engineers to whom a portion of the work has been delegated.

Electrical Drawings

Electrical drawings must show the complete electrical system and provide details illustrating the methods recommended by the structural engineer for fastening equipment to the structure to resist seismic forces. These must include:

TABLE 9.1 Seismic Bracing Protection at the Maximum Allowable Pipe Hanger Spacing Recommended by Most Pipe Manufacturers

Pipe characteristics		Pipe hangers			Lateral bracing		Longitudinal bracing	
Nominal diameter, in (cm)	Weight, lb/ft (kg/m)	Rod size, in (mm)	Rod spacing, ft (m)	Max. load, lb (kg)	Spacing, ft (m)	Max. load, lb (kg)	Spacing, ft (m)	Max. load, lb (kg)
1 (2.54)	3 (4.5)	⅜ (9.5)	7 (2.1)	21 (9)	14 (4.3)	42 (19)	28 (8.5)	42 (19)
1¼ (3.18)	4 (6.0)	⅜ (9.5)	7 (2.1)	28 (13)	14 (4.3)	56 (25)	28 (8.5)	56 (25)
1½ (3.81)	5 (7.4)	⅜ (9.5)	9 (2.7)	45 (20)	18 (5.5)	90 (40)	36 (11.0)	90 (40)
2 (5.08)	7 (10.4)	⅜ (9.5)	10 (3.0)	70 (32)	20 (6.1)	140 (63)	40 (12.2)	140 (63)
2½ (6.35)	10 (14.9)	½ (12.7)	11 (3.4)	110 (45)	22 (6.7)	220 (100)	44 (13.4)	220 (100)
3 (7.62)	12 (17.9)	½ (12.7)	12 (3.7)	144 (65)	24 (7.3)	288 (136)	48 (14.6)	288 (136)
3½ (8.85)	17 (25.3)	½ (12.7)	13 (4.0)	221 (100)	26 (7.9)	442 (200)	52 (15.8)	442 (200)
4 (10.16)	19 (28.3)	⅝ (15.9)	14 (4.3)	266 (121)	28 (8.5)	532 (241)	56 (17.1)	532 (241)
5 (12.7)	27 (40.2)	⅝ (15.9)	16 (4.9)	432 (196)	32 (9.8)	864 (392)	64 (19.5)	864 (392)
6 (15.2)	35 (52.1)	¾ (19.1)	17 (5.2)	595 (270)	34 (10.4)	1190 (540)	68 (20.7)	1190 (540)
8 (20.3)	56 (83.3)	⅞ (22.2)	19 (5.8)	1064 (483)	38 (11.6)	2128 (965)	76 (23.2)	2128 (965)
10 (25.4)	80 (119)	⅞ (22.2)	20 (6.1)	1600 (726)	20 (6.1)	3200 (1452)	40 (12.2)	3200 (1452)

TABLE 9.2 Seismic Bracing Protection Stipulated by Most Seismic Design Regulations at Normal Pipe Hanger Spacing

Pipe characteristics		Pipe hangers			Lateral bracing		Longitudinal bracing	
Nominal diameter, in (cm)	Weight, lb/ft (kg/m)	Rod size, in (mm)	Rod spacing, ft (m)	Max. load, lb (kg)	Spacing, ft (m)	Max. load, lb (kg)	Spacing, ft (m)	Max. load, lb (kg)
1	3	⅜	7	21	40	120	80	120
(2.54)	(4.5)	(9.5)	(2.1)	(9)	(12.2)	(54)	(24.4)	(54)
1¼	4	⅜	7	28	40	160	80	160
(3.18)	(6.0)	(9.5)	(2.1)	(13)	(12.2)	(73)	(24.4)	(73)
1½	5	⅜	9	45	40	200	80	200
(3.81)	(7.4)	(9.5)	(2.7)	(20)	(12.2)	(91)	(24.4)	(91)
2	7	⅜	10	70	40	280	80	280
(5.08)	(10.4)	(9.5)	(3.0)	(32)	(12.2)	(127)	(24.4)	(127)
2½	10	½	10	100	40	400	80	400
(6.35)	(14.9)	(12.7)	(3.0)	(45)	(12.2)	(181)	(24.4)	(181)
3	12	½	10	120	40	480	80	480
(7.62)	(17.9)	(12.7)	(3.0)	(54)	(12.2)	(218)	(24.4)	(218)
3½	17	½	10	170	40	680	80	680
(8.89)	(25.3)	(12.7)	(3.0)	(77)	(12.2)	(308)	(24.4)	(308)
4	19	⅝	10	190	40	760	80	760
(10.16)	(28.3)	(15.9)	(3.0)	(86)	(12.2)	(345)	(24.4)	(345)
5	27	⅝	10	270	40	1080	80	1080
(12.7)	(40.2)	(15.9)	(3.0)	(122)	(12.2)	(490)	(24.4)	(490)
6	35	¾	10	350	40	1400	80	1400
(15.24)	(52.1)	(19.1)	(3.0)	(159)	(12.2)	(635)	(24.4)	(635)
8	56	⅞	10	560	40	2240	80	2240
(20.33)	(83.3)	(22.2)	(3.0)	(254)	(12.2)	(1016)	(24.4)	(1016)
10	80	⅞	10	800	20	3200	40	3200
(25.4)	(119)	(22.2)	(3.0)	(363)	(12.2)	(1452)	(12.2)	(1452)

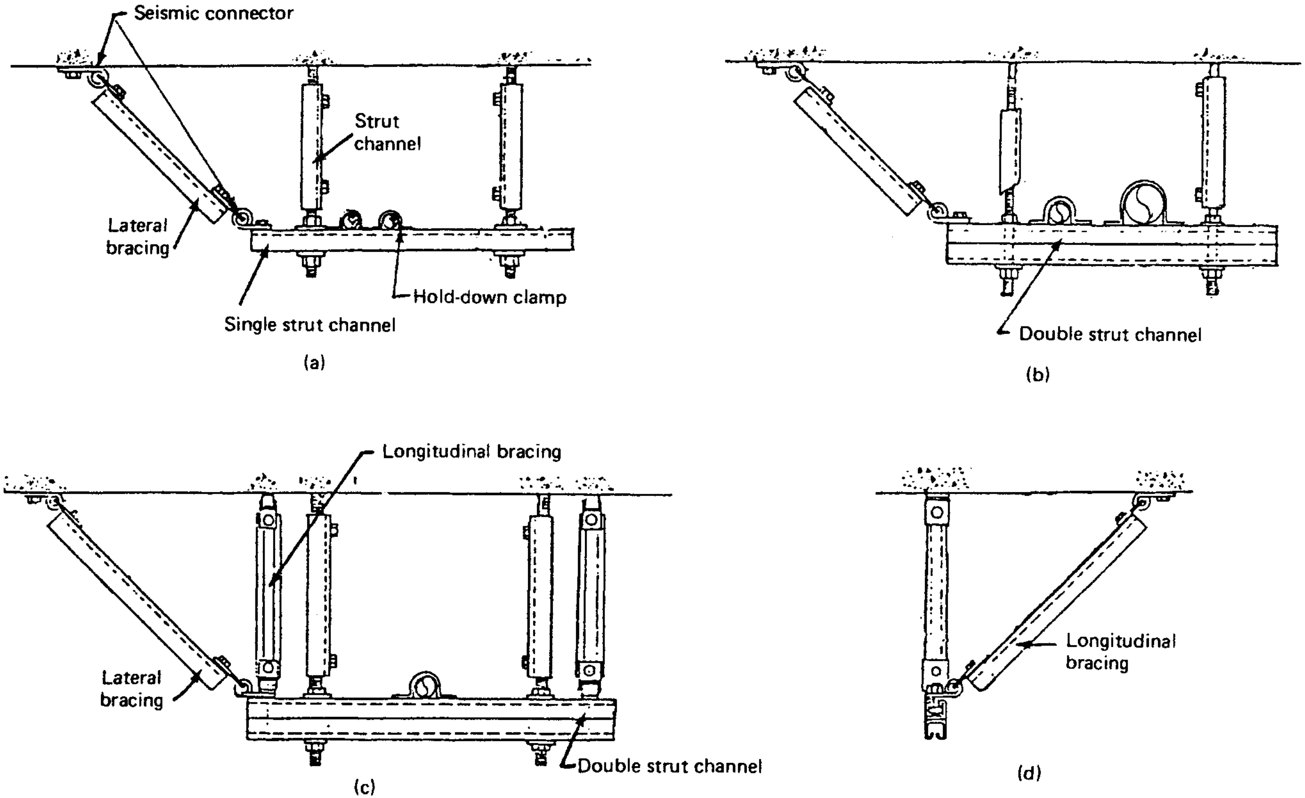

FIG. 9.5 Various types of lateral and longitudinal trapeze supports for piping. (*a*) Single channel, lateral bracing; (*b*) double channel, lateral bracing; (*c*) longitudinal bracing, front view; (*d*) longitudinal bracing, side view.

1. Electrical service entrance, with service switches, service feeds to the public service feeders, and characteristics of the electrical supply system in the building.
2. Transformers and their connections, if located in the building or on the site.
3. Main switchboard, power panels, light panels, and equipment. (Provide plan and diagram.)
4. Feeders and conduits. (Show sizes with schedule of the feeder breakers or switches.)
5. Lighting outlets, receptacles, switches, power outlets and circuits, isolated electrical systems.
6. Telephone system. (Show layout.)
7. Fire alarm systems with stations, sounding devices, and control boards.
8. Emergency lighting system (where required) with associated outlets, transfer switches, source of supply, feeders, and circuits.

Mechanical Drawings

Mechanical drawings must show the complete heating, ventilating, air-conditioning, and plumbing systems of the building. Drawings must show the details of fastening the following types of equipment to the structure to resist seismic forces:

1. Radiators and all steam-heated equipment, such as steam tables and humidifiers.
2. Heating and steam mains, including branches. (Show the pipe sizes.)
3. Heating surfaces of boilers and furnaces. (Show sizes and types.)
4. Pumps and tanks. (Show sizes and types.)
5. Air-conditioning systems with refrigerators, water and refrigerant piping, and ducts.
6. Ventilating systems. (Show duct sizes, including steam or water connections to air-handling units.)
7. Street sewer, house sewer, house drains, street water main, and water service into the building. (Show sizes and elevations.)
8. Soil, waste, and vent stacks with connections to house drains, fixtures, and equipment. (Show sizes and locations.)
9. Hot-, cold-, and circulation water mains, branches and risers from the service entrance, and tanks. (Show sizes and elevations.)
10. Riser diagram or some other acceptable method to show all plumbing stacks with vents, water risers, and fixture connections for multistory buildings.
11. Gas, oxygen, and special connections.
12. Fire-extinguishing equipment—sprinklers, wet and dry standpipes, fire extinguishers.
13. Plumbing fixtures and fixtures that require water and drain connections.

Codes and regulations require that all horizontal piping be supported at intervals that are sufficiently close to keep the pipes in alignment and to prevent sagging. Normally, most piping systems are supported at intervals that do not exceed 10 ft (3.3 m).

The intent of such codes and regulations is to ensure that seismically protected, rigidly supported piping and equipment are tied to the building structure in such a way as to permit maximum relative movement, while allowing for expansion and differential movement within and between structures. The use of flexible joints in piping systems should be minimized and must limit pipe movement so that the flexibility does not exceed the recommended allowable deflection, pipe end movements, and end loads. Rigid mechanical couplings should not be considered as flexible joints.

If a building has a sprinkler piping system installed within 6 in (15 cm) from the building structure and rigidly supported piping within 12 in (30 cm), the only items requiring seismic protection are items of building equipment such as pumps, tanks, transformers, emergency equipment, and heaters. Usually, if rigidly supported equipment is installed in accordance with the manufacturer's recommendations, it is probable that the earthquake code requirements have been complied with. Some equipment (such as large fans) must be mounted on flexible supports. In such cases, vibration isolators having built-in restraints that limit motion (i.e., snubbers) may be used, or conventional isolators may be used with auxiliary snubbers, as illustrated in Fig. 9.3.

It is unusual for all piping systems to be installed within 6 to 12 in (15 to 30 cm) from the building structure. Where the distance exceeds 12 in, the codes and regulations require that piping be seismically supported. Lateral bracing at a maximum spacing of approximately 40 ft (13.2 m) [20 ft (6.6 m) for gas piping] is recommended, as is longitudinal bracing for each run of main piping, but longitudinal spacing should not exceed 80 ft (26.4 m) [40 ft (13.2 m) for gas piping]. Four-way bracing at the top of the pipe riser and lateral guides at intermediate points not more than 30 ft (9 m) apart are recommended to keep the riser and main from shifting.

Lateral bracing for one pipe section may act as longitudinal bracing for the pipe section connected perpendicular to it, if the bracing is installed within 24 in (60 cm) of an elbow or tee of similar size. In some conditions, walls (including drywall partitions) and floors may replace the required lateral and longitudinal bracing for piping. Therefore, in most buildings, not more than 10 percent of the hanger system requires special seismic designs.

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CHAPTER 10

SPECIFICATIONS

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INTRODUCTION

A *specification* is a written document describing in detail the scope of work, materials and equipment to be used, method of installation, and quality of workmanship for a parcel of work to be placed under contract. A specification is usually utilized in conjunction with working (contract) drawings in building construction. Construction specifications must be accurate, clear, and concise—regardless of the type of building they are written for or whether they are architectural or engineering specifications. Clearly written specifications are essential because they remove any speculation about requirements and thus enable contractors to bid the project more intelligently.

This chapter is primarily concerned with specifications for plumbing systems in buildings, but the principles espoused are applicable to other types of building systems and to equipment incorporated in such systems. First, the general topic of specification writing is discussed. Then, contract documents and the terminology used in construction documents are described. Finally, the following topics are presented: project manuals, master specifications, and typical specifications for water supply and drainage systems.

SPECIFICATION WRITING

A paramount consideration of any specification is its technical essence, and this should be presented in language free of vague and ambiguous terms. The simplest words and phrases best convey the intended meaning. Essential information included in specifications must be complete, whether direct statements or references to other documentation. Consistency in terminology and organization of material contribute to the specification's clarity and usefulness. Punctuation should aid in reading and prevent misreading. Well-planned word order requires a minimum of punctuation.

The key to cost-effective and quality construction is complete communication of a project's requirements by the architect/engineer to the contractors and other participants involved in the project. Good communication of the design depends largely on having complete and fully coordinated construction documents.

Specifications must have uniform formats and uniform terminology to help the construction industry designers and contractors to converse and understand exactly the products and services desired by the owner. The specifications must be written in precisely worded sentences and well-constructed paragraphs that provide a clear understanding to those who will use them. Specification writers must have a thorough working knowledge of the construction industry as well as construction practices in the field. Because construction documents are legal instruments, the specifications must be written with a clear understanding of the legal principles involved in each of the documents. Stereotyped or redundant language should be avoided. With proper specifications, suppliers and contractors are able to have greater understanding of the work on which they bid.

Many architects and engineers have preferred to complete the design before the accompanying specifications are written. However, experience has shown that it is often advantageous to assemble the specifications at the same time.

An important principle of specification writing is that each requirement should be stated only one time and in one place, i.e., the most logical location. Information in one document should not be repeated in any of the other documents. Each document has a specific purpose and should be used precisely for that purpose. This simplifies the retrieval of information and substantially reduces the possibility of conflicts and discrepancies. This standardized approach to the placement of information within the construction documents is beneficial to all who are involved.

Specification Language

Specifications sometimes try to explain or give reasons for choices or alternatives. A "golden rule" of specification writing is to state only requirements; do not provide reasons for the requirements.

In a specification, avoid using the words *must, is to*, and *should*. The word *should* is indefinite and normally implies a preference not strong enough to warrant the use of the word *shall*.

Imperative Mode. The simple imperative mode is the recommended method for instructions covering the installation of products and equipment. The verb that clearly defines the action becomes the first word of the sentence. The imperative sentence is concise and readily understandable.

Indicative Mode. The traditional language of specification sentences is the indicative mode, passive voice. This requires the use of the word *shall* in nearly every statement. This sentence structure can cause unnecessary wordiness and monotony.

Shall. When used in a specification, the word *shall* is used with reference to the work required to be done by a contractor or supplier. It denotes the things the supplier shall do, documents they shall supply, features they shall build into the equipment, or performance levels the equipment shall meet. Wherever the word *shall* appears, it indicates that a requirement is being stated.

Will. The word *will* is used in connection with acts and actions required of the owner or of the architect/engineer. Thus the verb form *will* is used by the owner or purchaser as a self-imposed requirement. It denotes the information the owner will supply, documents the owner will review, and approvals the owner will issue—all at the proper time.

CONSTRUCTION DOCUMENTS AND TERMINOLOGY

Construction documents consist of contract documents and the bidding requirements, as illustrated in Fig. 10.1. The purpose of the construction documents is to communicate the written and graphic design for administration of the construction contract. Thus they include the following:

- Bidding requirements
- Contract forms
- Conditions of the contract
- Specifications
- Drawings
- Addenda
- Contract modifications

Contract documents contain the following written and graphic elements:

- Contract forms
  Agreement
  Performance bond
  Payment bond
  Certificates
- Conditions of the contract
  General conditions
  Supplementary conditions
- Specifications
- Drawings
- Addenda
- Contract modifications
  Change orders
  Field orders or construction change authorizations
  Supplemental instructions

Contract Forms

The following forms are included:

- *Agreement:* A written document signed by the owner and the contractor. It is the legal instrument binding the parties to the Work. The agreement defines the relationships and obligations existing between owner and contractor. By reference, it incorporates the other contract documents listed above.

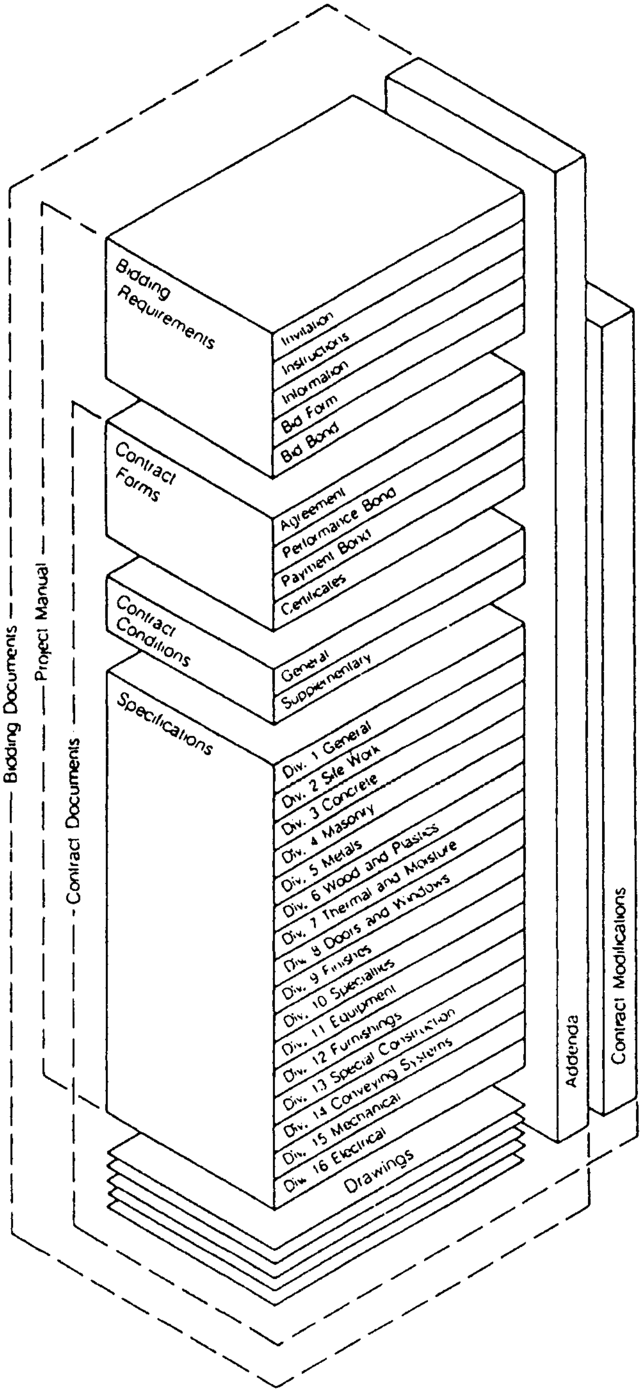


FIG. 10.1 The various components of the project manual, the bidding documents, and the contract documents. *(Manual of Practice, Construction Specifications Institute, 601 Madison St., Alexandria, VA 22314-1791.)*

- *Construction performance bond:* Provides financial protection for the owner in the event the contractor does not complete the work in accordance with the agreement.
- *Construction payment bond:* Protects the labor force and the suppliers of materials should the contractor fail to meet the obligations. Precludes the need for the labor force or the suppliers to seek payment directly from the owner because of nonpayment by the contractor.
- *Certificates:* Include certificates of insurance and certificates of compliance with applicable laws and regulations.

Conditions of the Contract

The *conditions of the contract* are those portions of the *contract documents* which define, set forth, or relate to contract terminology, the rights and responsibilities of the contracting parties and others involved in the *work*, requirements for safety and for compliance with laws and regulations, general procedures for the orderly prosecution and management of the work, payments to the contractor, and similar provisions of a general, nontechnical nature. Thus, conditions of the contract define the basic rights, responsibilities, and relationships of the parties involved in the construction process. Contract conditions are of the following two types:

- *General conditions:* The *general conditions* are that part of the *contract documents* (of the contract for construction) which sets forth many of the rights, responsibilities, and relationships of the parties involved. Thus they are general clauses that establish how the project is to be administered. They contain provisions which are common practice nationwide. Standard documents published by professional societies are often used.
- *Supplementary conditions:* The *supplementary conditions* represent that part of the contract documents which supplements and may also modify provisions of the general conditions. These supplements or modifications may be needed to provide for requirements unique to a specific project, for example, wage rates.

Specifications

Specifications are used to define specific materials, used in specific ways, at specific locations. Although a construction drawing may identify a thick pencil line only as *roofing*, the specifications will define the type of membrane, manufacturer's name, method of attachment, wind and fire resistance, installer qualifications, warranty, and related materials.

The *specifications* are that part of the contract documents consisting of written descriptions of a technical nature of materials, equipment construction systems, standards, and quality of work. Under the *uniform system*, the specifications comprise 16 *divisions*. The *uniform system* is the coordination of specification sections, filing of technical data and product literature, and construction cost accounting, organized into divisions based on an interrelationship of place, trade, function, or material. These divisions are as follows:

Division 1—General Requirements

Division 2—Sitework
Division 3—Concrete
Division 4—Masonry
Division 5—Metals
Division 6—Wood and Plastics
Division 7—Thermal and Moisture Protection
Division 8—Doors and Windows
Division 9—Finishes
Division 10—Specialties
Division 11—Equipment
Division 12—Furnishings
Division 13—Special Construction
Division 14—Conveying Systems
Division 15—Mechanical
Division 16—Electrical

The subject of this section of the handbook (i.e., water supply and distribution, drainage, and venting systems) is covered in "Division 15—Mechanical." This division includes the following sections:

Plumbing
Fire Protection
Heating, Ventilating, and Air-Conditioning (HVAC)
Gages
Mechanical Identification
Plumbing Pumps
Mechanical Insulation

Other divisions that contain sections that are relevant to water distribution piping include:

Division 2—Portable Water Piping
Division 2—Water Wells
Division 7—Joint Sealers

Drawings

Drawings are that portion of the *contract documents* showing in graphical or pictorial form the design, location, and dimensions of the elements of a *project*. They are a graphic representation of the work to be accomplished. They show the relationship of the materials to each other, including sizes, shapes, locations, and connections. The drawings may include schematic diagrams showing such things as mechanical and electrical systems. They may also include schedules of structural elements, equipment, finishes, and other similar items. Frequently, schedules may be included as part of the project specifications, in lieu of being shown on drawings

Addenda

Addenda are the written or graphic instruments that supplement the bidding documents for the purpose of clarifying, correcting, or adding to the specifications previously issued. Thus they are a written or graphic instrument which modifies or interprets the bidding documents, including *drawings* and *specifications*, by additions, deletions, clarifications, or corrections. They become part of the *contract documents* when the construction contract is executed. Typically they are issued prior to the opening of bids. However, AIA Document A201—*General Conditions of the Contract for Construction*—defines the addendum as being issued prior to the execution of the contract. This allows for a negotiated adjustment of the bid by issuance of an addendum.

Contract Modifications

Contract modifications are those additions to, deletions from, or modifications of the Work that are made after the agreement has been signed. The contract documents contain the legally enforceable requirements which become part of the contract when the agreement is signed. Contract modifications can be issued at any time during the contract period. They may be accomplished by any of the following:

- *Change order.* A written order to the contractor, signed by the owner and the architect/engineer, issued after the execution of the contract authorizing a change in the work, or an adjustment in the contract sum, or the contract time as originally defined by the contract documents. A change order may add to, subtract from, or vary the scope of Work. It may be signed by the architect/engineer alone (provided that the owner has given written authority for such procedure and that a copy of such written authority is furnished the contractor upon request) or by the contractor, if the contractor agrees to the adjustment in the contract sum or the contract time.
- *Field orders or contract change authorizations.* These are essentially the same, but have subtle differences. A written order effecting a minor change in the work (e.g., the labor to produce the construction required by the contract documents, or materials and equipment incorporated or to be incorporated in such construction), not involving an adjustment in the contract sum or an extension of the contract time, issued by the architect/engineer to the contractor during the construction phase.
- *Supplemental instructions.* Supplemental instructions are minor instructions or interpretations not involving change orders. Supplemental instructions allow the architect/engineer to direct changes not involving changes in contract sum or contract time.

PROJECT MANUAL

Figure 10.1 shows the various components of the *project manual*, the *bidding documents*, and the *contract documents*. As illustrated, the project manual includes contract forms, conditions of the contract, and the specifications, which have been described above. In addition, it includes the bidding requirements, i.e., those documents providing information and establishing procedures and conditions for the submission of bids. The bidding documents consist of the instructions to bidders, the bid form, and the proposed contract documents, including any addenda issued prior to receipt of bids.

Bidding requirements

Bidding requirements include the following:

- *Invitation to bid.* A solicitation of competitive bids. The term usually is employed in connection with private construction projects, but also may be used for government projects for the purchase of supplies or other goods.
- *Instructions to bidders.* Instructions contained in the bidding requirements for preparing and submitting bids for a construction project.
- *Information available to bidders.* Information containing the preliminary construction schedule, geotechnical data, and existing conditions.
- *Bid forms.* A form furnished to a bidder to be filled out, signed, and submitted as the *bid*.
- *Bid bond.* A form of security executed by the bidder as principal and by a surety.

MASTER SPECIFICATIONS

Entirely new specifications are seldom developed for each project. Instead, most design firms, government agencies, and large corporations use master specifications as a basis for their project specifications. These master specifications include items of work normally encountered by that organization. Each master section includes standard clauses normally applicable to the item of work and lists numerous possible alternatives. Specification notes within the text alter the specification to meet particular requirements. Paragraphs and articles that do not apply are deleted. Data can be omitted from a master specification; this omission does not require editing of other material as a result of the omission.

An office master specification serves as a vehicle for the compilation, elaboration, and refinement of specification data. New job experience can be systematically incorporated into the office master specifications for future use. A master specification provides an excellent basis for the preparation of project specifications by placing emphasis on consistency of text and speed of editing by means of deletion. Reasons for developing and using an office master specification or for subscribing to a commercially available one include:

- Improved efficiency in preparing specifications

- Expanded decision-making capability
- Avoidance of delays in project development
- Minimization of repetitive work
- Reduced errors and omissions
- Reduced exposure to liability
- Unified office technology
- Automated specification preparation
- Easier updating of specification data
- Potentially lower cost of specification preparation

Comprehensive master specifications, MASTERSPEC® and SPECTEXT, are available by subscription from two professional organizations—the American Institute of Architects (AIA) and the Construction Specifications Institute (CSI). Another method of preparing specifications is by the use of SweetSpec, which makes use of an interactive expert system.

MASTERSPEC

MASTERSPEC is a master specification for the construction industry developed by Production Systems for Architects and Engineers (PSAE), now the Professional Systems Division of the American Institute of Architects.[1] It is one of the most complete and widely used guide specifications available. This master specification carries the endorsement of the National Society of Professional Engineers and the American Consulting Engineers Council, which review the engineering sections for accuracy and adequacy prior to their publication. MASTERSPEC sections are titled, formatted, and numbered essentially in accordance with MASTERFORMAT and CSI's *Manual of Practice*.

SPECTEXT

SPECTEXT is copyrighted by the Construction Sciences Research Foundation and published by Construction Specifications Institute.[2] It is also available in Canada under the same name. It is published in CSI's 16-division format. Section titles and the five-digit numbering system are in accordance with the titles and numbering system in MASTERFORMAT. SPECTEXT is scheduled for revision every 5 years; portions of the text are revised quarterly. It is available both as hard copy and on diskettes for word processing.

SPECSystem$_{TM}$

SPECSystem[3] (the successor to SweetSpec) is an interactive expert system for writing specifications. First, a computerized dialogue takes place between a project architect or engineer and the computer's CD-ROM (compact-disk, read-only memory) containing the software and date files; the dialogue mimics that which would occur between an architect or engineer and an expert specification writer. For each section of the required specification document, the computer asks a series of questions in a logical decision-making order. (The sequence of questions is independent of the order of the final text of the specification document, which follows CSI's 3-part section organization. Unlike a simple checklist, the SPECSystem dialogue is "intelligent"; each subsequent question presented depends upon all previous responses. The software is updated by diskettes sent to the user each month.

Next, the software automatically assembles a specification document incorporating all the decisions made by the architect or engineer in the page format selected by the user. The program automatically renumbers and repaginates a section if paragraphs are added or deleted.

In addition to the specification, a set or coordination notes can be printed out. These notes remind the architect or engineer of information that must be shown on the drawings, or included elsewhere in the project manual, for total consistency with the specification section. Also, an *audit trail* may be printed out which consists of a record of the dialogue used in producing the section. Such an audit trail is shown in Appendix 10.1 which provides an example of the application of SPECSystem to the writing of a document specification for *Section 15415—WATER DISTRIBUTION SYSTEM*, given in Appendix 10.2.

REFERENCES

1. American Institute of Architects (AIA), 1735 New York Avenue, NW, Washington, DC 20006.
2. Construction Specifications Institute (CSI), 601 Madison Street, Alexandria, VA 22314-1791.
3. SPECSystem, Heery International, Inc., 999 Peachtree Street, NE, Atlanta, GA 30376-5401.

APPENDIX 10.1

EXAMPLE OF THE USE OF SPECSYSTEM™

```
1)  SECTION 15410 - PLUMBING PIPING:

Piping, associated fittings, and specialties for the following types of
plumbing systems may be specified in this section:

  Water distribution system.
  Drainage and vent system.

Plumbing fixtures and plumbing equipment are NOT included in this section and
must be specified elsewhere.

Do you wish to PROCEED?

Answer : Y

2)  SPECIFICATION FORM:

Select FORM of specification:

 1--STANDARD (unabridged).
 2--PRELIMINARY (design development).
 3--SHORT FORM (for work of limited scope).

Answer : 1

3)  TWO PLUMBING SYSTEMS:

Select plumbing system you wish to specify:

 1--Water distribution system ONLY (Section 15415).
 2--Drainage and vent system ONLY (Section 15420).
 3--Products for BOTH systems will be specified (Section 15410).

Answer : 1

4)  WATER DISTRIBUTION SYSTEM:

Select the ENVIRONMENT to which the water distribution piping system will
be subjected:

 1--Within a building (excluding under slab).
 2--Under ground or below slab.
 3--BOTH of the above.

Answer : 3

5)  WATER DISTRIBUTION - PIPING USED INSIDE BUILDING (EXCLUDING UNDER SLAB):

SELECT type(s) required (you may enter others in a subsequent question):

                                  AUDIT-1
```

1--Copper tubing, Type L; wrought copper fittings; soldered joints.
2--Galvanized steel pipe, seamless; galvanized malleable iron threaded fittings.
3--Galvanized steel pipe, seamless; mechanical grooved couplings and fittings.
4--CPVC plastic pipe; socket-type CPVC fittings; solvent-cemented joints.
5--PB plastic pipe or tubing; PB fittings; (you may select joint type in a subsequent question).

Answer : 2

6) WATER DISTRIBUTION PIPING - USED INSIDE BUILDING (EXCLUDING UNDER SLAB):

Galvanized Steel Pipe; Galvanized Malleable Iron Threaded Fittings: Enter specific application instructions.

[FORMAT: Use for pipe 4 inches and larger.]

Answer :
All piping within building.

7) WATER DISTRIBUTION PIPING - USED INSIDE BUILDING (EXCLUDING UNDER SLAB):

Do you wish to enter OTHER types of pipe and fittings to be used for the above application?

Answer : N

8) WATER DISTRIBUTION - PIPING USED UNDER GROUND OR BELOW SLAB:

SELECT type(s) required (you may enter others in a subsequent question):

1--Copper tubing, Type K; joints prohibited below ground.
2--PVC pipe (ASTM D 1785) Schedule 40; PVC fittings; solvent-cemented joints.
3--PVC pipe (ANSI/AWWA C900) Class 100; cast or ductile iron fittings; mechanical joints.
4--PB hot and cold water pipe or tubing; PB fittings; heat-fused or compression joints.
5--Ductile iron pipe with cement mortar lining; ductile iron fittings Schedule 150; rubber gasket joints.

Answer : 2

9) WATER DISTRIBUTION PIPING - USED UNDER GROUND OR BELOW SLAB:

PVC Pipe and Fittings (ASTM D 1785) Schedule 40: Enter specific APPLICATION instructions.

[FORMAT: Use for pipe 3 inches and smaller.]

Answer :
All underground piping.

10) WATER DISTRIBUTION PIPING - USED UNDER GROUND OR BELOW SLAB:

Do you wish to enter OTHER types of pipe and fittings to be used for the above application?

Answer : N

11) WATER DISTRIBUTION SYSTEM:

Select PITCH requirement for water distribution piping:

1--1/32 inch per foot (1/4 percent) downward slope toward drain point.
2--Piping to be installed LEVEL; NO pitch.
3--OTHER pitch requirement (to be entered).
4--NONE; no requirement specified.

Answer : 1

12) WATER METERS:

Will the work of this section include ANY responsibility for furnishing or installing a WATER METER?

1--YES; work included in THIS section.
2--NO; specified in DIVISION 2.
3--NO; water meter NOT required.

Answer : 3

13) WATER DISTRIBUTION SPECIALTIES:

Do you wish to specify any WATER DISTRIBUTION SPECIALTIES?

Answer : Y

14) WATER DISTRIBUTION SPECIALTIES:

Do you wish to specify MORE THAN ONE water distribution specialty type?

Answer : Y

15) WATER DISTRIBUTION SPECIALTIES:

```
How many distinct specialty TYPES do you wish to specify?  (If you are not
sure, enter a number comfortably larger than your estimate.)

Answer : 2


16)  WATER DISTRIBUTION SPECIALTY 1:

Select specialty TYPE:

 1--Water hammer arrestor.
 2--Strainer.
 3--Flexible connector.
 4--Hydrant.
 5--Backflow preventer.
 6--Specialty valve.
 7--OTHER type (to be entered).

Answer : 1

17)  WATER DISTRIBUTION SPECIALTY 1 - WATER HAMMER ARRESTOR:

How do you wish to specify this specialty?

 1--COMMODITY type product will be acceptable.
 2--DESCRIPTIVE requirements (to be entered -- model NOT specified).
 3--PROPRIETARY requirements (to be entered -- model and manufacturer
     specified; description optional).

Answer : 1

18)  MANUFACTURERS - WATER DISTRIBUTION SPECIALTY 1:

A LIST of manufacturers is:

 1--NOT REQUIRED.
 2--To be INCLUDED - NOT RESTRICTIVE.
 3--To be INCLUDED - RESTRICTIVE.

Answer : 2

19)  MANUFACTURER LIST - WATER HAMMER ARRESTOR:

Select any manufacturers to be INCLUDED in your specification; you may add
others in the next question.

 1--Jay R. Smith Manufacturing Company.
 2--Tyler Pipe Industries.
 3--Zurn Industries, Inc./Hydromechanics Division.
 4--ALL OF THE ABOVE.
```

Answer : 4

20) MANUFACTURER LIST - WATER DISTRIBUTION SPECIALTY 1:

Enter the names of any manufacturers to be included.

[FORMAT: ABC Manufacturing Company.
XYZ Products Corporation.]

***** NO ANSWER *****

21) WATER DISTRIBUTION SPECIALTY 1:

Enter specific APPLICATION instructions for this specialty.

[Format: Install specialty on supply side of each pressure-regulating valve and elsewhere as indicated.
Install specialty at each connection to mechanical equipment and elsewhere as indicated.]

Answer :
Install water hammer arrestors at the ends of long runs and on the supply side of plumbing fixtures.

22) WATER DISTRIBUTION SPECIALTY 2:

Select specialty TYPE:

1--Water hammer arrestor.
2--Strainer.
3--Flexible connector.
4--Hydrant.
5--Backflow preventer.
6--Specialty valve.
7--OTHER type (to be entered).

Answer : 4

23) WATER DISTRIBUTION SPECIALTY 2 - HYDRANT:

How do you wish to specify this specialty?

1--COMMODITY type product will be acceptable.
2--DESCRIPTIVE requirements (to be entered -- model NOT specified).
3--PROPRIETARY requirements (to be entered -- model and manufacturer specified; description optional).

```
Answer : 1

24)  WATER DISTRIBUTION SPECIALTY 2 - HYDRANT:

Select the COMMODITY TYPE hydrant you wish to specify:

 1--RECESSED, WALL-type.
 2--PROJECTING, WALL-type.
 3--FLOOR-level type.
 4--POST type.

Answer : 1

25)  MANUFACTURERS - WATER DISTRIBUTION SPECIALTY 2:

A LIST of manufacturers is:

 1--NOT REQUIRED.
 2--To be INCLUDED - NOT RESTRICTIVE.
 3--To be INCLUDED - RESTRICTIVE.

Answer : 2

26)  MANUFACTURER LIST - HYDRANT:

Select any manufacturers to be INCLUDED in your specification; you may add
others in the next question.

 1--Zurn Industries, Inc./Hydromechanics Division.
 2--Jay R. Smith Manufacturing Company.
 3--Josam Company.
 4--Tyler Pipe Industries.
 5--Woodford Manufacturing Company.
 6--ALL OF THE ABOVE.

Answer : 6

27)  MANUFACTURER LIST - WATER DISTRIBUTION SPECIALTY 2:

Enter the names of any manufacturers to be included.

[FORMAT:  ABC Manufacturing Company.
          XYZ Products Corporation.]

***** NO ANSWER *****


28)  WATER DISTRIBUTION SPECIALTY 2:

Enter specific APPLICATION instructions for this specialty.
```

[Format: Install specialty on supply side of each pressure-regulating valve and elsewhere as indicated.
Install specialty at each connection to mechanical equipment and elsewhere as indicated.]

Answer :
Install hydrants as indicated on the drawings.

29) WATER DISTRIBUTION VALVES:

Do you wish to specify requirements for GENERAL PURPOSE VALVES?

1--NO; requirements, if any, will be shown ON DRAWINGS.
2--YES; specify GENERAL requirements ONLY (applicable to all valves) -- detailed requirements will be shown on drawings.
3--YES; specify distinct VALVE TYPES.

Answer : 1

30) SYSTEM ACCESSORIES:

Do you wish to specify any system ACCESSORIES?

Answer : N

31) PIPING INSTALLATION:

Will any piping penetrate FIRE/SMOKE BARRIERS?

Answer : Y

32) FIRESTOPPING/SMOKESTOPPING:

Firestopping/smokestopping of pipe penetrations through fire/smoke barriers:

1--Will be accomplished by the plumbing piping installer.
2--Will be accomplished by another installer.
3--Is not required.

Answer : 1

33) PIPING INSTALLATION:

Will PIPE INSULATION be applied to any of the plumbing piping? (Note: Pipe insulation is NOT included in this section and must be specified elsewhere.)

Answer : Y

34) PIPING INSTALLATION:

Will any plumbing piping be installed ABOVE REMOVABLE CEILING PANELS?

Answer : Y

35) SPECIAL LOCATIONS OF FITTINGS:

Enter any special locations where fittings should be installed, to replace the blank in the following:

Special fitting locations include: ______________

[FORMAT: Yoke vents, 3rd floor.]

***** NO ANSWER *****

36) QUALITY ASSURANCE - REGULATORY REQUIREMENTS:

Enter the complete title and publishing information of the CODE with which the work of this section must comply, if you wish.

[FORMAT: American City Plumbing Code; Name of City, Name of State; 1987.]

***** NO ANSWER *****

37) MANUFACTURER'S EXPERIENCE:

Select manufacturer's experience requirement:

1--Minimum 5 YEARS' experience.
2--OTHER period (to be entered).
3--NONE; experience specification NOT REQUIRED.

Answer : 3

38) INSTALLER'S EXPERIENCE:

Select installer's experience requirement:

1--Minimum 5 YEARS' experience.
2--OTHER period (to be entered).
3--NONE; experience specification NOT REQUIRED.

Answer : 3

39) SUBMITTALS:

Is submittal of SHOP DRAWINGS required?

Answer : Y

40) SUBMITTALS:

Is submittal of PRODUCT DATA required?

1--YES; required for ALL products.
2--YES; required for ALL SPECIALTIES.
3--NO; not required.

Answer : 1

41) COORDINATION DRAWINGS:

Are COORDINATION DRAWINGS required?

1--YES; and must be SUBMITTED FOR INFORMATION BEFORE distribution to affected installers.
2--YES; but submittal prior to distribution is NOT required.
3--NO; coordination drawings NOT REQUIRED.

Answer : 2

42) COORDINATION DRAWINGS:

Go on to the next question if a requirement that the drawing SCALE must be 1/4 INCH = 1 FOOT OR LARGER is acceptable. Otherwise, enter a description of the required scale to replace the blank in the following:

Drawing scale: ______________________

[FORMAT: 1/4 inch = 1 foot.]

***** NO ANSWER *****

43) SUBMITTALS:

Is submittal of MANUFACTURER'S INSTRUCTIONS required?

1--YES; required for ALL products.
2--YES; required for ALL SPECIALTIES.
3--NO; manufacturer's instructions NOT REQUIRED.

Answer : 1

44) SUBMITTALS:

Is submittal of OPERATION AND MAINTENANCE DATA required?

1--YES; required for ALL products.
2--YES; required for ALL SPECIALTIES.
3--NO; operation and maintenance data NOT REQUIRED.

Answer : 1

45) EXTRA MATERIALS:

Enter requirements for EXTRA MATERIALS (if you wish to specify them) to replace the blank in the item shown below.

Furnish the following ______________________

[FORMAT: One extra valve key for each key-operated specialty item specified.]

***** NO ANSWER *****

46) RELATED SECTIONS:

Select any of the following cross-references you wish to include in this section. You may add others in a subsequent question.

1--Concrete, formwork, and reinforcing: Division 2.
2--Sanitary sewerage: Division 2.
3--Septic systems: Division 2.
4--Storm sewerage: Division 2.
5--Excavating and backfilling: Division 2.
6--Water service piping: Division 2.

Answer : 1 5 6

47) RELATED SECTIONS:

Select any of the following cross-references you wish to include in this section. You may add others in a subsequent question.

1--Firestopping/smokestopping: Division 7.
2--Flashing and sheet metal: Division 7.
3--Accessories for expansion compensation: Elsewhere in Division 15.
4--Fire protection piping: Elsewhere in Division 15.
5--Mechanical identification: Elsewhere in Division 15.
6--Pipe insulation: Elsewhere in Division 15.
7--Supports and anchors: Elsewhere in Division 15.

Answer : 1 4 5 6 7

48) RELATED SECTIONS:

```
Enter any additional cross-references to be included in this section.

[FORMAT FOR DIVISION 15:  Plumbing valves:  Elsewhere in Division 15.]
[FORMAT FOR OTHER DIVISIONS:  Piped utility materials:  Division 2.]

***** NO ANSWER *****


49)  REFERENCES:

Do you wish to include a COMPLETE LIST of all standards and other documents
referenced in the text?

Answer : Y
```

APPENDIX 10.2

SECTION 15415—WATER DISTRIBUTION SYSTEM

PART 1 - GENERAL

1.01 SUMMARY

A. Section Includes:
1. Water distribution system: The system includes potable cold-water and potable hot-water piping, and associated plumbing products inside building and extending to a point 5 feet outside building.
   a. Pipe and fittings.
   b. Specialties.

B. Related Sections:
1. Concrete, formwork, and reinforcing: Division 2.
2. Excavating and backfilling: Division 2.
3. Water service piping: Division 2.
4. Firestopping/smokestopping: Division 7.
5. Fire protection piping: Elsewhere in Division 15.
6. Mechanical identification: Elsewhere in Division 15.
7. Pipe insulation: Elsewhere in Division 15.
8. Supports and anchors: Elsewhere in Division 15.

1.02 REFERENCES

A. ANSI/ASME B1.20.1-1983 -- Pipe Threads, General Purpose (inch); The American Society of Mechanical Engineers; 1983.

B. ANSI/ASME B16.3-1985 -- Malleable Iron Threaded Fittings, Classes 150 and 300; The American Society of Mechanical Engineers; 1985.

C. ASTM A 53-90 -- Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless; 1990.

D. ASTM D 1785-89 -- Standard Specification for Poly(Vinyl Chloride)(PVC) Plastic Pipe, Schedules 40, 80, and 120; 1989.

E. PDI-WH 201-1977 -- Water Hammer Arresters; Plumbing and Drainage Institute; 1977 (Reprinted 1983).

1.03 SUBMITTALS

A. Product Data: Submit for each product specified in this section.

B. Shop Drawings: Prepare and submit shop drawings showing layout of plumbing system components. Include component sizes, rough-in requirements, service sizes and all other information necessary to demonstrate compliance with requirements of contract documents.

C. Manufacturer's Instructions:
  1. Submit for each product specified in this section.
  2. Include installation procedures.
  3. Include instructions for examination, preparation, and protection of adjacent work.

D. Operation and Maintenance:
  1. Submit maintenance and operating data for each product specified in this section.
  2. Include the following information:
    a. Instructions for starting and operating equipment.
    b. Operating limits which, if exceeded, may result in hazardous or unsafe conditions.
    c. Cleaning, preventive maintenance, and lubrication schedule and procedures.
    d. List of special tools, maintenance materials, and replacement parts.

1.04 DELIVERY, STORAGE, AND HANDLING

A. Execute product manufacturer's special instructions to prevent damage to products.

B. Protect the following items from prolonged exposure to sunlight:
  1. PVC pipe or fittings.

C. Provide factory-applied plastic end caps on each length of pipe and tube. Maintain end caps through shipping, storage, and handling to prevent damage and to prevent entrance of dirt, debris, and moisture.

D. Protect stored pipes and tubes. Elevate above grade. Enclose with durable, waterproof wrapping. If stored inside, do not exceed structural capacity of floor.

E. Store piping in flat position. Take precautions as required to ensure pipes are not deformed.

F. Protect the following from moisture and dirt by storing products in enclosed space inside building or by packaging with durable, waterproof wrapping:
  1. Fittings.
  2. Specialties.

1.05 PROJECT CONDITIONS

A. Location and arrangement of plumbing materials are indicated on drawings. Install as indicated. Obtain approval of the Architect for any significant deviation from the system design or from the intent of the design, before installation is executed.

1.06 COORDINATION

A. Use manufacturer's instructions and data to determine rough-in requirements and locations of products connected to piping.

B. Coordination Drawings:
1. Provide coordination drawings for water distribution system.
2. Include information necessary to properly coordinate work of this section with other work.
3. Include the following:
    a. Details showing relationships of system components with other building components.
    b. Clearance required around each product for installation, ventilation, access, operation, and maintenance.
4. Prepare drawings to an accurate scale of 1/4 inch = 1 foot, or larger.
5. Distribute to affected installers of related work.

1.07 SEQUENCING AND SCHEDULING

A. Coordinate work of this section with work of other sections as necessary.

1.08 MAINTENANCE

A. Extra Materials:
1. Furnish the following:
    a. One key for every key-operated hydrant.

PART 2 - PRODUCTS

2.01 MATERIALS - GENERAL

A. Do not use plumbing products manufactured from metal alloys containing more than 6 percent lead in potable water piping system.

2.02 WATER DISTRIBUTION SYSTEM

A. Pipe and Fittings Used inside Building (Excluding under Slab):
1. Galvanized steel pipe: (ASTM A 53) Schedule 40, seamless.
    a. Fittings: (ANSI/ASME B16.3) Class 150, galvanized malleable iron, threaded.
    b. Application:
        1. All piping within building.

B. Water Distribution Pipe and Fittings Used under Ground or below Slab:
1. PVC - polyvinyl chloride plastic pipe: (ASTM D 1785) Schedule 40.
    a. Fittings: Of same material, socket type.
    b. Joints: Solvent cemented.
    c. Application:
        1. All underground piping.

C. Specialty 1:
  1. Water hammer arrestor:
    a. Description:
      1. Bellows style arrestor.
      2. Casing and bellows: Stainless steel.
      3. Pressure-rating: 250 psi.
      4. Tested and certified for compliance with PDI-WH 201.
    b. Manufacturers: Products of the following manufacturers, provided they comply with requirements of the contract documents, will be among those considered acceptable:
      1. Jay R. Smith Manufacturing Company.
      2. Tyler Pipe Industries/Tyler Corporation.
      3. Zurn Industries, Inc./Hydromechanics Division.
    c. Application:
      1. Install water hammer arrestors at the ends of long runs and on the supply side of plumbing fixtures.

D. Specialty 2:
  1. Hydrant:
    a. Description:
      1. Recessed type for wall installation, nonfreeze.
      2. Cast bronze, with chrome-plated face.
      3. Handle key: Tee-shaped.
      4. Anti-siphoning device.
      5. Hinged cover: Lockable.
      6. Inlet: 3/4-inch.
      7. Hose outlet: 3/4-inch.
      8. Casing: Bronze, sized for wall thickness indicated.
    b. Manufacturers: Products of the following manufacturers, provided they comply with requirements of the contract documents, will be among those considered acceptable:
      1. Jay R. Smith Manufacturing Company.
      2. Josam Company.
      3. Tyler Pipe Industries/Tyler Corporation.
      4. Woodford Manufacturing Company.
      5. Zurn Industries, Inc./Hydromechanics Division.
    c. Application:
      1. Install hydrants as indicated on the drawings.

PART 3 - EXECUTION

3.01 EXAMINATION

A. Examine conditions in spaces where plumbing piping installation is indicated.

B. Verify placement of fixtures and equipment to determine locations of rough-in connections.

C. Correct unsatisfactory conditions before beginning installation of products specified in this section. Commencement of installation indicates acceptance of conditions.

3.02 PREPARATION

A. Pipe and Fittings:
  1. Ream and deburr piping and tubing ends.
    a. Steel pipe: Bevel plain ends.
  2. Clean scale, dirt, and other deleterious materials from pipe (inside and outside) and fittings (inside and outside) before assembly.

3.03 INSTALLATION

A. Perform installation in accordance with the manufacturer's instructions, except where more stringent requirements are shown or specified, and except where project conditions require extra precautions or provisions to ensure satisfactory performance of the work.
  1. Exposed piping is indicated on drawings. Conceal all other piping in pipe chases, in walls, above ceilings, in utility spaces, or below floors.
  2. Install piping as close as possible to the building's structural elements, such as columns, walls, beams, joists, and slabs.
    a. Provide adequate space around piping to allow proper application of insulation. Finished piping insulation minimum clearance: 1 inch, all around.
    b. Piping installed above lay-in ceilings: Provide adequate clearances above lay-in panels to permit removal and replacement of panels.
  3. Install pipes in parallel groups.
  4. Space individual pipes to allow servicing of plumbing system components.
  5. Install piping bend-free and sag-free.
  6. Support and anchor pipe as specified elsewhere in Division 15.
  7. Fire-stop/smoke-stop all pipe penetrations through fire/smoke barriers in accordance with requirements of the firestopping and smokestopping section in Division 7.
  8. Joining pipes and fittings:
    a. Steel:
      1. Threaded joints:
        a. Form tapered pipe threads in accordance with ANSI/ASME B1.20.1.
        b. Use clean sharp dies to cut threads.
        c. Ream threaded ends and deburr.
        d. Use proper sealant or joint lubricant on male pipe threads at all joints.
        e. Tighten as necessary to form solid joint.

B. Water Distribution System:
  1. Pitch: 1/32-inch-per-foot (1/4 percent) to drain point.
  2. Specialties:
    a. Install specialties as indicated.
  3. Connections:
    a. Piping runouts to fixtures: Install runouts to fixtures. Size

piping as required.

b. Mechanical equipment: Provide connections to equipment as required.

3.04 CLEANING

A. Water Distribution System:

1. Clean and disinfect water distribution system to meet regulatory requirements.

3.05 PROTECTION

A. Plug all piping system openings whenever installation is temporarily interrupted or halted for the day.

END OF SECTION 15415

CHAPTER 11

INSTALLATION OF WATER SYSTEMS IN BUILDINGS

George Kauffman
Plumbing Contractor, George Kauffman Plumbing

INTRODUCTION

This chapter discusses various factors that must be considered in installing a water distribution system in a building. These include selection of piping to be installed; how joints and connections are made in a piping system; methods for anchoring, hanging, and supporting piping; the use of sleeves where pipes penetrate a partition; the installation of expansion loops, joints, and offsets to absorb the expansion of piping; the application of devices to eliminate water hammer; and the underground installation of piping. When installation is complete, the system should be tested according to the procedures set forth in the next chapter.

SELECTION OF TYPE OF PIPING TO BE INSTALLED

The following factors should be considered in the selection of a type of piping material for water supply systems:

Initial cost
Installation cost
Expected service life
Weight
Chemical resistance
Susceptibility to corrosion
Formability
Thermal expansion
Friction losses in the piping
Bursting strength
Pressure rating

Rigidity
Resistance to crushing
Combustibility
Ease of making joints
Space requirements
Applicable standards and specifications
Suitability for underground installation

This section describes the characteristics of steel, copper, brass, and plastic piping used in water distribution systems.

Data for the pressure drop resulting from the flow of water through pipes of various materials are given in Figs. 7.2 through 7.7. These data show that for a pipe of the same diameter, and for the same flow velocity, steel pipe produces the largest pressure drop. The losses in brass and copper pipe and tubing are somewhat lower; they are also lower in plastic pipe and tubing.

Galvanized Iron and Steel Pipe

Steel pipe used in plumbing systems is either plain (black) iron or galvanized (zinc-plated). It may be extruded (i.e., seamless) or welded (i.e., having a seam). It is available in the following classifications: standard weight, extra-strong weight, and double extra-strong weight. Within these classifications are a variety of wall thicknesses, expressed as "schedules," ranging from Schedule 10 (the lightest) to Schedule 160 (the heaviest). The relationship between schedule and wall thickness varies with pipe size. (Steel pipe used in drainage systems is described in Chap. 18.)

Steel pipe has excellent rigidity, high compressive strength, and high structural strength. Its initial cost is usually higher than other types of pipe, but its handling and installation costs may be lower. Its coefficient of thermal expansion is relatively low, but provisions for an expansion loop should be made, according to the directions given under "Controlling Thermal Expansion and Contraction," when long runs of piping are installed. Other advantages include availability in long lengths, good fire resistance, low initial cost, and good flow characteristics.

Pressure Ratings. Two types of steel pipe are available in the U.S.A.: (*a*) continuous butt-welded pipe and (*b*) seamless pipe. The former is generally used at normal pressures; the latter is generally used in high-pressure systems. The pressure ratings for such pipe, for various nominal diameters, can be obtained from Ref. 1.

Standards and Specifications. Applicable standards and specifications include ASTM Standard A-53, which applies to continuous butt-welded and seamless pipe when coiling or bending is required, and ASTM Standard A-120, which applies to continuous butt-welded pipe and to seamless pipe most generally used for plumbing and in general applications when coiling or bending is not required.

Copper Piping Materials

Copper tube is widely used in water systems because it is easily formable, easy to join, economical of space, and resistant to interior scaling because of its smooth surface. The smooth surface also contributes to low frictional losses for the flow of water. Because copper tube is light in weight, it is relatively easy to haul and install. Its resistance to most chemicals found in domestic water is conducive to a long life.

Types of Copper Tube. Copper tube used in plumbing is primarily of three types: **K**, **L**, and **M**. Each type represents a series of tubes that differ in size and wall thickness. Type **K** has the heaviest wall thickness and therefore is the most costly of the three types. It is suitable for all uses—primarily for piping systems at temperatures in excess of 140°F (60°C) and/or high pressures, both for water systems in buildings and for underground water service. Since its wall thickness is the heaviest of the three types, it provides the longest service life. Type **L** is suitable for service in both building interiors and underground installations. In areas where the water pressure fluctuates greatly, this type of tube should be used. Either type **K** or type **L** may be used where bending is required. Type **M** has the smallest thickness of the three types and therefore a shorter service life. It is generally recommended for use in the interior of buildings.

Hard-temper copper tube in straight lengths is marked in distinguishing colors to indicate the type of tube, the name or trademark of the manufacturer, and country of origin. The identifying colors are type **K**, green; type **L**, blue; type **M**, red, and type **DWV**, yellow. Soft-temper copper tube is not color-coded in this way, but distinguishing colors are used for identification on cartons and shipping tags. Type **DWV**, which has thinner walls than the other three types of copper tube, is primarily used in drainage, waste, and vent lines.

Pressure Ratings and Bursting Strength. The rated internal working pressure of copper tube depends on (*a*) the service temperature—the higher the temperature, the lower the rating, (*b*) whether the tube is annealed (soft tube) or drawn (hard tube)—drawn tubing has the higher pressure rating, (*c*) the size of tubing—the larger the diameter, the lower the pressure rating, and (*d*) the type of material—type **K** has the highest rating, **L** the next highest, **M** the third highest. Pressure ratings for specific sizes of tubes and tube materials can be obtained from the Copper Development Association.[2]

Bending. Copper tube can be formed at the job site because of of its excellent ductility. Because it forms readily, expansion loops and other bends necessary in such a piping system can be made quickly and simply with hand tools (such as mandrels, dies, forms, and fillers) or power-operated bending machines. Because the tube can be bent to shape, it often is possible to avoid the use of elbows and joints, but it is necessary to check with local authorities to determine if this is acceptable under the local code.

When properly bent, a copper tube will not collapse on the outside of the bend and will not buckle on the inside of the bend. It can be bent with a hand bender whose size is appropriate for the size of the tube being bent. Usually the size of the tool corresponds to the nominal outside diameter of the tube—not the standard tube size. Table 11.1 provides a guide for typical bending radii for either machine bending or bending by hand with circular wooden disks.[2]

How a Bend Is Made. Although there may be slight differences in bending techniques associated with different commercially available bending devices, the basic procedure is as follows:

TABLE 11.1 Bending Guide for Copper Tube

Tube size, in (cm)	Tube type	Temper	Minimum, band radius, in (cm)	Type of bending equipment
¼ (0.64)	K, L	Annealed	¾ (1.9)	Lever type
⅜ (0.95)	K, L	Annealed	1½ (3.8)	Lever or gear type
			3 (7.6)	None; by hand*
	K, L, M	Drawn	1¾ (4.4)	Gear type
½ (1.27)	K, L	Annealed	2¼ (5.7)	Lever or gear type
			4½(11.4)	None; by hand*
	K, L, M	Drawn	2½ (6.3)	Gear type
¾ (1.91)	K, L	Annealed	3 (7.6)	Lever or gear type
	K		4½(11.4)	None; by hand*
	L		6 (15.2)	None; by hand*
	K	Drawn	3 (7.6)	Gear type
	K, L		4 (10.2)	Heavy-duty gear type
1 (2.54)	K, L	Annealed	4 (10.2)	Gear type
			7½ (19.1)	None; by hand*
1¼ (3.2)	K, L	Annealed	9 (22.9)	None; by hand*

*When bending by hand, without the use of bending equipment, a circular wooden disk is used. The radius of the disk should be about ½ in (1 cm) less than the minimum bend radius shown.

Source: Adapted from Ref. 2.

1. Open the handle of the lever-type bender to a 180° position. Then raise the tube holding clip so that it is out of the way, and insert the tube in the forming-wheel groove, as shown in Fig. 11.1*a*.
2. Secure the tube in the bender by lowering the tube holding clip, and turn the handle of the bender to a right-angle position, engaging the shoe over the wheel, as shown in Fig. 11.1*b*.
3. Now rotate the handle, in a continuous motion, to the desired angle, which is indicated by a calibration on the forming wheel, as shown in Fig. 11.1*c*.
4. Pivot the handle to a right angle with the tube, as shown in Fig. 11.1*d*, and disengage the forming shoe in order to release the bent tube.

Standards and Specifications. Standards and specifications include:

ANSI/ASME B16.22	*Wrought Copper and Copper Alloy Solder Joint Pressure Fittings*
ANSI 16.26	*Cast Copper Alloy Fittings for Flared Copper Tube*
ANSI B16.18	*Cast Bronze Solder Joint Pressure Fittings*
ASTM B-302	*Threadless Copper Tube*
ASTM B-88	*Seamless Copper Water Tube (Types K, L, M)*
ASTM B-42	*Copper Pipe*

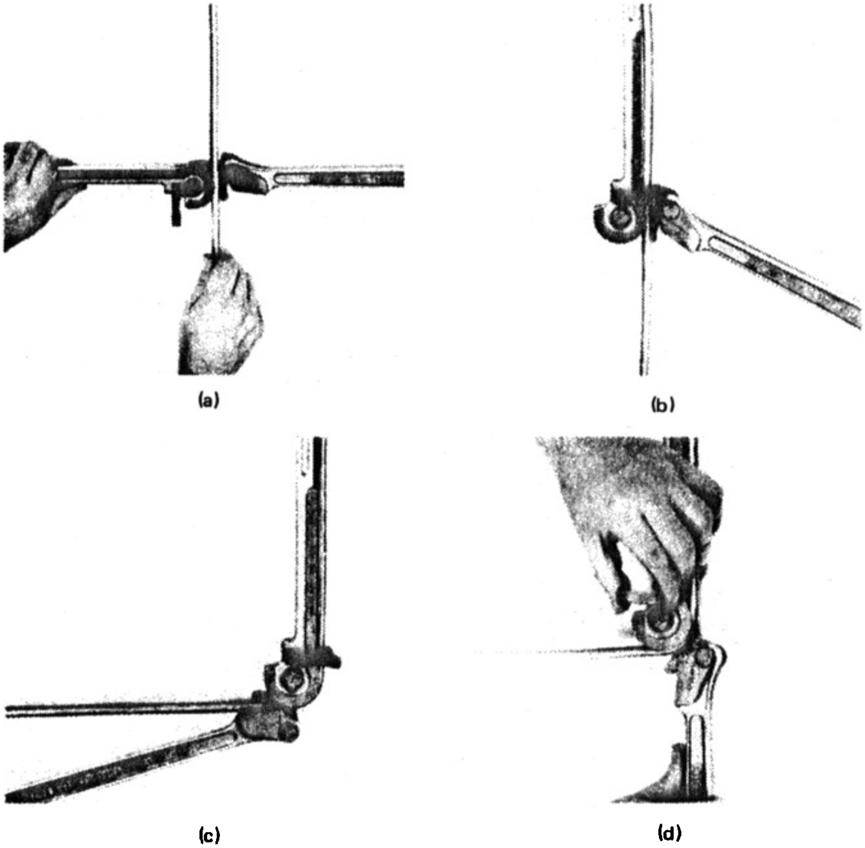


FIG. 11.1 Making a bend in a copper tube using a lever-type bender. (*a*) The tube is inserted in the bender. (*b*) The tube is secured. (*c*) The handle of the bender is turned to the desired angle. (*d*) The tube is released. *(Adapted from Ref. 2.)*

Brass Piping Materials

Brass is an alloy consisting primarily of copper (about 85 percent) and zinc (about 15 percent), but it may also include some tin and nickel in different proportions. The material cost and the installation cost for brass is higher than for copper, but so is the strength. Brass pipe provides very good resistance to interior scaling. It has slightly lower resistance to flow at high velocities than most copper tube, and it is much better in this respect than steel pipe. Therefore, it is especially suitable for high-velocity water systems.

Standards and Specifications. Standards and specifications include:

ANSI B16.15	*Cast Bronze Threaded Fittings (125 and 250 Class)*
ANSI B16.24	*Bronze and Flanged Fittings (150—300 Class)*

ASTM B-43	*Seamless Brass Pipe*
ASTM B-135	*Brass Tube*

Plastic Piping Materials

Plastic pipe is formed from a material that contains, as an essential ingredient, one or more organic polymeric substances. Although a solid, when subjected to heat and/or pressure the plastic material flows, so it can be used to form products for piping systems. Its advantages include low initial cost, light weight, high flexibility, good corrosion resistance, and availability in long lengths. Disadvantages include poor fire resistance, production of toxic gas upon combustion of some types of plastics, poor resistance to solvents, low pressure ratings at high temperatures, and susceptibility to change in some plastics as a result of prolonged exposure to sunlight. Although exposure to sunlight during normal construction periods is not harmful, it should not be exposed to direct sunlight for long periods of time. Where such exposure exists, the plastic pipe should be wrapped with tape made for this purpose, at least 0.040 in (1 mm) thick, or painted. Physical properties of plastic piping materials, with information on characteristics of commercially available piping, are given in Ref. 3.

Plastic pipe must be protected from mechanical damage (e.g., slitting or puncturing). Vertical piping, outside a building, should not extend more than 2 ft (0.6 m) above grade and should be protected from mechanical damage and exposure. Where it passes through drilled or notched studs or masonry walls, it should be protected from abrasion that may result from movement of the pipe by thermal expansion and contraction. Such protection may be obtained by passing the plastic tubing through a plastic sleeve or grommet specially designed for this purpose.

Where plastic water supply piping is installed in a building, a permanent sign, "This building has nonmetallic interior water piping," should be fastened on the main electric service panel. This warning should be given, since the electrical wiring in most buildings depends on metal water pipe for a connection to ground.

Types. The most widely used types include:

Acrylonitrile-butadiene-styrene (ABS). Used in drainage systems, storm sewers, and underground electrical conduit. Types I and II are available in Schedules 40 and 80 and some special sizes. For Schedule 40, the joints are solvent-cemented; for Schedule 80, the joints are solvent-cemented or threaded.

Chlorinated polyvinyl chloride (CPVC). The most widely used of the plastics; used in both hot- and cold-water systems and in drainage systems (see Chap. 18), especially in water and waste lines where corrosion may be a problem. Available in Schedules 40 and 80, but only the latter can be threaded.

Polyethylene (PE). Used in cold-water domestic supply lines and in cold-water lines in air-conditioning systems. Available in Schedules 40 and 80.

Polyvinyl chloride (PVC). The most widely used plastic piping in cold-water systems, as well as in sewage and waste lines. It is highly resistant to chemicals and corrosion. It is available in a wide range of thicknesses.

The mark *ASTM D-2846* and the mark *NSF* indicate that a product meets the requirements of the American Society for Testing and Materials and the National

Sanitation Foundation, respectively. Such markings and logos appear every 5 ft (1.5 m), so they remain legible after installation; they include the manufacturer's name (or trademark), production code, seal or name of the evaluating laboratory, pressure rating, nominal size, standard dimension ratio (SDR), and size of the pipe. Many of the standards and specifications for plastic pipe and associated fittings are given in Ref. 3.

Fittings should be marked unless their size makes such marking impractical. Then the fittings should be identified by some symbol that is defined in the manufacturer's literature.

Ductile-Iron Pipe

Ductile iron is cast iron in which the carbon is reformed by magnesium inoculation, resulting in a material having exceptionally high strength without otherwise changing its basic properties. As a result, ductile-iron pipe has largely replaced iron water mains that were common many years ago. Good corrosion resistance makes this type of pipe especially useful in underground installations.

Pressure Ratings. The pressure rating of ductile-iron pipe having a nominal diameter between 3 and 24 in (7.6 and 61 cm) is 350 psi (2413 kPa) plus a surge pressure of 100 psi (689 kPa).

Standards and Specifications. Ductile-iron pipe, centrifugally cast in metal molds or sand-cast in sand molds, is manufactured in accordance with ANSI Standard A21.51 and AWWA Standard C151.

JOINTS AND CONNECTIONS

Steel Piping Materials

Steel piping is usually connected by threaded joints. It is available in lengths with threaded ends, or threads can be cut, as described below. (Welding of galvanized steel pipe should be avoided, since it results in the emission of a toxic gas from the zinc coating.)

Making a Threaded Joint. In making a threaded joint on steel pipe, the following steps should be taken:

1. Cut the pipe square to the axis of the pipe.
2. Remove any burrs with a reamer or half-round file. Ensure that filings are cleaned from the pipe.
3. Thread the pipe by means of a hand-operated tool called a *stock* or a power threading machine. The correct size of die (i.e., thread-cutting device) is inserted in the stock and carefully engaged on the end of the pipe to be threaded so that the axes of the pipe and the die are aligned. In general, the nominal

length of thread has been cut on the pipe when the front surface of the die is flush with the end of the pipe. Table 11.2 shows the characteristics of a standard pipe thread conforming to the American Standard taper pipe thread, ANSI B2.1–1968. Of special interest in pipe layout and dimensioning is the last column, "Tight-fit makeup length of thread," which provides the normal allowance recommended for thread engagement with fittings for tight joints.[4]

4. Apply pipe compound to the pipe thread—do not apply it to the fitting. Only pipe compound that is specifically manufactured for this purpose should be used.
5. After engaging the pipe thread in the fitting, tighten the fitting on the pipe by means of a pipe wrench. Do not tighten excessively.
6. Remove the excess compound from the pipe.

Grooved Joints. A grooved joint is illustrated in Fig. 18.12. Its use is advantageous in joining steel pipe where some flexibility is required and the piping is subject to vibration. The joint is formed by means of a mechanical coupling that fits in grooves cut near each end of the two pipes to be joined. A rubber gasket is used in the joint to provide a seal. A large selection of such gaskets is available for various temperature ranges and for various types of water.

Copper Piping Materials

Copper tube can be joined to fittings either by soldering or by making a flared joint. *Soldering* is the joining of metals by fusion, using an alloy, often in wire form, whose melting temperature does not exceed 800°F (417°C). *Brazing* is the joining of metals by a nonferrous "filler metal," sometimes called "hard solder," usually in rod or wire form. For copper tube joints, the melting temperature of the filler metal is usually between 1100 and 1500°F (593 and 816°C).

Types of Solders. Solders usually consist of some combination of tin, antimony, silver, and lead. Passage of amendments to the Safe Water Drinking Act in 1986 effectively banned the use of solders containing lead, such as the traditional solder containing 50 percent tin and 50 percent lead, in water supply systems (although they may be used in drainage systems). This type of solder has a relatively low melting temperature, and it fills capillary spaces easily. The melting characteristics of lead-free solders that can be used with equal success are shown in Fig. 11.2. These include combinations of tin-antimony and tin-silver in the proportions shown. Such lead-free solders are applied, as described below, by the same techniques used for tin-lead. Lead-free soldered joints have a major advantage over lead-tin joints—they are much stronger. Specifications for solder metal are covered in ASTM Standard B-32.

Fluxes. Soldering flux is applied to the surfaces to be joined to (*a*) remove residual traces of oxides, (*b*) promote "wetting" of the surfaces by the molten solder, and (*c*) protect the surfaces being soldered from oxidization during heating of the joints. Fluxes are mildly corrosive and usually contain chlorides of zinc and ammonium. Some liquid and paste fluxes are identified as "self-cleaning"; i.e., they are said to remove some oxides and dirt films without mechanical abrasion, but their use involves the risk of nonuniform cleaning and of possible further corrosive action after soldering of the joint has been completed.

TABLE 11.2 American Standard Taper Pipe Threads for Steel Pipe

Nominal pipe size, in	Die size classification	Number of threads per inch	Nominal length of thread on pipe, in	Tight-fit makeup length of thread, in
⅛	Tiny	27	⅜	¼
¼	Very small	18	9⁄16	⅜
⅜	Very small	18	9⁄16	⅜
½	Small	14	¾	½
¾	Small	14	¾	9⁄16
1	Medium	11½	15⁄16	11⁄16
1¼	Medium	11½	15⁄16	11⁄16
1½	Medium	11½	1	11⁄16
2	Medium	11½	1⅛	¾
2½	Large	8	1½	15⁄16
3	Large	8	1 9⁄16	1
4	Large	8	1 11⁄16	1⅛
5	Large	8	1 13⁄16	1¼
6	Large	8	1⅞	1 5⁄16
8	Large	8	2 1⁄16	1 7⁄16
10	Large	8	2 5⁄16	1⅝
12	Large	8	2½	1¾
15	Large	8	2¾	1¾

Source: Adapted from Ref. 4.

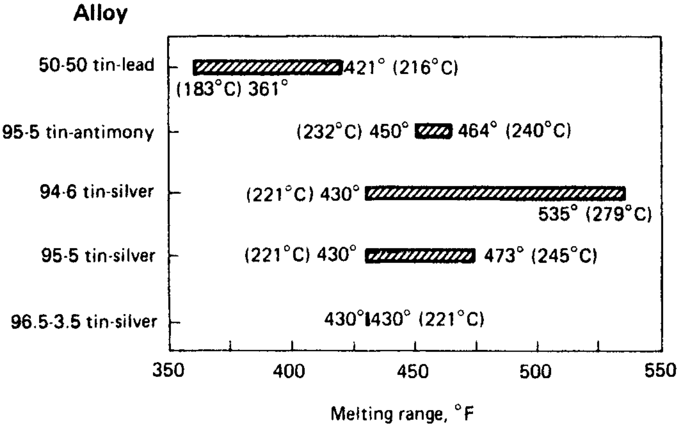


FIG. 11.2 The melting characteristics of various types of lead-free solders compared with solder composed of 50 percent lead and 50 percent tin. *(Adapted from Ref. 2.)*

Selection of Type of Solder. The selection of the type of solder should be based on cost, operating pressure, and temperature to which the joint will be subjected. While the cost of lead-free solders is higher per unit weight than the cost of traditional solders containing lead, this increase is partially offset by the lower densities of the lead-free solders.

Where greater joint strength is required (as in high-pressure lines), an alloy of 95 percent tin and 5 percent antimony solder can be used. Strength considerations should include the stress on the joints caused by thermal expansion and contraction.

Making Soldered Joints. The following steps should be taken in forming a soldered joint between a tube and a fitting:

1. First cut the tube with a hacksaw, a carbide-tipped blade, a portable band saw, or a three- or four-wheeled tube cutter, for example. The cut must be square to the linear axis of the tubing.
2. Ream the cut end of the tube with a half-round file. Remove any burrs. If the tube is out-of-round as a result of cutting, it should be brought back to true roundness by means of a shaped plug and sizing ring.
3. Mechanically clean the ends to be joined with sand cloth (00), a wire brush, or cleaning pads, for example. A chemical cleaner can be used if it is carefully rinsed off, according to instructions provided by its manufacturer. In the cleaning process, make sure that no particles of material fall into the tube or fitting to be joined.
4. Apply flux to the surfaces to be joined as soon as possible after cleaning, with either a clean cloth or a brush. Then remove any excess flux.
5. Assemble the joint to be joined, making sure that the tube firmly meets the end of the fitting socket.
6. Support the tube and fittings adequately during assembly and soldering.

7. Check the tolerances of a joint with a feeler gage to obtain an estimate of the amount of solder required.
8. Apply heat to the joint uniformly—avoiding overheating, which will burn the flux, reduce its effectiveness, and require that the joint be opened and recleaned. Acceptable heat sources include acetylene, propane, and certain types of manufactured gas. The torch types that are preferred are of the single-tip swirl type.
9. Heat the fitting evenly around its entire circumference, as shown in Fig. 11.3*a*. The residual heat from the torch should strike the surface of the tube. Now bring the bottom surface of the tube, as shown in Fig. 11.3*b*, to about the 7 o'clock position.
10. Apply a sufficient, but not excessive, amount of solder. When the solder begins to melt *from the heat of the tube and fitting*, push the solder straight into the joint. Capillary action should draw all the solder that is required into the joint; this action is most effective when the space between the surfaces to be joined is between 0.002 and 0.005 in (0.05 and 0.013 mm) wide. Now apply the torch to the base of the fitting on the same line with the solder. Continue this technique across the bottom to the 5 o'clock position. Permit the solder in this area to harden so that it forms a dam that prevents solder from running out of the joints at the sides as solder is applied to the top and sides. Do *not* heat and start feeding solder at the top of the joint.
11. Continue upward from the 5 o'clock position, keeping the torch slightly ahead of the solder being applied. Small drops behind the application of the solder are an indication that the joint is full to that point and will take no more solder. Continue this technique to the 12 o'clock position, as shown in Fig. 11.3*c*, and move down the opposite side to the point of initial application. Then overlap about ¾ in (2 cm).
12. After checking the bottom of the joint to ensure that the dam is still in solid condition, apply solder in an upward direction, as in Step 11, to the unsoldered portion of the joint.
13. Remove the heat source, and continue applying wire solder until the joint will accept no more solder.
14. When the solder has solidified, wipe the joint free of excess flux on the exterior of the tube.

It is important that there be no prolonged time interval between steps. For example, a cleaned joint should not be allowed to stand overnight; otherwise, the cleaned surface will reoxidize. During the soldering process, the solder should be applied over a section not larger than about 3 in (8 cm).

Filler Metal for Brazed Joints. In making a brazed joint, care should be taken in selecting the filler metal. Important in making this selection is the *melting range*, i.e., the range between the temperature at which the filler metal starts to melt on heating and the temperature at which the filler metal is completely melted. Brazing filler metals are of two classes: (*a*) alloys containing 30 to 60 percent silver (the BAg series) and (*b*) copper alloys that contain phosphorus (the BCuP series). The latter series contains cadmium and produces highly toxic fumes when heated, so adequate ventilation is essential. The strength of the joint does not depend on the type of filler metal; it depends primarily on thoroughly cleaning the surfaces to be joined and on maintaining proper clearance between the outside of

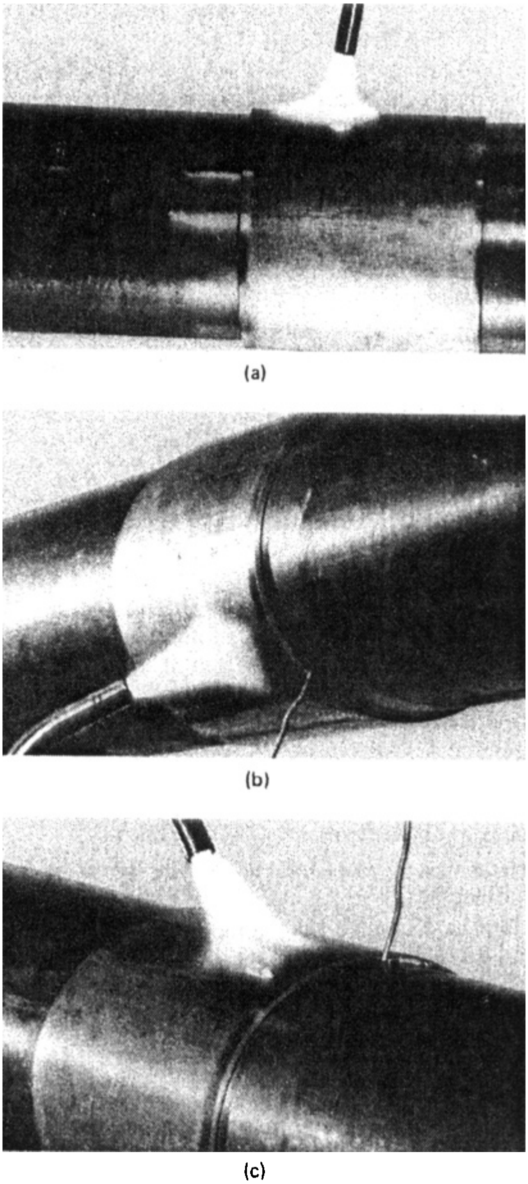


FIG. 11.3 Steps in the process of joining copper tube by solder. (*a*) Heat the tube and fit it evenly around the circumference. (*b*) Apply the heat to the bottom surface. When the solder begins to melt from the heat of the tube and fitting, push solder into the joint. (*c*) Using the solder at the bottom of the joint as a dam, complete the joint; start at one side and move over the top to the other side. *(Adapted from Ref. 2.)*

the tube and the socket of the fitting. Brazing filler metal (classification BCuP-3 or BCuP-4) is covered in ANSI Standard ANSI/AWS A5.8.

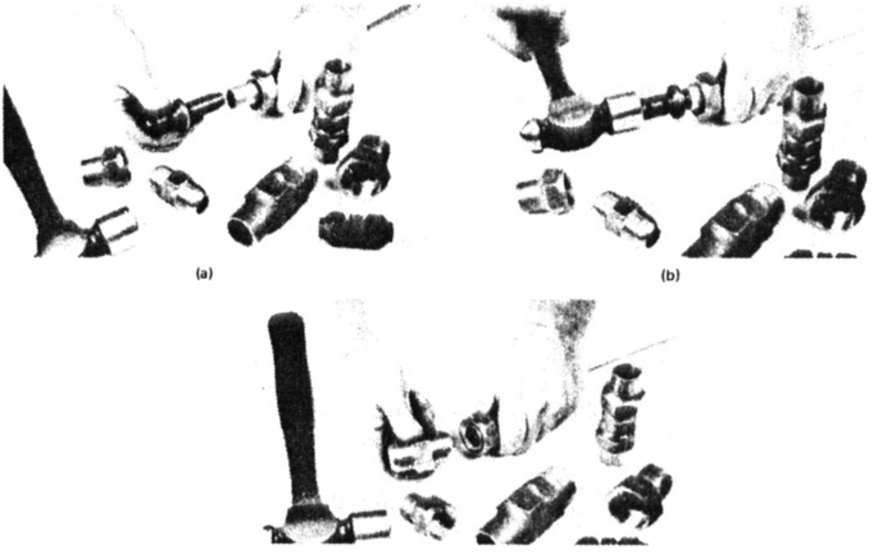
Making a Brazed Joint. First follow Steps 1 through 3 for making a soldered joint. Then continue as follows:

4. Apply flux with a brush to the cleaned surfaces to be joined, avoiding the application of flux inside the tube.
5. Assemble the joint by inserting the tube in the socket so that the tube is against the stop. Support the assembly firmly and ensure that alignment is maintained during the brazing operation.
6. Apply heat to the parts to be joined, heating the tube first. Air-acetylene is sometimes used on smaller sizes, but an oxyacetylene flame is preferred. A slightly reduced flame should be used; it should have an inner blue cone, the outer portion being white. Sweep the flame around the tube in short strokes at right angles to the axis of the tube. Do not allow the flame to remain stationary; otherwise, the tube at that point may be damaged.
7. Now heat the fitting. Apply the heat uniformly, avoiding excessive heating. Then sweep the flame from the fitting to the tube.
8. When the flux appears liquid and transparent on both the tube and fitting, sweep the flame back and forth between the tube and fitting so as to maintain heat on the parts to be joined. The flame must be moved constantly to avoid burning either the tube or fitting.
9. Apply the filler material (i.e., the brazing wire, rod, or strip). When the melting temperature has been reached, the filler metal will be drawn into the joint by capillary action. Avoid allowing the flame to strike the filler metal directly. The filler material should be visible completely around the joint. If the filler metal fails to flow properly, the temperature of the surface may be too low or oxidation of the surfaces may have occurred.

Making Flared Joints. A *flared joint* is a mechanical joint made by flaring one end of a tube in such a way as to receive a special fitting which fits in the flare. It can be taken apart and reassembled without difficulty. Flared joints are especially useful in an area where fire hazard will not permit the open flame required for soldering or brazing or in an area where wet conditions prevail. Figure 11.4 illustrates various steps in making a flared joint in a copper tube line.

The procedure is as follows:

1. Cut the tube to the required length, ensuring that the tube is cut square to the the axis of the tube.
2. Remove all burrs with a half-round file or reamer.
3. Slip the coupling nut over the end of the tube as shown in Fig. 11.4*a*.
4. Insert the flaring tool into the tube as illustrated in Fig. 11.4*b*. Drive the flaring tool into the tube by a succession of light hammer strokes to achieve the desired flare. (An alternative procedure is to use a tool containing a metal swedge. When the swedge is screwed down into the opening, a flare of appropriate size is formed.)
5. Assemble the joint by placing the fitting squarely against the flare. Engage the



(a)

(b)

(c)

FIG. 11.4 Steps taken in making a flared joint. (*a*) The coupling nut is slipped over one end of the tube. (*b*) The flaring tool is inserted into the tube. (*c*) The joint is assembled by placing the fitting squarely against the flare and then engaging the coupling nut with the fitting threads. Then the joint is tightened. *(Adapted from Ref. 2.)*

coupling nut with the fitting threads. Tighten with two wrenches, one on the nut and one on the fitting.

Plastic Piping Materials

The following methods are commonly used in joining plastic piping.

Mechanical Compression Joints. A mechanical compression joint generally includes a joining unit which contains O-rings. When tightened with nuts, the O-rings compress, creating an airtight, watertight connection. The manufacturers of such joints provide explicit directions for their assembly.

Flared Joints. In making flared joints with plastic pipe and plastic fittings, these steps should be followed:

1. Cut pipe or tubing square.
2. Remove all burrs.
3. Place the nut over end of piping.
4. Lubricate the point of the flaring tool and the tubing to be flared. Use nontoxic liquid soap or other lubricant recommended by the manufacturer.
5. Flare piping with a listed tool according to the tool manufacturer's recommendations.

6. Assemble the joint.
7. Tighten flare nuts according to manufacturer's recommendation. *Do not overtighten.*

Joining by Use of an Elastomeric Gasket The joining procedure is as follows:

1. For field cuts, cut end of pipe square with a hand saw and miter box, a mechanical saw, or a tube cutter designed for plastic.
2. Ream and bevel end of pipe (unless already done by manufacturer).
3. Remove and clean the gasket and groove; then replace the ring.
4. Mark pipe in a contrasting color to indicate the proper insertion depth as recommended by the manufacturer (unless already done by manufacturer).
5. Apply lubricant recommended by pipe manufacturer to end of pipe. Do not apply lubricant to gasket or the groove unless otherwise specifically recommended by manufacturer.
6. Insert pipe into fitting until mark on pipe is even with fitting.

Joining by Heat Fusion. (Also see "Joints in Drainage Systems" in Chap. 18.) In this technique, the mating surfaces are joined by means of heat, so they fuse and become essentially one piece.[5] Joining of two surfaces is accomplished in the following way:

1. Cut pipe or tubing with a tubing cutter designed specifically for plastics. Tubing should be cut square, i.e., perpendicular to the length. If other cutting methods are used, care must be taken to remove any excess material, flashing or burrs.
2. Chamfer the outside corner of the pipe end [for 1¼-in (3.1-cm) and larger iron pipe] with proper chamfering tool.
3. Clean pipe or tubing end. (Pipe must be free of dirt and grease.)
4. Place depth gage on pipe or tubing end. This prevents pipe from bottoming out on the fitting.
5. Clamp cold ring around pipe with one side contacting the depth gage. (Cold ring rounds the pipe end and limits the depth that the heater face and socket fitting slide over pipe end.)
6. Use an insert stiffener for ½-in (1.3-cm) and ¾-in (1.9-cm) pipe to ensure pipe or tubing roundness.
7. Clean fitting. (Socket must be free of dirt and grease.)
8. Clean the heating tool after each fusion.
9. Place pipe or tubing end and fitting adjacent to heater elements.
10. Temperature of heating tool should be no less than 500°F (260°C) and should not exceed 525°F (274°C).
11. Push pipe or tubing end, heater, and fitting together with an even pressure.
12. Use the following chart or manufacturer's recommendations for heating and cooling times.

Size, in (cm)	Heating time, s	Minimum cooling time, s
½ (1.3)	5–7	20
¾ (1.9)	7–9	20
1 (2.5)	8–10	20
1¼ (3.1)	10–12	20
1½ (3.8)	10–12	20
2 (5.1)	12–15	30

13. Ensure that joint is intact and formed properly.

Joining Plastic Pipe by Use of Solvent Cement and Primers. Plastic pipe may be joined with solvent cement and primers as follows:

1. Cut pipe square with hand saw and miter box, mechanical cutoff saw, or tube cutter designed for plastic.
2. Ream and chamfer pipe (to eliminate sharp edges, beads, and burrs).
3. Clean all dirt, moisture, and grease from pipe and fitting socket. Use a clean, dry rag.
4. Check dry fit of pipe in fitting. Pipe should enter fitting socket from one-third to three-fourths depth of socket.
5. Soften inside socket surface by applying an aggressive primer which is a true solvent for PVC and is recommended by the manufacturer.
6. Soften mating outside surface of pipe to depth of socket by applying a liberal coat of the (aggressive) primer. Be sure entire surface is softened.
7. Again coat inside socket surface with the (aggressive) primer. Then, without delay, apply solvent cement liberally to outside of pipe. Use more than enough to fill any gaps.
8. Apply a light coat of PVC solvent cement to inside of socket using straight outward strokes (to keep excess solvent out of socket). This is also to prevent solvent cement damage to pipe. For loose fits, apply a second coat of solvent cement. Time is important at this stage.
9. While both the inside socket surface and the outside surface of the pipe are *soft* and *wet* with solvent cement, forcefully bottom the pipe in the socket, giving the pipe a one-quarter turn, if possible. The pipe must go to the bottom of the socket.
10. Hold the joint together until tight.
11. Wipe excess cement from the pipe. A properly made joint will normally show a bead around its entire perimeter. Any gaps may indicate insufficient cement or the use of light-bodied cement on larger diameters where heavy-bodied cement should have been used.
12. Do not disturb joint for the following periods:
    30 min minimum at 60 to 100°F (16 to 38°C)
    1 h minimum at 40 to 60°F (4 to 16°C)
    2 h minimum at 20 to 40°F (−7 to 4°C)
    4 h minimum at 0 to 20°F (−18 to −7°C)

Handle the newly assembled joints carefully during these periods. If gaps (Step 11) or loose fits are encountered in the system, double these periods.

The system should not be pressurized until the joints have cured (set) at least as long as recommended by the manufacturer.

Except when used on the job site, solvent cements should be stored in a cool place. Since primers are toxic, they should not be allowed to touch skin. The use of gloves is highly recommended.

Ductile-Iron Piping

The following standard types of joints can be made with this type of piping:

Making a Push-On Joint. This type of joint consists of a special bell that is cast integrally with the pipe. The bell is provided with an internal groove in which a heavy rubber gasket is retained. The joint is made in the following way:

1. Thoroughly clean the groove and bell socket and insert the gasket, making sure that it faces the proper direction and that it is correctly seated.
2. After cleaning dirt or foreign material from the plain end, apply lubricant in accordance with the pipe manufacturer's recommendations. The lubricant is supplied in sterile cans, and every effort should be made to keep it sterile.
3. Be sure that the plain end is beveled; square or sharp edges may damage or dislodge the gasket and cause a leak. When pipe is cut in the field, bevel the plain end with a heavy file or grinder to remove all sharp edges. Push the plain end into the bell of the pipe. Keep the joint straight while pushing. Make deflection after the joint is assembled. .
4. Small pipes can be pushed into the bell socket with a long bar. Large pipes require additional power, such as a jack, lever puller, or backhoe. The supplier may provide a jack or lever pullers on a rental basis. A timber header should be used between the pipe and jack or backhoe bucket to avoid damage to the pipe.

Making a Mechanical Joint. A mechanical joint in ductile-iron piping typically consists of four parts, as illustrated in Fig. 11.5: a *flange*, which is cast integrally with the bell of the pipe; a *rubber gasket*, which fits into the recess in the socket; a *follower ring*, which compresses the gasket; and *bolts and nuts*, which are used to tighten the joint. Such a joint can be made using an ordinary ratchet wrench, as follows:

1. Wipe clean the socket and the plain end. The plain end, socket, and gasket should be washed with a soap solution to improve gasket seating. Place the gland on the plain end with the lip extension toward the plain end, and then place the gasket with the narrow edge of the gasket toward the plain end, as shown in Fig. 11.5*a*.
2. Insert the pipe into the socket, and press the gasket firmly and evenly into the gasket recess. Keep the joint straight during assembly. Make deflection after joint assembly but before tightening bolts, as shown in Fig. 11.5*b*.
3. Insert the bolts, then tighten them to a normal range of bolt torque while at all times maintaining approximately the same distance between the gland and the

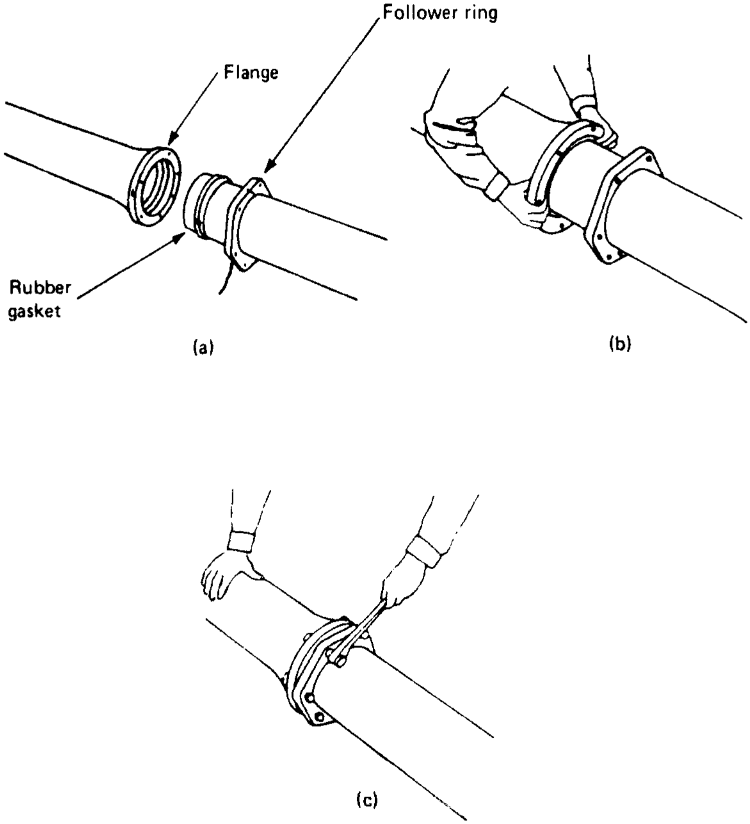


FIG. 11.5 Steps taken in making one type of mechanical joint in ductile-iron piping. (*a*) The two ends to be joined are thoroughly cleaned. The follower ring and the rubber gasket are slipped over the plain end. (*b*) The plain end is pushed into the socket. (*c*) Bolts are inserted and then tightened. *(From Ref. 6.)*

face of the flange at all points around the socket. This can be accomplished by partially tightening the bottom bolt first, then the top bolt, next the bolts at either side, and finally the remaining bolts. Repeat the process until all bolts are within the appropriate range of torque. In large sizes, 30 in (76 cm) through 48 in (122 cm), five or more repetitions may be required, as shown in Fig. 11.5*c*.

Making a Flanged Joint. A flanged joint, such as the one shown in Fig. 11.6, is advantageous in buildings where space is limited and where handling of the pipe and space are a problem. A flanged joint consists of two companion flanges, bolted together and made leakproof by means of a gasket. Flanges are made of cast iron, cast steel, and malleable iron. Gaskets are made of a rubberized composition, rubber, asbestos composition, and copper. Flanged joints are convenient when pipe must be removed and replaced. Flanged joints are seldom used for underground water mains except at valves and fittings for meter settings, valve vaults, and similar installations. Flanged joints are made in the following way:

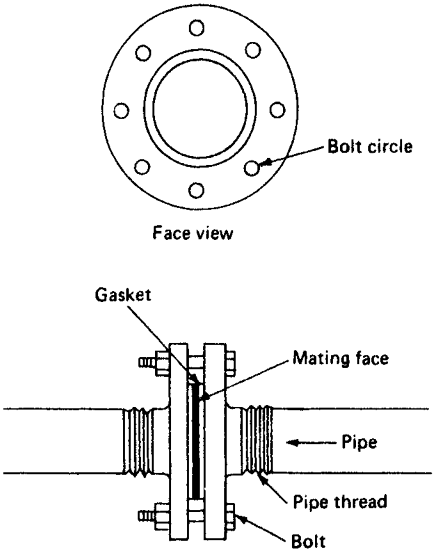


FIG. 11.6 Detail showing one type of flanged joint.

1. Cut the pipe so that it is square to the axis of the pipe, and make a thread according to the directions given above in "Making a Threaded Joint."
2. Remove any burrs with a half-round file or reamer, and ensure that all filings are removed from the pipe.
3. Apply a pipe compound to the thread of the pipe—not to the flange. Use only a compound specifically manufactured for this purpose.
4. Engage the flanges on the pipe ends; then assemble the joint, placing a gasket between the two faces.
5. Bolt the flanges together. Tighten opposite flanges, but do not tighten any bolt completely the first time.
6. Wipe away any excess pipe compound.

ANCHORS

An *anchor* is a device used in a piping system to secure the piping to a structure, usually the building. In concrete construction, typically, an anchor is provided by a metal insert in a beam or overhead concrete slab, as illustrated in Fig. 11.7. The inserts are installed prior to the pouring of concrete, so they become an integral part of the slab, thus ensuring a secure installation.

Anchors also can be attached to an existing concrete slab by any of several methods. For example, a hole can be drilled in the concrete to receive an expansion bolt. Another common method is to to attach the anchor by a powder-actuated shot which inserts the anchor to the correct depth. The size of the powder shot must be carefully selected, for if it is too weak, the anchor will not be inserted deep enough to provide a firm attachment, and if it is too large, the concrete may be shattered.

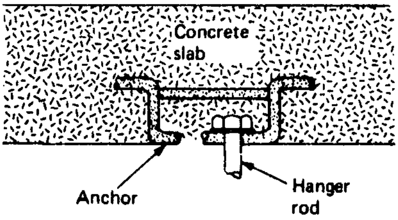


FIG. 11.7 A section showing an anchor embedded in a concrete slab.

PIPE HANGERS, SUPPORTS, AND CLAMPS

Types of Hangers

A *hanger* is a device, securely attached to the building construction, from which one or more horizontal pipes are suspended from the floor or structure above. Usually the length of the hanger is adjustable, as illustrated in Fig. 11.8. In many installations it is convenient to suspend several pipes from a pair of hangers. Such a device, called a *trapeze*, is shown in Fig. 11.9. Where there may be movement of the pipe as a result of temperature changes, the pipe may be supported on a roller hanger, as illustrated in Fig. 11.10, to permit movement of the pipe with respect to the hanger. A hanger may also include a steel-spring vibration isolator, as shown in Fig. 11.11.

In general, it is advantageous to use a hanger that is fabricated of the same material as the piping; i.e., use plastic hangers for plastic piping, etc. The hanger should be sufficiently strong to support its proportionate share of the load of the piping. Hangers that are used with insulated piping on hot-water lines should not be in contact with the pipe but should be insulated from it. In such a case, a pipe clamp may be used around the exterior of the insulation.

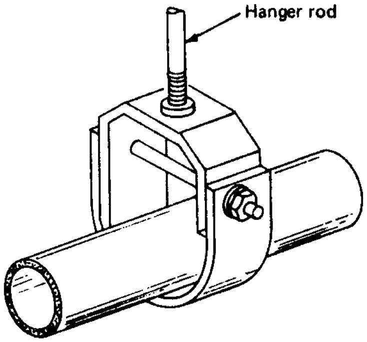


FIG. 11.8 An adjustable hanger supporting a pipe.

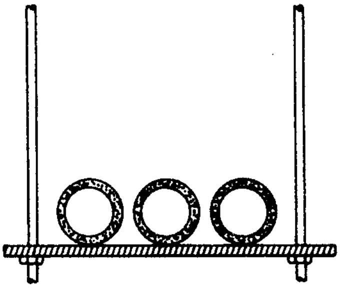


FIG. 11.9 A trapeze for hanging several pipes from the same supports.

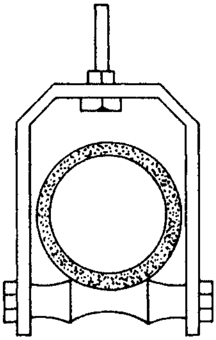


FIG. 11.10 A hanger that supports a pipe on a roller to allow for movement resulting from thermal expansion or contraction.

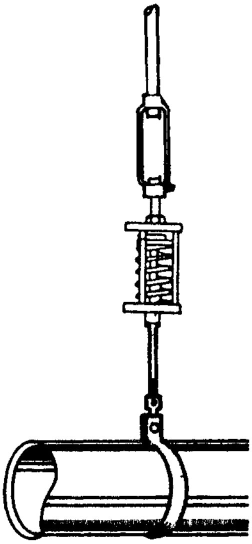


FIG. 11.11 A pipe hanger used in conjunction with a vibration isolator to reduce the transmission of pipe vibration to the building structure.

Floor Supports for Piping

Large pipes are sometimes supported by a floor mount, such as the saddle shown in Fig. 11.12. A support of this type may include a roller to permit movement of the pipe caused by its expansion and contraction.

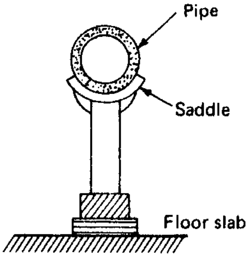


FIG. 11.12 A pipe supported by a saddle on a floor mount.

Hanger Spacing and Location

The hangers should be spaced sufficiently close to each other to (*a*) maintain alignment of the piping, (*b*) carry the weight of the pipe and its contents, and (*c*) prevent sagging of the piping, which may result in the accumulation of deposits of calcium or other minerals contained in the water within the piping at its low points. This spacing depends on the piping material, i.e., whether it is

TABLE 11.3 Recommended Pipe Support Spacing for Pipes of Different Materials and Various Diameters

Pipe diameter, in (cm)	Pipe support spacing, ft (m)			
	Steel	Copper	Brass	Plastic
1½ (3.8) and smaller	10 (3.0)	6 (1.8)	8 (2.4)	4 (1.2)
2 (5.0) and larger	10 (3.0)	10 (3.0)	10 (3.0)	4 (1.2)

steel, copper, brass, or plastic. Table 11.3 shows recommended spacing for these materials. The hangers should be located as close as possible to load concentrations, for example, where there is a heavy valve in the line. Also see Table 9.1.

Vertical Supports

A wall clamp or bracket may support one or more horizontal pipes, as shown in Fig. 11.13. Similarly, clamps may support one or more vertical pipes as they penetrate a hole in a building slab, as illustrated in Fig. 11.14. The opening in such an arrangement permits noise to be transmitted from one floor to another through the opening around the pipes unless it is suitably stopped with fiberglass and caulking.

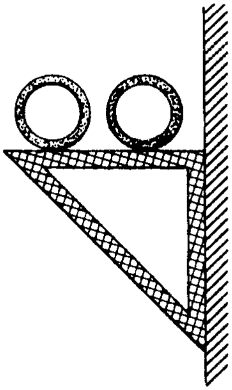
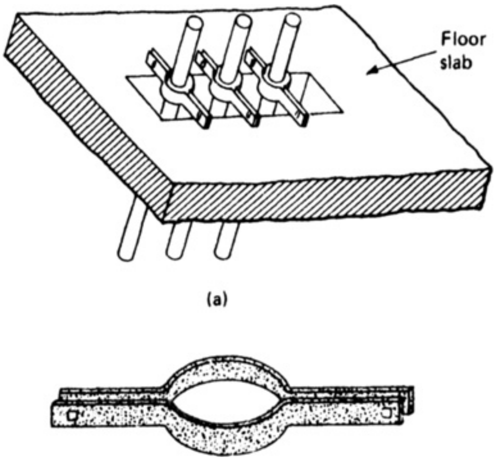


FIG. 11.13 Horizontal pipes supported by a wall bracket.

SLEEVES

A *sleeve* is a cylindrical insert (placed in a construction form for a partition) that is located where a pipe is to pierce a partition. Concrete is poured around the insert, thereby providing the desired opening. The sleeve is usually fabricated of a material



(b)

FIG. 11.14 (*a*) Several vertical pipes, supported by clamps, penetrate a hole in a building slab. (*b*) Detail of a supporting clamp.

such as galvanized steel, cast iron, wood, or plastic. The sleeve should pass completely through the partition, as illustrated in Fig. 11.15. The diameter of the sleeve should be at least one pipe size larger than the enclosed pipe size, and it must be larger where insulation is required. If a sleeve is to be inserted in a concrete floor that will be wet intermittently, it should extend approximately 2 in (5 cm) above the surface of the floor to prevent water from flowing through the opening to the floor below. The function of the sleeve is to permit passage of the pipe through the partition or floor, but the pipe must not be in mechanical contact with the sleeve; otherwise, noise and vibration transmitted along the piping will be communicated to the building structure. Furthermore, if the pipe is in contact with the sleeve, additional noise will be generated when there is expansion or contraction of the piping, resulting in scraping of the piping against the building structure. The space between the sleeve and the piping should be filled with a material approved by the authority having jurisdiction. Thus it is essential that sleeves used in vertical risers be installed in an aligned position.

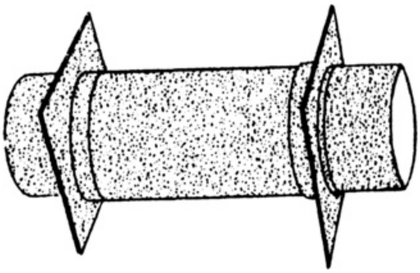


FIG. 11.15 A typical sheet-metal sleeve. Such a sleeve is placed in a concrete form before concrete is poured, resulting in a hole that permits one or more pipes to penetrate the wall.

CONTROLLING THERMAL EXPANSION AND CONTRACTION

All piping materials expand with an increase in temperature and contract with a decrease in temperature. The total change in pipe length ($L_1 - L_2$) for a change in temperature ($T_2 - T_1$) is given by

$$L_2 - L_1 = C_e L_1 (T_2 - T_1) \tag{11.1}$$

where L_1 = pipe length at temperature T_1
L_2 = pipe length at temperature T_2
C_e = coefficient of linear expansion of pipe material

This equation has been used to calculate the data given in Table 11.4, which shows the amount of linear expansion for a 100-ft (30.5-m) pipe that is subject to a temperature change of 100°F (55.5°C) for various types of pipe materials. For example, for a temperature change of 100°F (55.5°C), a copper tube will change 1.1 in (2.9 cm) in length. If the change in temperature is half this value, then the corresponding change in length will be half this value. Likewise, if the length of pipe is a fraction of the 100 ft (30.5 m) assumed in the calculations of this table, then the change in length will be this same fraction of the value of linear expansion given in Table 11.4.

Developed Length Required in an Expansion Loop

An *expansion loop*, illustrated in Fig. 11.16, is a large-radius bend in a pipeline to absorb longitudinal thermal expansion or contraction in the pipeline due to a change in temperature. Alternatively, a *U-bend* (four elbows), an *offset* (two elbows), or a *change in direction* (one elbow), illustrated in Fig. 11.17*a, b*, and *c*, may be used for this purpose. The *developed length* of such an expansion configuration is the length measured along the centerline of the pipe and fittings. For

TABLE 11.4 Piping Expansion with Temperature Change

Piping material	Coefficient of linear expansion C_e	Total expansion in 100-ft (30.5-m) pipe length for 100°F (55.5°C) temperature change			
		ft	m	in	mm
Cast iron	0.00000595	0.0595	0.018	0.714	18.1
Steel	0.0000065	0.065	0.020	0.780	19.8
Wrought iron	0.0000068	0.068	0.021	0.816	20.7
Copper	0.0000095	0.095	0.029	1.140	28.9
Red brass	0.0000104	0.104	0.032	1.248	31.7
ABS, type I	0.000056	0.560	0.171	6.720	171.0
PVC, type I	0.000028	0.280	0.085	3.360	85.3
PVC, type II	0.000055	0.550	0.168	6.600	168.0

Source: L. S. Nielsen, Ref. 4.

example, the developed length of the loops of Fig. 11.17 are shown by dashed lines. In general, it is good design practice to limit the movement taken up by an expansion loop to a maximum of ½ in (3.75 cm). The developed length of an expansion loop that can take up a change in length of this value is given in Table 11.5 for various materials and for various nominal pipe diameters.

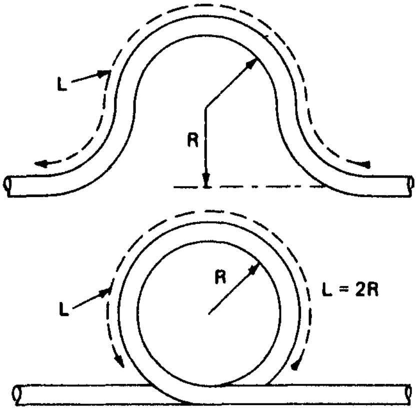


FIG. 11.16 Two types of copper expansion loops. The radius required in such a loop depends on expected changes in length. See Table 11.4. *(Adapted from Ref. 2.)*

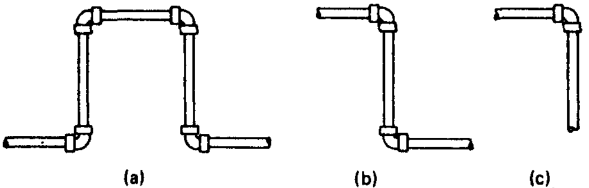


FIG. 11.17 Configurations used to absorb changes in length resulting from thermal expansion or contraction. (*a*) A U-bend; (*b*) an offset; (*c*) a change in direction.

WATER HAMMER (ALSO SEE CHAP. 20)

Water hammer is a pounding noise in a plumbing system that is produced when the flow of water is suddenly interrupted. It is caused by the sharp rise in pressure at a shutoff valve or faucet, resulting in a shock wave which reflects back and forth in the system. For example, a gate valve or any quick-closing valve is more apt to produce water hammer than a globe valve or needle valve because it stops the flow of water more suddenly. Water hammer not only is a source of annoyance to tenants in a building but also may result in damage to the piping.

Water hammer can be eliminated by the installation of a device that will absorb the shock. One such device, shown in Fig. 11.18, consists of a capped pipe nipple that provides an air chamber in the line; the shock is taken up by compression of the air confined in the nipple. If water fills the nipple, the air chamber

TABLE 11.5 Developed Length of Expansion Joints and Swing Joints

For absorbing 1½ in (37.5 mm) of expansion

Nominal pipe size, in (mm)		Standard steel pipe, ft (m)		Standard red brass pipe, ft (m)		Standard copper pipe, ft (m)		Schedule 40 ABS pipe, ft (m)		Schedule 40 PVC pipe, ft (m)	
½	(12.7)	6.92	(2.11)	7.66	(2.34)	8.30	(2.53)	1.92	(0.586)	2.12	(0.647)
¾	(19.0)	7.70	(2.35)	8.55	(2.61)	9.25	(2.82)	2.14	(0.653)	2.36	(0.720)
1	(25.4)	8.68	(2.65)	9.60	(2.93)	10.4	(3.18)	2.40	(0.732)	2.65	(0.808)
1¼	(31.8)	9.75	(2.97)	10.8	(3.29)	11.7	(3.57)	2.70	(0.824)	2.98	(0.909)
1½	(38.1)	10.4	(3.18)	11.5	(3.51)	12.5	(3.81)	2.89	(0.881)	3.19	(0.973)
2	(50.8)	11.5	(3.51)	12.7	(3.87)	13.8	(4.21)	3.19	(0.973)	3.52	(1.07)
2½	(63.5)	12.8	(3.90)	14.2	(4.33)	15.4	(4.70)	3.56	(1.09)	3.93	(1.20)
3	(76.2)	14.2	(4.33)	15.7	(4.79)	17.0	(5.19)	3.93	(1.20)	4.34	(1.32)
4	(102.0)	16.0	(4.88)	17.7	(5.40)	19.2	(5.86)	4.44	(1.35)	4.90	(1.49)

Source: L. S. Nielsen, Ref. 4.

can be restored by opening the petcock and draining the chamber. Commercial devices that perform a similar function are called *water-hammer arresters*. They are designed so the water in the system will not contact the air cushion; once installed, they require no further maintenance. They should be located close to the source of the water hammer. A standard is available that covers such manufactured devices.[7]

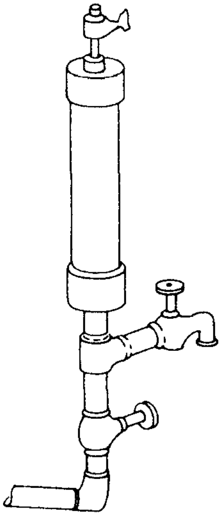


FIG. 11.18 A capped pipe-nipple that serves as a water hammer arrester. The volume of air within it is used to take up the shock generated by water hammer. Should the the air within it be replaced with water, the petcock provides a means of venting the chamber and reactivating the unit.

VALVES AND THEIR INSTALLATION

A *valve* is a device used in a water system to start or stop, regulate, or prevent the reversal of flow of water in a system. The basic components of most valves include (*a*) the *body* of the valve; (*b*) a *disk* that moves in and out of the water flow, its position determining the quantity of flow; (*c*) a *stem* that controls the position of the disk; (*d*) a *seat* for the disk; (*e*) *end connections*; and (*f*) a *bonnet* that connects the movable stem to the body of the valve. The most commonly used types of bonnets are the screwed bonnet, the bolted bonnet, the union bonnet, and the pressure-seal bonnet.

Valve Selection

The type of valve selected for a given installation depends on the type of service, pressure drop requirements, the temperature of the water, the accuracy of the regulation required, and the ease of repair or replacement. For on-off service, usually a gate valve, ball valve, or butterfly valve is used. For flow regulation or throttling, usually a globe valve, ball valve, or butterfly valve is used. Check valves are used to prevent the reversal of water flow. Various types of valves and their characteristics are described below.

Gate Valves

A *gate valve* is illustrated in Fig. 11.19. Rotation of the handle causes a gatelike disk to lower (or raise) and thus shut off (or permit) the flow of water. This type of valve is intended to operate either fully open or fully closed. When fully open, it offers the least resistance to the flow of water, and therefore the lowest pressure drop, of any of the the various types of valves.

Gate valves may be classified as having a *rising stem* (used in applications where the position of the stem is useful in providing a visual indication of whether the valve is open or closed), a *nonrising stem* [generally used in smaller lines—sizes up to 2 in (5 cm)], or an *outside screw and yoke* (used in larger lines where the position of the stem provides a visual indication of whether it is open or closed). Valves also are classified according to design of the disk: *solid-wedge disk, double disk*, or *split-wedge disk*.

Globe Valves

A *globe valve*, illustrated in Fig. 11.20, operates in the following way. Water enters the body of the valve at a right angle to a plug or disk that controls the flow of liquid through the valve. In order to ensure a positive closing of the valve, an insert, acting as a seat for the plug or disk, is used. A globe valve is generally used where stop and start service is required, but it provides better service as a throttling valve than the gate valve, described above, and is relatively easy to repair. Relatively few turns are required to go from the fully open to the fully closed positions, and the distance of travel may be used as an indication of the rate of flow through the valve.

This valve is constructed so the the seat and disk provide a positive shutoff.

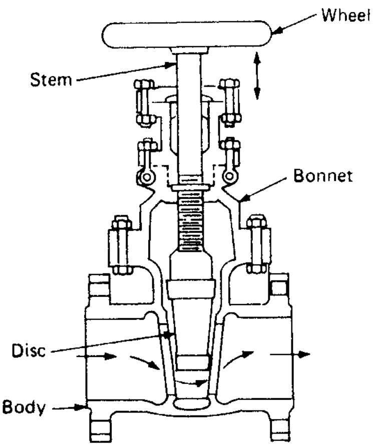


FIG. 11.19 A gate valve. *(Courtesy of the Valve Manufacturers Association of America.)*

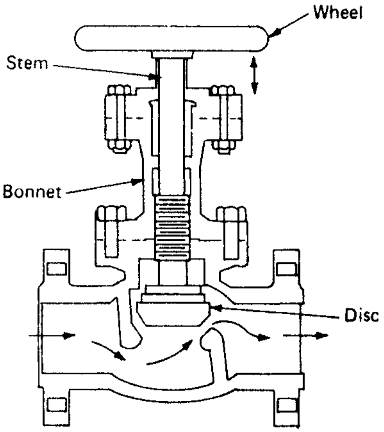


FIG. 11.20 A globe valve, showing its various components. *(Courtesy of the Valve Manufacturers Association of America.)*

Various types of disks are available for different types of water services. For example, *composition disks* are suitable for use at high temperatures and where the water carries particles that might damage a disk. Although they do not last as long as metal disks, they provide a longer service life for the seat, since the disk takes most of the wear; composition disks also are less costly to replace. *Metal disks* have a longer service life and can be used at higher temperatures than composition disks. They provide a positive shutoff and are recommended for throttling. *Plug-type disks* are most suitable for throttling service where close control is required.

Angle Globe Valves

An *angle globe valve* is of the same basic design as a globe valve. It is designed for the same type of service but offers less resistance to flow. Such valves are intended for use where the line changes direction by 90°. They save the expense of an extra fitting, while providing an additional point of control.

Ball Valves

A *ball valve*, shown in Fig. 11.21, regulates flow by means of the position of a solid ball with a hole through it (controlled by the handle) that turns on a vertical axis. When the valve is open, the hole through the ball connects the valve inlet to the valve outlet, with almost no pressure drop. Its other advantages include straight-through flow which minimizes turbulence, little maintenance, a tight seal, quick opening, and small space requirements. Little torque is required to operate this type of valve. Since it is controlled by a lever handle which indicates whether the valve is in the open or closed position, this type of valve is useful in systems in which it is important to have a visual indication of whether the valve is open or closed.

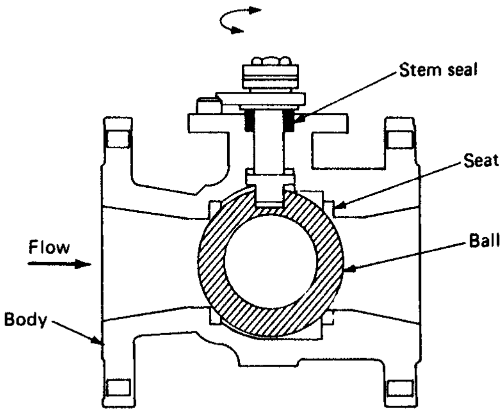


FIG. 11.21 A ball valve. *(Courtesy of the Valve Manufacturers Association of America.)*

Butterfly Valves

A ***butterfly valve***, shown in Fig. 11.22, is a valve that controls the flow of water by a circular disk having its pivot axis perpendicular to the direction of flow. When the plane of the disk is along the axis of the line, the valve is fully open; when the plane of the disk is perpendicular to this direction, the valve is fully closed. The primary application for this valve is where absolute shutoff is required—although it is also used for throttling. This type of valve is favored where control by an electric motor is required.

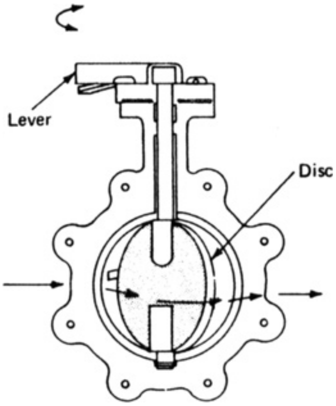


FIG. 11.22 A butterfly valve. *(Courtesy of the Valve Manufacturers Association of America.)*

Check Valves

A *check valve* is a valve used to prevent the reversal of flow in a line. A *swing check valve*, illustrated in Fig. 11.23, opens as a result of line pressure and automatically closes when the pressure stops. It thus eliminates backflow but permits full, unobstructed flow when open. It is commonly installed upstream of a shutoff valve. In a *check valve*, flow is controlled by the position of a horizontal disk. Under conditions of normal flow, the disk rises as a result of pressure that is applied to it, thereby permitting flow through the valve. The disk is seated by backflow (thus preventing flow in a direction opposite to normal flow) or by gravity when there is no backflow. It is commonly installed upstream of a shutoff valve, which it resembles in construction, flow characteristics, and pressure drop.

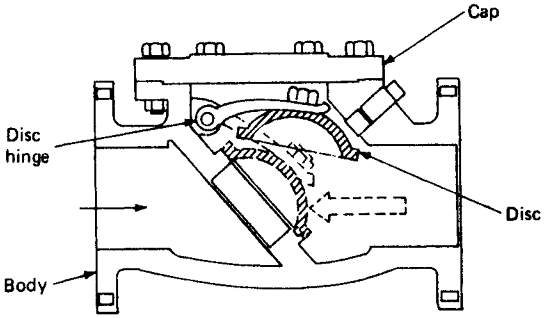


FIG. 11.23 A swing check valve. *(Courtesy of the Valve Manufacturers Association of America.)*

Valve Installation

In installing a valve, these steps should be followed:

1. Cut the pipe threads to the standard length given in Table 11.2 for steel pipe. Pipe threads should not be cut so that the end of the pipe will run up against the diaphragm or the gate of the valve.
2. Clean the threaded end of the pipe thoroughly before installing the valve. This is to prevent mill scale, dirt, and metal chips from damaging the valve seat.
3. Apply a pipe compound to the pipe threads—not the the valve threads—to prevent the compound from entering the valve and damaging it.
4. Tightly close all screwed-end valves during installation to ensure that the valve remains rigid and to prevent dirt from getting on the seat. Valves with soldered or brazed joints should be open when installing the valve on the piping to (*a*) reduce the heat transfer to the disk and (*b*) prevent possible pressure buildup within the gate valve.
5. In tightening the valve on the pipe, apply the wrench to the end of the valve next to the pipe to which it is being connected. This is to prevent distortion of the body of the valve.
6. Support the pipe lines adequately to avoid placing stresses on the valve.
7. Do not force the pipe line into position by means of the valve. This may distort the valve—especially if it is fabricated of bronze.

8. Follow the applicable plumbing code regarding installation of valves.

Further Installation Recommendations

The following practices ensure an effective, reliable, and maintainable system:

- At the water service entry to the building, provide a gate valve.
- On the discharge side of each water meter, provide a control valve that is not smaller in size than the building water service.
- In multiple-dwelling units, provide a control valve for each dwelling unit so that the flow of water to that unit can be shut off without affecting the other units. Each valve should be accessible inside the unit controlled.
- In multiple dwellings, install a valve at the foot of each water supply riser. In addition, where there are water supply downfeed pipes, install a valve at the top of each such pipe from the booster system and a valve at the base where one is required to isolate the riser for servicing.
- Provide a valve or fixture stop at each plumbing fixture.
- At the water supply to each hot-water storage tank or water heater, install a valve near the equipment.
- Place all water supply control valves where they are accessible for maintenance.

UNDERGROUND INSTALLATIONS

Trenching, Filling, and Installation

Trench bottoms should be uniformly graded and consist of either undisturbed soil or one or more layers of compacted backfill that has been excavated from the trench and that is free of rocks, foreign material, and frozen earth. The backfill around pipes should be tamped to provide firm, continuous support and proper compaction. It should be at least 12 in (30 cm) thick over the pipes, but joints should be left exposed until the piping has been inspected and pressure-tested.

Water piping should not be laid in the same trench as the building sewer or drainage piping, which is not constructed of materials approved for use within a building, unless (*a*) the bottom of the water pipe is at least 12 in (30 cm) above the top of the sewer line and (*b*) the water line is placed on a solid shelf excavated at one side of the common trench. Pipes that are buried in cinders, acid soil, ammonia-bearing soil, or other corrosive materials must be protected with a coating, such as plastic tape at least 0.010 in (0.025 cm) thick, or coal tar with felt wrapping, or other approved materials. The number of joints that are buried should be kept to a minimum.

A control valve that is readily accessible should be installed to control all underground piping. Valves that are installed in the ground should be located in an accessible box or sleeve and provided with some type of identification. Water meters should not be located in deep pits.

The width of the trench that receives the piping is usually determined by "single-pass capability" of the excavation equipment used to dig the trench. It should be wide enough to permit the pipe to be laid, properly joined, and covered with backfill. For a trench no more than 24 in (30 cm) deep, the width of the trench should be approximately 18 in (40 cm) plus the width of the pipe. For a trench 24 to 60 in (60 to 150 cm) deep, the width of the trench should be about 18 in (45 cm) plus the width of the pipe. For a trench deeper than 60 in (150 cm), the width of the trench should be about 24 in (30 cm) plus the width of the pipe. If more than one pipe is installed in the trench, add 4 in (10 cm) plus the width of the pipe for each additional pipe.

CATHODIC PROTECTION

Metal piping and metal tanks that are buried in soil are subject to electrolytic action in which the flow of electrical current through the soil results in corrosion of the metal. This form of corrosion may be prevented by reversing the direction of flow of current causing the corrosion. This can be done by electrically connecting the piping to a metal plate (usually zinc or magnesium) that is buried in the soil. The plate, called a *sacrificial anode*, must be more corrodible than the pipe itself. Often, the plate is packed in the soil with a chemical backfill in order to improve its efficiency and stability as an anode. With this arrangement, the sacrificial anode is attacked instead of the pipe itself.

This type of corrosion control, called *cathodic protection*, requires no source of electric current; it merely requires the metal plate and an electrical conductor to connect it to the piping. But since the sacrificial anode is corroded instead of the piping, this metal plate must be replaced when it is eventually consumed. Repair and maintenance costs are not significant. If the piping is mechanically connected, it must be provided with a good electrical connection between the sections of pipe. Also, the piping must be insulated electrically from any nearby metal structures which are also in the soil. Commercial installations, usually engineered by a specialist in this type of protection, often are provided with a device to indicate when the sacrificial anode has been consumed.

Regardless of whether an underground pipe or tank has cathodic protection, the metal should have a protective coating, as described in the above section.

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1. *Handbook of Steel Pipe*, American Steel and Iron Pipe Institute, Washington, D.C., 20036.
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CHAPTER 12

TESTING OF PLUMBING SYSTEMS

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INTRODUCTION

The primary concern of this chapter is the testing of plumbing systems in buildings. The major objective of such a test is to ensure that a system is tight. Any leaks or other defects must be corrected.

First, this chapter describes the tests on potable water supply systems, including cold-water and hot-water piping. The chapter notes that after the tests have shown that there are no leaks in such a system and the system has been accepted, it must be disinfected before use. The chapter describes the various chemicals that may be used for this purpose and how potable water systems are disinfected. It then discusses the testing of drainage and vent systems.

The National Standard Plumbing Code,[1] in addition to other model plumbing codes, requires that all new plumbing work, and such portions of existing systems that may be affected by new work or by any changes, shall be inspected to ensure compliance with all requirements of the code and to ensure that the installation and construction of the plumbing system is in accordance with the approved drawings. Testing procedures vary, to some extent, with applicable code and the local jurisdiction. It is important to ensure that any testing that is carried out conforms to such requirements.

TESTING OF WATER SUPPLY SYSTEMS

New plumbing systems and parts of existing plumbing systems which have been altered, repaired, or extended must be tested to show that they are free of leaks and defects. Until a plumbing system has been inspected, tested, and accepted as prescribed in the applicable code, no part of the piping system may be covered or concealed. The entire system should be available for inspection. In many jurisdictions, the testing must be conducted in the presence of a duly appointed representative of the administrative authority. Such testing is performed in two stages: (*a*) on the rough plumbing system and (*b*) on the completely installed system, including fixtures, faucets, etc.

Testing the Rough Piping Installation

The following steps should be taken in testing the piping system before the fixtures, faucets, trim, and final connections are made to the equipment:

1. *Install hose bibs for filling the piping system with water and to permit the evacuation of air from (i.e., venting) the system.* There should be a hose bib (or similar device) at the bottom of the piping system for filling the system with water and at least one more at the highest point of the system for venting. Depending on the size and piping layout, several other hose bibs may be required for venting the system, as shown in Fig. 12.1. In this illustration, hose bibs HB-2 and HB-3 are required for venting while the system is being filled through hose bib HB-1.
2. *Cap all openings.* All connections to future fixtures must be capped so they are watertight. Temporary caps will be removed after the pressure test, described below, is completed.

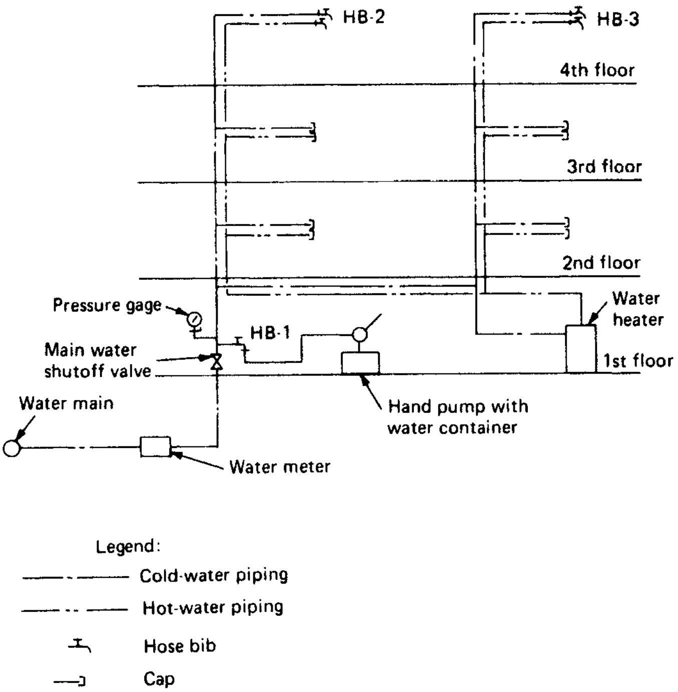

FIG. 12.1 Testing the piping of a water distribution system in a building. The letters *HB* indicate hose bibs. Water pressure in the system is increased by a hand pump or suitable equivalent.

3. *Fill the system with potable water.* With the bib at the top of the piping system in the open position, fill the system with water through the hose bib located at the bottom position. Air will then be forced out of the piping through the top bibs. During the time the piping system is being filled, all hose bibs for venting must be open. When water emerges from all the open hose bibs, all air in the system has been displaced by water. Then all hose bibs must be tightly closed.
4. *Attach a pump and a pressure gage to the piping system.* Depending on the size of the piping system, the pump (used to create pressure in the system) may be a manual pump or a centrifugal pump activated by an electric motor. In general, a manually operated pump is satisfactory for most applications. Water should then be pumped into the system until the pressure gage indicates the pressure desired for the test.
5. *Subject the piping system to a hydrostatic test.* The magnitude of the test pressure that is required by various codes or jurisdictions is different, but it is usually recommended that test pressure be equal to or higher than the following:
   a. 1½ times the pressure at which the piping system will operate. Water pressure of existing water supplies can be obtained from the local water department.
   b. 125 psi (862 kPa).
6. *Sustain the maximum pressure for a period of at least 3 h.* After the test pressure is attained, close hose bib HB-1. Maximum pressure should be sustained for this period of time without any loss of pressure, as determined from readings of the pressure gage. If pressure is maintained, the system is watertight. If the pressure decreases, there is a leak in the system. The pipes should then be inspected to determine the location of the leaks. The leaks should be repaired and a new pressure test performed. This process must be repeated until it is shown that the maximum pressure is maintained without pressure loss for at least 3 h.
7. *If, during the testing procedure, the water supply system may be subject to freezing, an air test may be substituted for the hydrostatic test of Step 6.* The air test is carried out as follows. First replace the water pump with an air compressor. Then raise the air pressure to 40 psi (276 kPa). At this pressure, check for leaks by applying liquid soap to the joints and connections. When all leaks appear to have been corrected, raise the air pressure to a value equal to 1½ times the water pressure to which the system will be subjected. With the air compressor turned off and the hose bib HB-1 shut off, the pressure must be maintained within the system for a period of at least 2 h. If this is not the case, then previously undetected leaks must be found and repaired and the entire system retested.

Testing the Complete Plumbing System

After the rough piping installation has been shown to be watertight and has been accepted, then the following steps should be taken:

1. Install and connect all faucets, fixtures, hose connections, trim, and valves.
2. Connect the water piping system to the water supply.
3. Subject the entire system to the hydrostatic test of Step 5, above. Check for leaks. When all leaks have been detected and repaired, proceed with the operation test of the next step.
4. All bibs, fixtures, flush valves, pumps, tanks, and other appurtenances should

be activated to show that the water quantities required for proper operation are adequate and that their operation is satisfactory.

DISINFECTING THE POTABLE WATER SUPPLY SYSTEMS IN BUILDINGS[1,2]

After the above testing has been completed, all aerators, filters, and strainers should be cleaned (after disinfection, they must be replaced), and the entire system should be flushed with potable water to rid it of impurities and debris. Water should be run through the piping by opening the various faucets and valves until, by visual inspection, the water appears to be running clean, and no impurities such as sand, rust, and similar small particles are observed in the bowls of the plumbing fixtures.

Next, determine if the authorities having jurisdiction have any requirements concerning disinfection of a newly installed potable water system to be placed in service. Where local code requirements are more stringent than the following suggested procedure, they must be strictly adhered to. The following procedure, performed by approved applicators or qualified personnel, is recommended:

1. One of the following chemicals, all of which add chlorine to the water, may be used to disinfect water: (*a*) chlorine gas, (*b*) chlorine liquid, (*c*) sodium hypochlorite, or (*d*) calcium hypochlorite (comparable to commercial products such as Maxochlor and Perchloron). Other types of disinfectants are described in Chap. 1.
2. Inject a disinfecting agent through the hose bib located at the water service entrance (HB-1 in Fig. 12.1). The injection should take place at a slow and even rate. The flow of this disinfection agent into the main connected to the public water supply is prohibited. Therefore, during disinfection, either the water supply connection should be disconnected or the main water valve should be effectively shut off to prevent any contamination from entering the main water supply.
3. Allow the disinfecting agent to flow into the system by opening hose bibs or faucets in each branch until the chlorine residual concentration is not less than 50 ppm of available chlorine. Then close all valves and accessories. Allow the chlorinated water to stand in the system for a period of not less than 24 h.
4. After the 24-h period of retention, the residual chlorine should not be less than 5 ppm. If it is less, the above process must be repeated.
5. If the concentration of residual chlorine is 5 ppm or greater, flush the system thoroughly with potable water before it is put in service.
6. The flushing should continue until (*a*) the residual chlorine in the system, as measured by orthotolidin tests, is not greater than that in the main water supply and (*b*) biological tests show that there is absence of coliform organisms. Such water samples should be taken from faucets located at the highest floor and farthest from the main water supply.
7. If it is impractical to disinfect the water storage tank by the above means, then the entire interior of the tank should be swabbed with a solution containing 200 ppm of available chlorine and allowed to stand for at least 3 h before flushing.

8. After final flushing of the system has been completed, at least one water sample should be obtained from the cold-water line and the hot-water line. Water samples must be submitted to a state laboratory which should certify that the water does not contain organisms in excess of standards for potable water. Before the water system has been disinfected, flushed, and tested by the laboratory, the system must not be used as a source of potable water. Signs shall be posted at each faucet stating:

   CAUTION: Nonpotable water. Do not drink.

   These signs shall be removed after the laboratory test proves that the water from the system is safe for drinking.

TESTING DRAINAGE AND VENT SYSTEMS

Except for outside leaders and perforated or open-jointed drain tile, the piping of the drainage and venting systems must be tested on completion of the rough piping installation. Walls and pipe chases should not be closed until the piping has been tested and any problems corrected. Either the *water test* or the *air test*, described below, may be used. In testing drainage and vent systems, the test pressure should be equal to at least a 10-ft (3-m) column of water for the entire drainage and vent system except for the upper 10 ft (3 m) of the system. Furthermore, the test pressure should not exceed the equivalent of a 100-ft (30-m) column of water because some of the drainage and vent system piping components (such as seals, caulked joints, etc.) are not designed to withstand higher pressures. Therefore, the test of a system in a building higher than 100 ft (30 m) should be carried out in sections of the building.

All new plumbing work, and such portions of existing systems as may be affected by new work or any changes, must be inspected to ensure compliance with the applicable code and to assure that the construction and installation is in accordance with approved drawings.

Water Test

A water test should not be used in a location where the temperature during the test is, or may fall, below the freezing point of water, i.e., 32°F (0°C). A test plug is required to close openings during the testing procedure.

Types of Test Plugs for Sealing Off Flow in a Pipe. One type of test plug, made of rubber or some other suitable elastomer, is shown in Fig. 12.2. It is attached to a valve and air compressor, as illustrated. It forms a seal in the following way. With the valve open, air is fed to the test plug. When it is fully inflated, it completely blocks the pipe. Then the valve is closed and the air compressor removed, providing a watertight seal.

Another type of test plug is shown in Fig. 12.3. This plug is inserted in the open end of a pipe subject to test. Turning the handle, while the knob is held fixed, causes the rubber gasket to be compressed between the washers; this causes the gasket to expand against the interior wall of the pipe, forming a watertight plug.

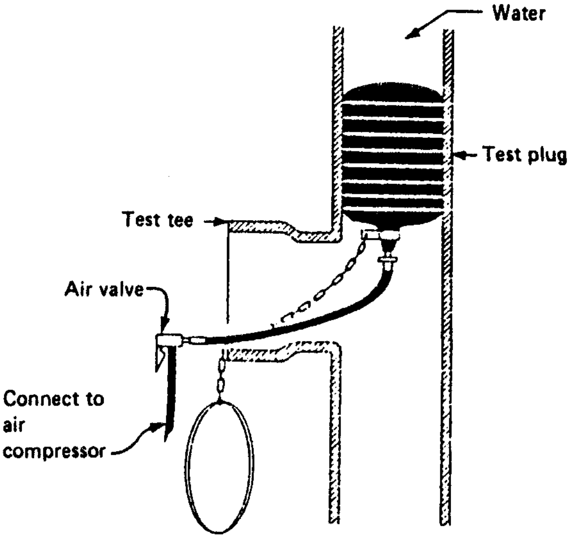

FIG. 12.2 A test plug installed in a drainage system to test it for leaks. The test plug is connected to an air compressor (through a valve) which is used to inflate it. Note that a ring and chain are attached to the test plug to provide for its easy removal at the completion of the test. It is important to cover the test tee opening temporarily when removing the test plug; otherwise, the water in the pipe above may flow through the test tee and flood the building. *(Adapted from Ref. 1.)*

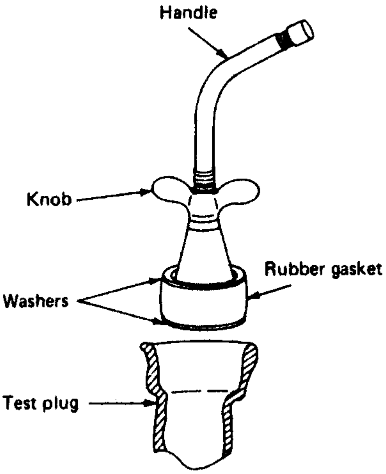

FIG. 12.3 A test plug in which a watertight seal is provided by mechanical means.

Test Procedure. In applying such a test on a drainage and vent systems, the following steps should be taken (on an entire drainage system or in sections of a system after rough piping has been installed):

1. Install a test tee at the base of a drain or vent riser.
2. (*a*) *If applied to the entire system*: Close all openings tightly (except the highest opening), and fill the system with water until it overflows from the top of the stack. Or (*b*) *if applied to sections of the system*: First plug each opening tightly (except the highest opening of the section under test), and fill the section with water to the highest point. No section should be tested with less than a 10-ft (3-m) head of water. In testing successive sections, at least the upper 10 ft (3 m) of the preceding section should be tested, so that no joint or pipe in the building [except the uppermost 10 ft (3 m) of the system] shall have been submitted to a test of less than a 10-ft (3-m) head of water.
3. The water should remain in the system, or in the section of the system under test, for at least 15 min before the inspection starts.
4. Make an inspection to ensure that the system is watertight at all points. The dropping of the water level, after the pipes are full, is an indication of a leak. The entire piping system must then be inspected—including all test plugs, all fittings, and cleanouts.
5. When the test is complete, remove the test plug or test plug assembly.

Air Test

An air test is recommended in lieu of a water test where there is danger of water freezing during the test. Air testing has the additional advantage of applying pressure uniformly throughout the section under test; in contrast, a water test imposes a higher pressure on the lower portions of the piping system.

During an air test, caution must be exercised if there are large changes in temperature. A large drop in temperature may result in a drop in the air pressure indicated by the pressure gage. This drop in reading may not be the result of a leak in the piping system but may be the result of temperature drop.

Test Procedure. The following steps should be taken in applying the air test:

1. Close all outlets and inlets in the system.
2. Attach an air compressor to the system. Isolate it from the piping system.
3. Increase the pressure in the system to a value of 5 psi (34 kPa), or enough to balance a column of mercury 10 in (25 cm) in height.
4. If additional air is not introduced, be sure that this pressure is maintained for at least 15 min. If this pressure is not maintained, determine leaks by inspection and soap solution applied to selected piping sections or components. After the leaks are located, replace or repair the faulty piping, fittings, and connections, and repeat the test until the piping system is proved to be airtight.

Testing Complete Drainage and Vent Systems

The final test on the system should be made by the smoke test, described below, except where the authority having jurisdiction accepts the peppermint test as a substitute. These tests are to assure that connections for all plumbing fixtures are absolutely gastight and watertight and that fixture traps are sound.

Smoke Test. The following steps are carried out in this test:

1. First, fill all traps with water.
2. Produce a thick smoke by burning oily waste, tar paper, or similar material in the combustion chamber of a smoke-test machine. The smoke machine is connected to the lower end of the drainage system, and bellows are then operated to fill the pipes with smoke.
3. When the smoke appears from the top of the stack, close the stack with a test plug. Then build up and maintain a pressure of 1 in (2.5 cm) of water. Maintain this pressure until the end of the test.
4. Locate leaks by determining the places where smoke and odors escape from the piping system. Since the leaks are sometimes too small for the escaping smoke to be detected visually, they may be detected by their odor. Sometimes it is helpful to close windows and doors so that any escaping odor may be detected more easily. The leaks then can be found by applying a soap solution to the suspected spots.

Peppermint Test. An odor test of the following type is simpler than a smoke test, but the results are not always satisfactory because there may be insufficient pressure in the pipes to force the odor through the leakage paths; also, it may be difficult to locate the site of a leak after an odor is detected. The following steps are carried out in this type of test, which uses oil of peppermint, ether, or a similar volatile and odoriferous substance:

1. Fill all traps with water.
2. Close the outlet end of the drainage system, and close all vent openings except the top of one stack.
3. Pour 1 oz (28 g) of oil of peppermint for every 25 ft (7.6 m) of stack, but at least 2 oz (57 g), down each roof vent stack terminal to be tested.
4. Pour 1 gal (4 L) of boiling water down each stack.
5. Close the top of the stack immediately.
6. Search for possible leaks by the sense of smell. Bar anyone from the building who has recently handled peppermint until the search has been completed.

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1. *National Standard Plumbing Code*, National Association of Plumbing-Heating-Cooling Contractors, Falls Church, VA 22046.
2. *Standard for Hypochlorites*, AWWA B 300; *Standard for Liquid Chlorine*, AWWA B301; *Standard for Disinfecting Water Mains*, AWWA C601; *Standard for Disinfecting Water Storage Facilities*, AWWA D105; American Water Works Association, Denver, CO 80235.

CHAPTER 13

PROTECTING WATER SUPPLY SYSTEMS

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INTRODUCTION

This chapter discusses the protection of potable water supplies from impurities which may enter the water distribution system. A water system may become nonpotable by the introduction of a contaminant or a pollutant. A *contaminant** is considered to be a health hazard; a *pollutant*,* although aesthetically objectionable, is not considered to be a health hazard.

Impurities may be introduced into the drinking water supply by means of backflow. *Backflow* is the undesirable reversal of flow of water (or mixtures of water and other liquids), gases, or substances into the distribution pipes of the potable water supply from any source. A device which eliminates the possibility of backflow is called a *backflow preventer*. A *cross-connection* is any actual or potential connection between the potable water supply system and any other source through which it is possible to introduce impurities into the water supply system. This chapter discusses methods for the control of cross-connections by the use of backflow preventers specifically designed for this purpose.

BACKFLOW

Water always flows from a region of higher pressure to a region of lower pressure. As water flows through the water supply pipes, the pressure decreases because of frictional losses in the valves, fittings, and pipes. Thus, there is a decrease in the pressure as water flows farther along in the distribution system. Figure 13.1 shows the normal pressure at different points within the distribution system. When a valve in the system is opened to atmosphere, there is a drop in the system pressure at that point, causing the water to flow to that point and to

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* There are no generally accepted definitions for these terms. In Chap. 1, their meanings are different.

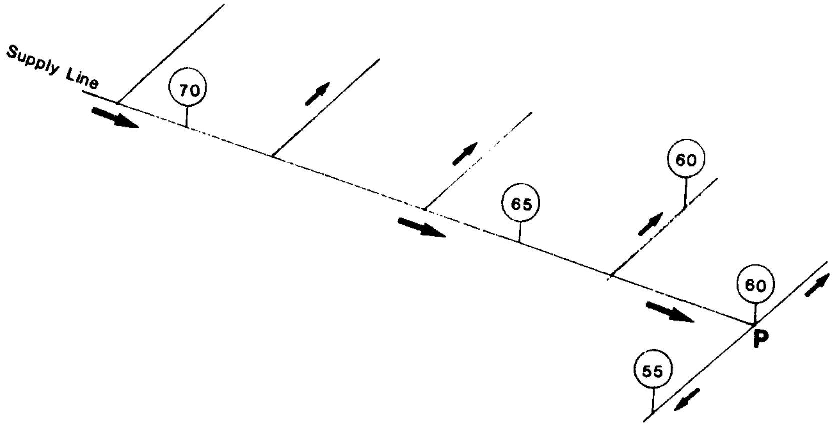

FIG. 13.1 Measured values of ambient pressure (in arbitrary units at points) along a water supply line in a building. Note the decrease in pressure in the downstream direction as a result of frictional losses in valves, fittings, and piping.

discharge to the atmosphere. An undesirable or unplanned change in pressure somewhere in the system may cause backflow.

Under conditions of backflow, the flow of water in a supply system is in a direction other than that intended (i.e., in a direction that is the reverse of normal flow). There are two types of backflow, described below.

Backflow due to Back Pressure

Back pressure is any increase of pressure in the downstream piping system (by pump, elevation of piping, etc.) which causes a reversal of the normal direction of flow. Back pressure occurs whenever the downstream pressure in a piping system exceeds the supply pressure, causing backflow. For example, back pressure sometimes occurs when the pressure in a boiler exceeds the water supply line pressure, thereby forcing boiler water through the makeup water supply line into the potable water system. Another common example of back pressure occurs when a booster pump is used to increase the pressure of a water line. For example, a booster pump may be installed in a high-rise building to increase the water pressure at higher floors, where it otherwise may be inadequate.

Figure 13.2 shows measured values of pressure for the same conditions as Fig. 13.1, except that a booster pump has been added, increasing the pressure at point *P* to a value above its ambient value (the *ambient pressure* is the normal operating pressure in any particular location of a water system). The pressure increase results in backflow. The increase in pressure overcomes the ambient system pressure and causes a reversal of the direction of flow.

Backflow due to Back Siphonage

Back siphonage is the flow that occurs when the pressure at some point in a water distribution system drops below the ambient pressure within the system. For example, in the case of a break in the public water main, pressure is lost and

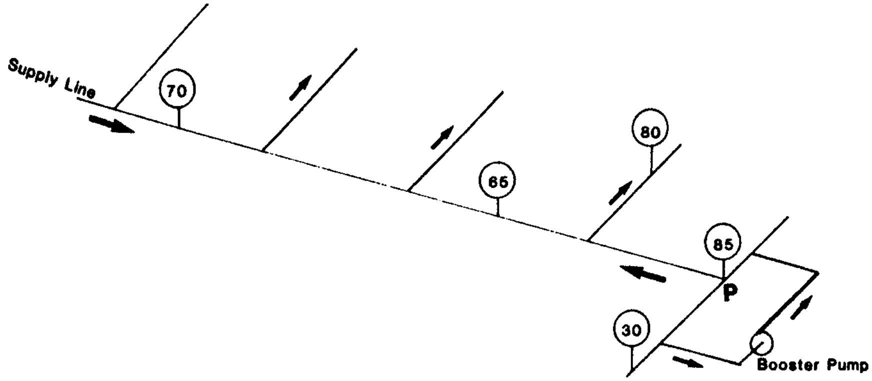

FIG. 13.2 Measured values of pressure at points along a water supply line in a building. In contrast to Fig. 13.1, here a booster pump has been added, causing the pressure at point *P* to rise above its ambient value and resulting in backflow.

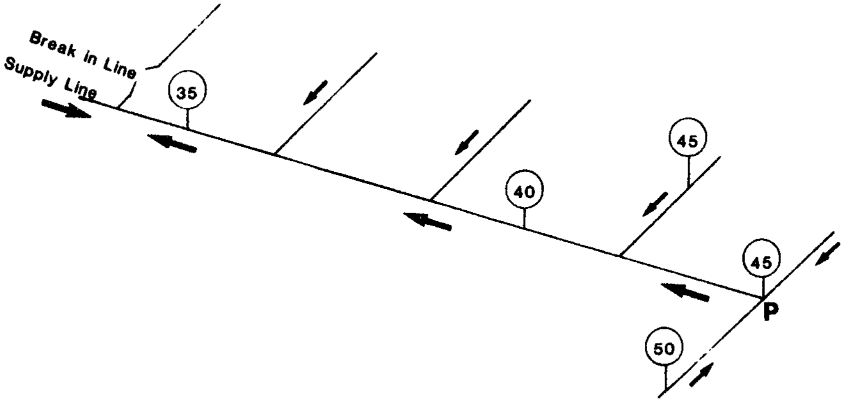

FIG. 13.3 Measured values of pressure at points along a water supply line in a building. As a result of loss of pressure in the supply main, there is a temporary reversal of flow.

water is siphoned to the point of lowest pressure, which is located at the point of the break. Relatively high water usage may also result in back siphonage. Such a situation occurs during a fire when the fire department uses all available sources of water to extinguish the fire, thus lowering the pressure in the system at the point of use. Figure 13.3 shows measured values of pressure of a water system with a break in the line, resulting in a back siphonage condition.

TYPES OF CROSS-CONNECTIONS

Inlet-Type Cross-Connections

An *inlet-type cross-connection* is a connection between a potable distribution system and a receiving vessel which is not under pressure.

A *gravity-type cross-connection* is an inlet-type cross-connection used for filling a receptacle. For example, in Fig. 13.4*a* water that enters a tank over the top rim terminates at some point below the overflow rim of the tank. In this instance the water supply line is not continuously submerged. Such a situation occurs in the makeup line of a cooling tower, where the fill line ends at a point lower than the overflow rim of the recovery pool of the cooling tower. Another typical cross-connection of this type is shown in Fig. 13.4*b*, where a faucet over a lavatory sink is below the overflow rim of the sink, or extended to that point by a hose. This is considered a cross-connection because a loss of pressure in the supply line can result in back siphonage. Then water in the sink will be sucked up through the faucet into the potable water supply.

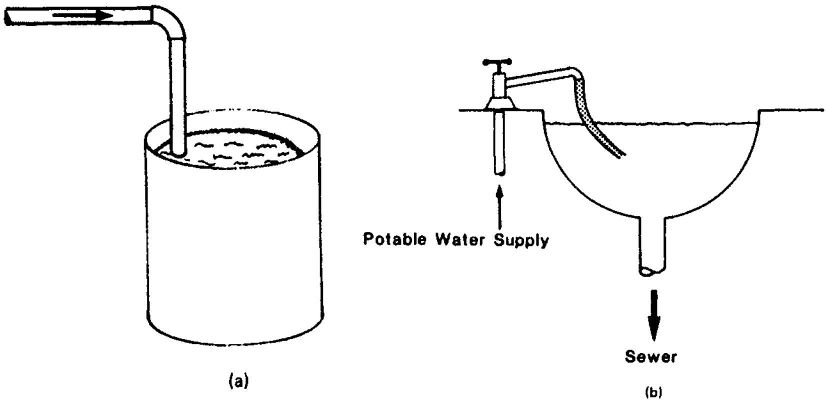

FIG. 13.4 (*a*) Example of an over-rim connection between a potable water supply and a nonpotable fluid. If the tank is full, back siphonage may occur. (*b*) An over-rim connection on a lavatory sink using a hose may create an indirect cross-connection to the sewer.

A *low-inlet-type cross-connection* is a direct pipe or hose connection that supplies water at or near the bottom of an open (nonpressurized) tank; the supply inlet is always submerged, as in Fig. 13.5.

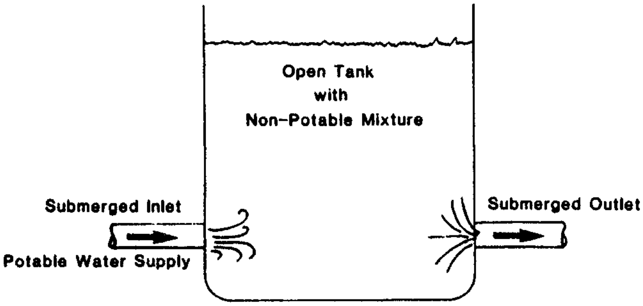

FIG. 13.5 An inlet which is always submerged supplies potable water to a nonpotable mixture in a tank.

Direct Cross-Connections

In Fig. 13.6, potable water is connected to a valve, which is the only separation between the potable line and a nonpotable substance under pressure. This is considered a *direct cross-connection* because a potable water line is piped directly into another pipe or to a pressure tank carrying a nonpotable substance. Typical examples of this type of connection are the quick-fill water supply line for a boiler and the emergency connection to a circulating hot-water system.

A potable source separated from a nonpotable source by a shutoff valve alone is considered a direct cross-connection, since the shutoff valve does not provide backflow protection. This is because a shutoff valve may leak and because it may be left open when it should remain closed.

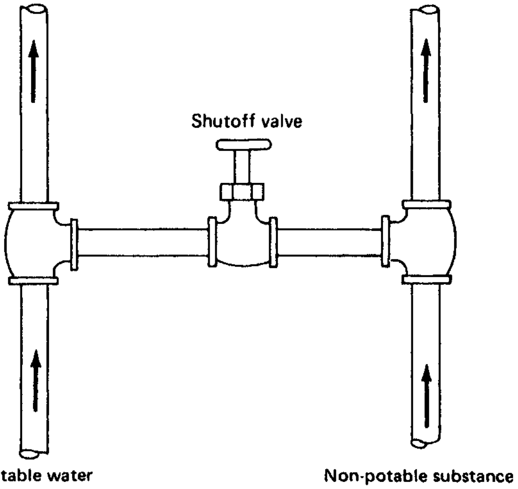

FIG. 13.6 A valve connects a potable water supply with a nonpotable fluid under pressure. This is considered a direct cross-connection.

BACKFLOW PREVENTERS

There are five basic methods of preventing backflow through a cross-connection between a potable water system and a nonpotable system. These methods make use of (*a*) an air gap, (*b*) a double-check-valve assembly, (*c*) the reduced-pressure-principle backflow prevention assembly, (*d*) a pressure-type vacuum breaker, or (*e*) an atmospheric-type vacuum breaker. Each of the backflow-prevention assemblies is designed to provide protection under specific hydraulic conditions and against specific hazards. The backflow preventers must be installed properly and used under the hydraulic condition for which they were designed to operate. They should always be installed in a horizontal orientation. A bypass arrangement should not be installed around backflow preventers, since this would defeat the purpose of the installation. Should continuous service be essential, then two or more backflow preventers should be installed in parallel to allow for maintenance without service being disrupted.

Air Gap

In a potable water supply system, an *air gap* is a physical separation between the water supply line and the nonpotable water in a tank or receiving vessel into which the supply line discharges, as illustrated in Fig. 13.7. The air gap separation must be at least twice the effective diameter of the supply pipe, measured vertically above the overflow rim of the receiving vessel. In no case should the separation be less than 1 in (2.5 cm).

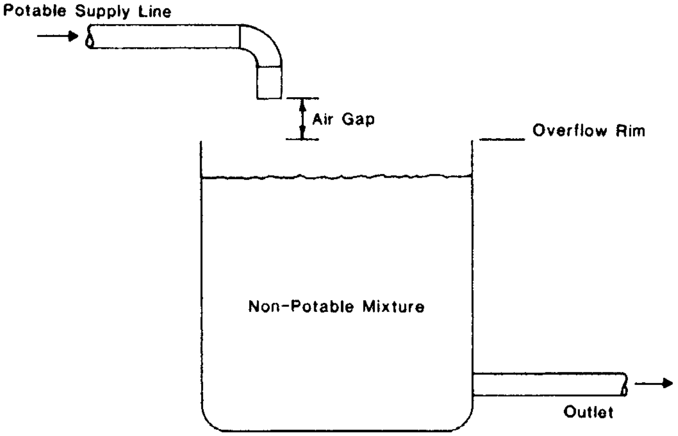

FIG. 13.7 Schematic diagram of an air gap. The vertical separation of the gap should be at least twice the effective diameter of the supply line, but never less than 1 in (2.5 cm).

Because there is an actual separation, there is no possibility of backflow between the potable and nonpotable supply systems. Therefore, the air gap can protect against both pollutants and contaminants under either back pressure or back siphonage conditions. The air gap is the only acceptable means of protecting against lethal hazards. Sewage and radioactive materials are the only hazards which are termed *lethal hazards* because of the potential epidemic dangers.

Because an air gap introduces a physical break in the water supply line, the water pressure from the supply line is lost at that point. Therefore, some exterior means (usually a booster pump) is required to repressurize the water supply for use past the point of the air gap. Once the water enters the receiving vessel, it is considered to be nonpotable water. Therefore, the water cannot be used for domestic use. In this case a separate line to supply water for domestic use may be required.

Double-Check-Valve Assembly

A *double-check-valve assembly*, shown in Fig. 13.8, consists of two independently operating check valves, including resiliently seated (i.e., without a metal-

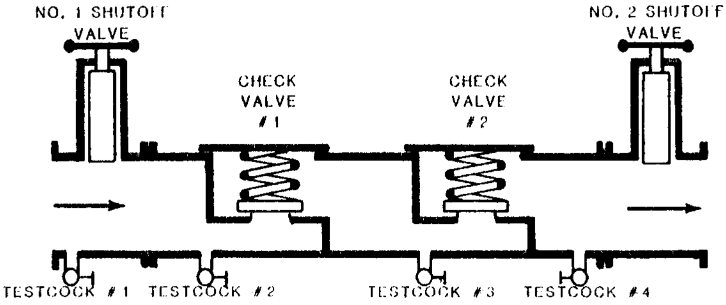

FIG. 13.8 Section showing a double-check-valve assembly.

to-metal seal) shutoff valves at each end and resiliently seated test cocks. A *check valve* is a valve which permits water to flow only in one direction. Such check valves utilize an elastomer (such as neoprene) to assure a tight seal between the disk and the seat against which the disk presses. Each check valve is internally loaded by a spring or a weight to increase the reliability of the seal. The loading is internal to prevent any alterations from external sources. However, even with such design features, a check valve can easily become fouled by debris in the water system. Therefore, a single check valve does not provide adequate protection against backflow.

Although a double-check-valve assembly may be used to prevent backflow resulting from back pressure or back siphonage conditions, it provides adequate protection only against pollutants (i.e., non-health-hazard materials). It does not provide adequate protection against contaminants (i.e., health hazards) because of the susceptibility of the check valves to fouling.

Installation. Typical installations of a double-check-valve assembly, illustrated in Fig. 13.9, should be located in an area of the building where leakage and spillage (which may occur during annual testing and maintenance) will not be objectionable. An assembly should be located between 12 in (30.5 cm) and 30 in (76 cm) above the floor for purposes of maintenance. Clearance should be provided for shutoff valves and test cocks so that they may be operated without hindrance.

Reduced-Pressure-Principle Backflow Preventer

A *reduced-pressure-principle backflow preventer*, illustrated in Fig. 13.10, consists of two independently operating check valves and a hydraulically dependent, mechanically independent differential-pressure relief valve located between the two check valves, at a lower elevation than the first check valve. This type of backflow preventer includes resiliently seated test cocks and resiliently seated shutoff valves at each end. (A *test cock* is a valve allowing access to the pressure in different regions of the backflow preventers for testing purposes.)

The region between the two check valves is called the *zone of reduced pressure*, commonly referred to as the "zone." The water pressure in the zone is reduced by the friction loss through the first check valve. The water pressure in the zone should be at least 2 psi (13.8 kPa) lower than the line pressure. If it is not, the relief valve will open, venting the water in the zone to the atmosphere. If one

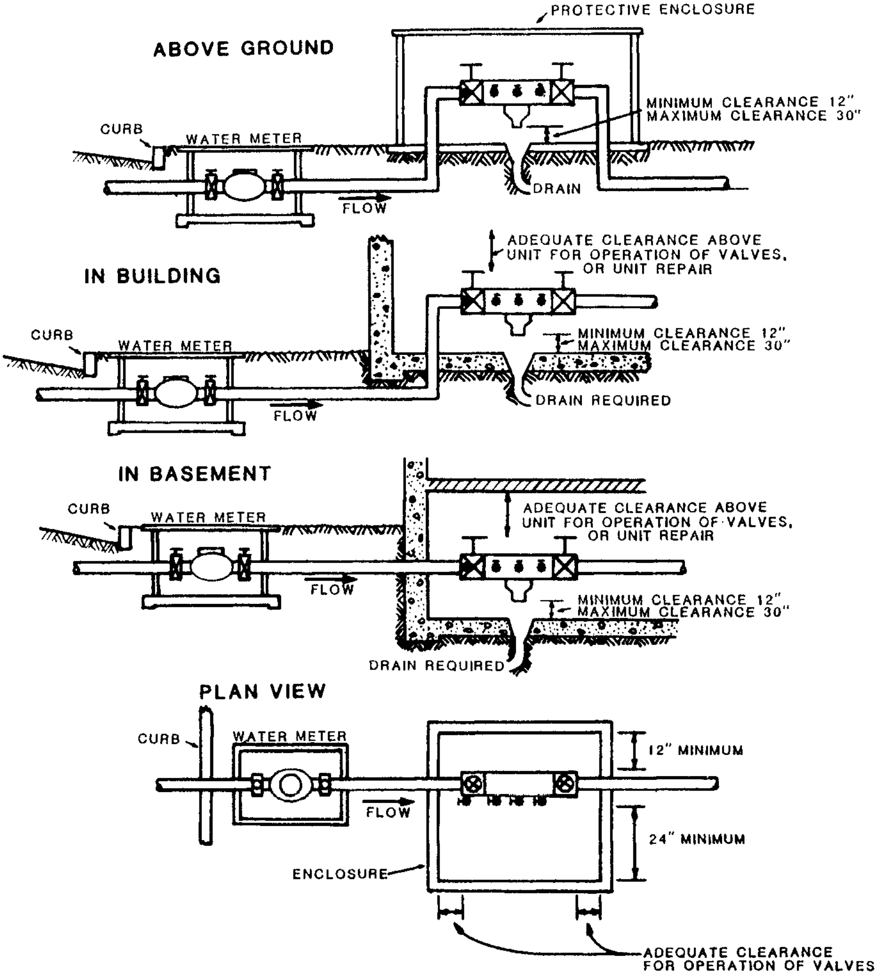

FIG. 13.9 Typical installation of a double-check-valve assembly or a reduced-pressure-principle backflow preventer showing necessary clearances.

or both of the check valves become fouled with debris, backflow will not occur because of the operation of the relief valve. Even if the first check valve leaks, the pressure in the zone increases to some point, so that it is no longer 2 psi (13.8 kPa) lower than the supply pressure. Because of leakage from upstream through the first check valve, pressure in the zone increases, thereby decreasing the differential pressure across the first check valve. At a differential pressure called the *opening point*, the relief valve opens, permitting water in the zone to be released. Therefore, water cannot flow in the reverse direction. If a back siphonage condition occurs, the same action takes place. Because the relief valve operates on a differential pressure basis, the relief valve opens if either the pressure in the zone increases or the supply pressure drops, thereby providing protection against

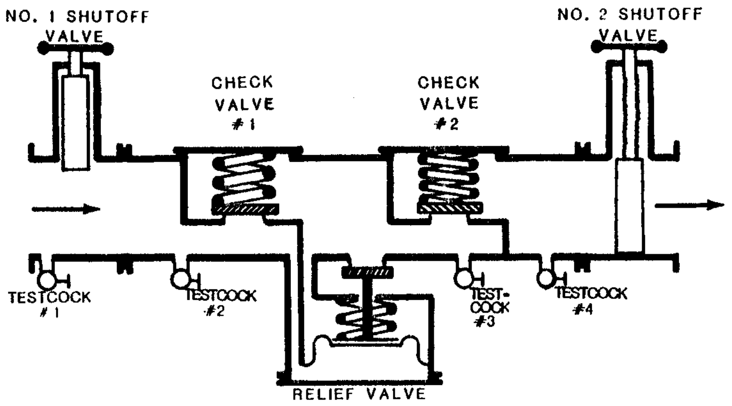

FIG. 13.10 Section showing a reduced-pressure-principle backflow prevention assembly.

backflow. If the second check valve leaks under a back pressure condition, the relief valve opens to the atmosphere as a result of the increase in pressure in the zone.

Because of its design characteristics, the reduced-pressure-principle assembly is considered to be the most reliable form of backflow protection other than an air gap. Such an assembly may be used to protect against either a pollutant or a contaminant under both back pressure and back siphonage conditions. Although there are frictional losses in the assembly, and therefore a resulting pressure drop, this drop is small enough that a booster system is normally not required. However, in certain situations the pressure drop may be enough to necessitate a booster system.

Installation. Figure 13.9 shows typical installations for reduced-pressure-principle assemblies. There is the possibility of the relief valve opening or perhaps spitting under fluctuating pressure conditions. Therefore, adequate drainage must be provided to carry off the occasional discharge of the relief valve. Such a discharge may be a nuisance or hazard. The relief valves on such assemblies may release as much as 3 to 60 gpm (0.2 to 3.8 L/s) of water or more. For this reason, adequate drainage should be provided, and the reduced-pressure-principle assembly should be installed above the ground. If installed below grade (for example, in a pit), it could be surrounded by contaminants or pollutants. In this case, a cross-connection could be created through the relief valve of the backflow preventer. These assemblies may be installed indoors, provided that the possibility of discharge is accounted for.

Backflow preventers of this type installed for protection of the public water supply should be placed in an accessible location above the ground, with at least a 12-in (30.5-cm) clearance from the bottom of the assembly to the ground. As with the double-check-valve assembly, adequate clearances should be provided for the shutoff valves and test cocks.

A reduced-pressure-principle assembly should be installed so that the relief valve is lower in elevation than the first check valve to ensure the discharge of water from the relief valve port when the port is open. In addition, the assembly must be installed in the horizontal orientation. Otherwise, water may collect in the body of the backflow preventer even with the relief valve open, and this water could be siphoned upstream into the potable supply.

Pressure-Type Vacuum Breaker

A *vacuum breaker* is a backflow preventer designed to break the vacuum which causes the water to be sucked in the reverse direction of flow under back siphonage conditions. A *pressure-type vacuum breaker* (PVB), illustrated in Fig. 13.11, contains an independently operating, internally loaded check valve and an independently operating air inlet valve on the discharge side of the check valve. This type of backflow preventer has resiliently seated test cocks and a resiliently seated shutoff valve at each end. The check valve allows water to flow in only one direction. The air inlet valve permits air to flow into the assembly to break any vacuum and disrupt backflow, should there be a loss of pressure upstream.

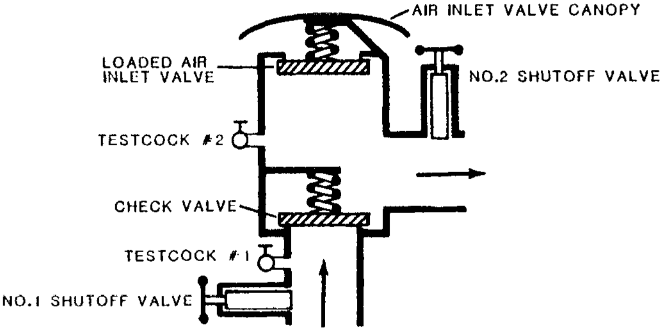

FIG. 13.11 Section showing pressure-type vacuum breaker.

The pressure-type vacuum breaker may be used to protect against either a pollutant or a contaminant. However, it is designed for use only under back siphonage conditions.

Installation. A typical pressure-type vacuum breaker must be installed at least 12 in (30.5 cm) above the highest point of downstream use, as shown in Fig. 13.12. If this assembly is installed in a medical facility, it should also be at least 72 in (183 cm) above the ground. This is to prevent back pressure from being applied to the assembly when a piece of equipment or hose is elevated during usage. Because this type of backflow preventer permits air to enter the water line, it should never be installed in a location where the air quality is questionable or dangerous. For example, in laboratories containing sinks or water sources within a hood, the pressure-type vacuum breaker should be installed outside the hood. Such an assembly may not be used to protect a water source which is subject to back pressure. In this case it is necessary to use a reduced-pressure-principle backflow preventer or a double-check-valve assembly, depending upon the degree of hazard.

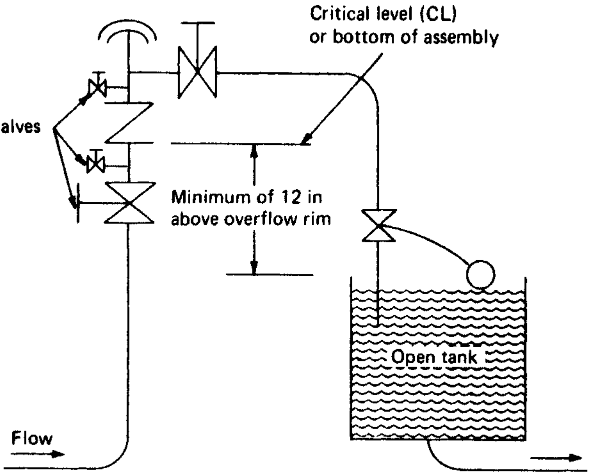

FIG. 13.12 Typical installation of a pressure-type vacuum breaker.

Atmospheric-Type Vacuum Breaker

An *atmospheric-type vacuum breaker* (also known as a *non-pressure-type vacuum breaker*) is shown in Fig. 13.13. It contains a *float check* (one part of which acts as both a check and an air inlet float), a check seat, and an air inlet port. An upstream shutoff valve may be an integral part of the assembly. With the vacuum breaker not under pressure, the float check rests upon the check seat. As water flows through the assembly, it causes the float check to float up off the seat and to seal against the air inlet port, thereby permitting water to flow through. If pressure is lost upstream (or the flow of water is turned off), the float check falls, thereby opening the air inlet port. This permits air to enter the line and break the backflow of water. When the float check falls and seats against the check seat, water cannot flow upstream. Because the check valve and air inlet are not loaded

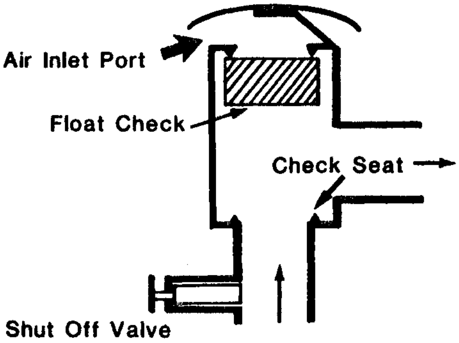

FIG. 13.13 Section showing an atmospheric-type vacuum breaker.

by a spring or mass, this type of vacuum breaker may not be used under continuous pressure. If subject to continuous pressure, the float check could permanently seal against the air inlet port, thereby causing the vacuum breaker to act as a piece of pipe, without backflow protection. Since the device may not be under continuous pressure, shutoff valves (manual or automatic) must not be installed downstream of this type of assembly. The atmospheric-type vacuum breaker provides protection only against back siphonage of either a pollutant or a contaminant.

Installation. A typical installation of an atmospheric-type vacuum breaker is shown in Fig. 13.14. Such a vacuum breaker should be installed at least 6 in (15.2 cm) above the highest point of use [in any type of medical facility, the assembly should also be at least 72 in (183 cm) above the ground]. Because it must not operate under continuous pressure, there must be no shutoff valves downstream, and it cannot be installed in a location where it will be used for more than 12 h in a 24-h period. Since air can enter the water supply line through this type of backflow preventer, it should not be installed in a location where the air around it is contaminated, polluted, or hazardous.

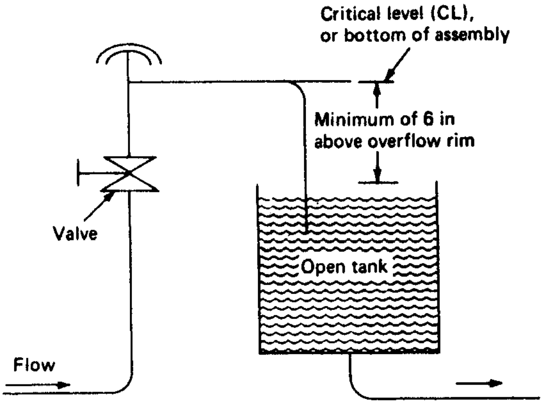

FIG. 13.14 Typical installation of an atmospheric-type vacuum breaker.

SYSTEM PROTECTION

It is the responsibility of the water supplier to protect its distribution system from any source of contamination or pollution (according to the federal Safe Drinking Water Act Amendments of 1986). The water supplier may require the customer to provide backflow protection at the water service connection of a building if (*a*) there is reason to believe that water usage within the building may result in cross-connections or (*b*) contaminants or pollutants are routinely used in the building. In either case, an appropriate backflow preventer should be installed at the water service connection. Usually either a reduced-pressure-principle assembly or a double-check-valve assembly is used in order to provide protection against both back pressure and back siphonage.

When a new facility is in the planning stages, the need for and proper type of backflow protection must be determined, and consideration should be given to possible future needs. After occupancy, the local water supplier, plumbing inspector, or health department official may inspect the premises and require a change in the backflow protection. The cost of any such change or upgrading of backflow protection at a later date can be quite high. If there is no possibility that toxic substances will be used on the premises in the future, then there is no reason to install a more expensive reduced-pressure-principle backflow prevention assembly. In this case, a double-check-valve assembly provides adequate protection.

Many facilities have more than one service connection, for any of several reasons. For example, a single service may not be capable of supplying the needs of the entire building, or one service may be for domestic use only while the other is for industrial use or for use as a fire line. If there are two services, the protection requirements of each must be evaluated because of the possibility that the two services will become interconnected. For example, consider an installation in which one water line is used for industrial purposes and another for domestic purposes (to supply offices and bathrooms with water). At some future time someone may tap into the domestic water supply to provide additional water for industrial purposes, thereby creating a cross-connection between the two services. Another example of a cross-connection occurs within a building when there are two interconnected potable lines with one service having higher pressure than the other. This results in a *flow-through condition* from the higher-pressure service to the lower-pressure service, possibly allowing pollutants or contaminants to transfer through a cross-connection. Even if a cross-connection does not exist, used water may flow from the building into the main water distribution system via a lower-pressure service connection. The water supplier considers any water to be *used water* once it passes through the meter and becomes the property of the customer; used water is considered to be nonpotable by the water supplier, as it has not been under the supplier's complete control. Because of this, when two services are interconnected, both services need to be protected; the type of protection should be that required for the service having the higher hazard.

Fire Sprinkler Systems

There is some danger of impurities from a fire sprinkler system flowing back into the potable water supply unless a backflow preventer is utilized. For example, many fire sprinkler systems use black-iron piping, a material not acceptable for transporting potable water. Water that stands in black-iron pipe for a long period of time is not potable. Therefore, backflow protection for fire sprinkler systems of this type is necessary. Similarly, cross-connection control is required for fire protection lines which contain chemicals to fight fuel fires or contain antifreeze chemicals. At many facilities an auxiliary water supply is used in case of fire. Such an auxiliary source is not necessarily potable. It may be a pond, a nearby river, or a well. The connection of such a source to the fire service, which is also supplied from the potable drinking supply, constitutes a cross-connection, therefore requiring backflow protection. Where the fire sprinkler system is not considered a health hazard, a double-check-valve assembly may be used. Where it is considered a health hazard, a reduced-pressure-principle backflow prevention assembly must be used.

Because fire lines are used only in emergency situations to save property and life, the water supplier very rarely meters a fire line. This gives rise to the possible unauthorized use of water from a fire line. A fire line is often a convenient source of water, and because there is no meter, the customer is not charged. Therefore, most water suppliers require some sort of detection device at the fire service connection to indicate leaks or unauthorized use of water.

When both backflow protection and water usage detection are necessary, either of two backflow preventers are used: a *double-check detector assembly* or a *reduced-pressure-principle detector assembly*. These assemblies consist of a backflow preventer which is the full size of the water line with a bypass arrangement [normally a ¾- or 1-in (1.9- or 2.5-cm) line] that contains a backflow preventer of the same type and a meter to detect flow through the bypass arrangement. These are complete assemblies with carefully matched components which are designed so that all flow through the assembly [up to and including 3 gpm (0.2 L/s)] flows only through the bypass arrangement and registers accurately on the meter. However, when the water consumption is large, water flows through the mainline unit, thereby providing full flow for fire fighting. The reduced-pressure-principle detector assembly should always be used in situations where the fire sprinkler system contains a hazardous substance (antifreeze, fuel-fire-fighting chemicals, etc.). A double-check detector assembly should be used for fire lines containing substances which may not be considered health hazards but which could be objectionable.

Fire-fighting systems, like all building water systems, must be evaluated individually to determine if backflow protection is required and, if so, what type.

PROTECTION OF A WATER DISTRIBUTION SYSTEM WITHIN A BUILDING

Backflow protection at the meter or service connection is designed to protect the water supplier's system from impurities which may enter the system from a customer's building. Backflow protection is also necessary to protect the occupants of the building from cross-connections which may exist within the building. This is where internal, or point-of-use, protection must be applied. Not only must each of the premises be examined to determine if a hazard exists, but each point of water usage must be examined. Any cross-connection, whether physical or potential, must be protected. Table 13.1 lists the types of backflow prevention assemblies commonly used to protect against cross-connections. For example, if a hose may be connected to a faucet, a cross-connection may result, so the faucet should be protected. This is especially true in a utility room where cleansing chemicals are often used. A boiler room or mechanical room should have a water supply with backflow protection. If water is not supplied through a backflow preventer, it is likely that water will be taken from any convenient source, possibly creating a cross-connection with this source. For example, a boiler room should have water supplied through a backflow preventer for the makeup line to the boiler. Otherwise, water could be piped in from a nearby sink or some unprotected supply, thus creating a cross-connection with the boiler water. A protected water supply, set aside for a specific purpose, diminishes the possibility of cross-connections being created.

It is necessary to evaluate each facility to see which type of backflow protection will be needed, if any. Internally, it is necessary to evaluate each point of use

TABLE 13.1 Several Types of Cross-Connections

The X indicates the appropriate type of backflow preventer

Type of connection	Air gap	Double-check-valve assembly	Reduced-pressure-principle assembly	Pressure-type vacuum breaker	Atmospheric-type vacuum breaker
Back-pressure from:					
Pumps, tanks, and lines handling:					
Sewage substances	X				
Toxic substances	X		X		
Nontoxic substances	X	X	X		
Steam lines and steam boilers					
Boiler or steam connection to toxic substance	X		X		
Boiler or steam connection to nontoxic substances (boiler blowoff not connected directly to sewer)	X	X	X		
Inlet-type water connections not subject to back pressure:					
Waste line (not subject to back pressure due to waste line stoppages)	X		X	X	X
Low inlet to receptacles containing toxic substances	X		X	X	X
Low inlet to receptacles containing nontoxic substances	X	X	X	X	X
Low inlet into domestic water tank			No protection required		
Lawn sprinkler systems	X		X	X	X
Coils or jackets used as heat exchangers in compressors, degreasers or other equipment:					
In toxic substances	X		X	X	X
In nontoxic substances			No protection required		
Flush valve toilets	X				X
Toilet and urinal tanks	X				X
Through urinals					X
Valved outlets or fixtures with hose attachments which may constitute a cross-connection:					
Toxic substances	X		X	X	X
Nontoxic substances	X	X	X	X	X

to determine the proper cross-connection control method. Each type of assembly must be installed properly and in the hydraulic condition under which it was designed to operate. Bypass arrangements should not be installed around backflow preventers, as this would defeat the purpose of the installation. Should continuous service be necessary, then the backflow preventers should be installed with two or more in parallel to allow for maintenance without service being disrupted. Local codes and ordinances regarding backflow prevention and cross-connection control should be consulted for specific requirements.

REFERENCE

Manual of Cross-Connection Control, 8th ed., Foundation for Cross-Connection Control and Hydraulic Research, University of Southern California, Los Angeles, CA 90089-0231, June 1988.

CHAPTER 14

HOT-WATER SUPPLY SYSTEMS

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INTRODUCTION

This chapter describes various aspects of hot-water supply systems. First, the types of fuels used in hot-water heaters are discussed. This is followed by a description of various direct-fired heaters (gas-fired, oil-fired, and electric water heaters). Then indirect water heaters are considered, including the storage-type, instantaneous-type, and semi-instantaneous type. Next, requirements for water at more than one temperature are described. These include the mixing of water at different temperatures, blending, and dual-temperature systems. The various components in hot-water systems are discussed, along with safety requirements.

Next, methods of employing heat-recovery systems to reduce heating costs are considered. It is then shown how to estimate hot-water demand and how to determine the required heater capacity and the required storage tank capacity. This is followed by a discussion of considerations in the design of a hot-water system. Finally, a step-by-step procedure is given for the design of such a system.

TYPES OF WATER HEATERS

Fuels Used in Water Heaters

The principal sources of heat energy used in hot-water heating systems are gas, oil, and electricity. In certain geographic areas, coke, coal, and wood are used, but the specialized hot-water heating equipment required for the use of such fuels is not generally available. The choice of source of heat energy depends on:

1. Its availability as a fuel
2. Its fuel cost
3. The type of hot-water heating equipment required

4. The adequacy of service facilities and replacement parts for such equipment
5. Space requirements for the equipment and possible requirements for a chimney or vent and access to a supply of air for combustion.

Direct-Fired Water Heaters

In a direct-fired water heater, the source of heat (gas, oil, or electricity) is located where the water is heated. This is in contrast to an indirect water heater, where the water is heated by a remotely located heat source, as described in the section "Indirect Water Heaters," below.

A supply of air for combustion is required for heaters of this type (except electric heaters). This supply must be adequate if the efficiency of the heater is to be maintained. The quantities specified in code requirements should be considered as the absolute minimum values.

Gas-Fired Heaters. Gas-fired heaters use natural gas, manufactured gas, or propane gas as their source of fuel. Such heaters may have atmospheric burners, forced-draft burners, or condensing-type burners. Their combustion efficiencies vary but are, approximately, 75 percent for atmospheric burners, 80 percent for forced-draft burners, and 90 to 95 percent for condensing-type burners. Gas-fired heaters are particularly susceptible to loss of efficiency and to malfunctions (puffs or explosions) if the source of combustion air is inadequate. A residential automatic water heater of gas-fired type is illustrated in Fig. 14.1. In this heater, the temperature is automatically controlled by the thermostat. The *anode* is a metal rod (such as magnesium) that is anodic to the other metals in the tank, which provides protection against corrosion. The *dip tube* is a water inlet pipe inside the tank to convey water to, or near, the bottom of the tank. Gas-fired heaters are usually compact and of highly specialized designs.

It is important to install all the safety devices and accessories specified by the manufacturer if the water heater is to provide satisfactory performance and long life. Safety can be compromised by (*a*) the lack of adequate air for combustion, (*b*) an improperly sized or improperly installed gas vent or chimney, or (*c*) incorrectly located operating controls.

Gas-fired heaters in residences are generally provided with a storage tank and have fully automatic controls. Small water heaters without a tank are sometimes used in isolated or remote washrooms, as described under "Instantaneous-Type Heaters." In larger installations, the most commonly used gas-fired hot-water heaters are of the following types: (*a*) hot-water supply boilers, (*b*) instantaneous heaters, (*c*) combined automatic heater and storage tank, and (*d*) circulating hot-water heaters used with a storage tank.

Oil-Fired Heaters. Oil-fired heaters (i.e., heaters using oil as fuel for heating) are generally direct-fired and have forced-draft burners. They are usually fully automatic in operation and are provided with a storage tank. Larger installations may include hot-water boilers, instantaneous-type heaters, or circulating-type heaters with an associated storage tank. Installation procedures are described in Ref. 1.

The complexity of an oil-fired burner increases with the viscosity (grade number) of the fuel oil it uses. Number 3 fuel oil or domestic fuel oil is most widely used, except in very large installations. Light-grade fuel oils are generally used to minimize repairs and maintenance. An oil-fired heater requires cleaning and soot removal more frequently than a gas-fired heater. This is because soot will greatly

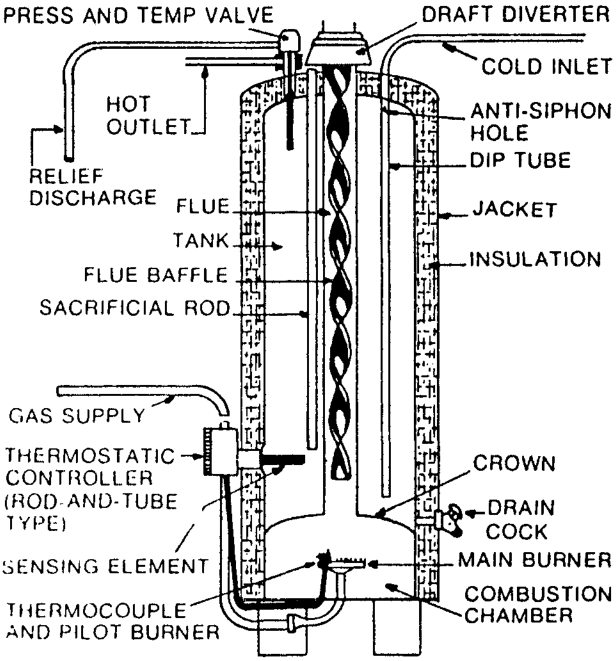

FIG. 14.1 A residential automatic gas-fired water heater. *(Courtesy of Rheem Manufacturing Co.)*

reduce the efficiency of the heater. For example, a layer of oil soot only ⅛ in (0.03 mm) thick may result in a loss of efficiency of about 10 percent.

Electric Water Heaters. In general, electric water heaters are fully automatic and have a storage tank, one or more electric heating elements, and operating and safety controls. The heating elements are available in a variety of standard voltages and wattages to meet the specific requirements of the installation.

It is often economical to heat water during off-peak periods when the cost of electricity is lowest and store the water for later use during peak demand periods. For larger electrically heated hot-water systems, this type of control is essential to minimize the cost of electric power for water heating.

The use of an electric water heater is advantageous because (*a*) this type of heater does not require a supply of combustion air, (*b*) it does not require venting to the outdoors, (*c*) it does not require a chimney, (*d*) it is inherently a clean system—no soot or grime is generated, and so it may be installed in areas of a building where a heater fired by a fossil fuel may be impractical, (*e*) it may reduce space requirements for a heater, and (*f*) the possibility of fuel leakage is obviated.

Indirect Water Heaters

An *indirect water heater* is one in which the water is heated by a heat source that is remotely located from the water heating equipment. Usually, hot water (i.e., the heating medium) is conveyed to a heat exchanger by means of a separate supply and return piping system, as illustrated in Fig. 14.2. A *heat exchanger*, illustrated in Fig. 14.3, is a device that transfers heat from one fluid to another. It is important to ensure that the walls of the heat exchanger do not become perforated through erosion or corrosion. Such perforations would establish a cross-connection between the fluid from the remotely located heater and the water being heated, resulting in possible contamination of the water supply.

Indirect water heaters generally are classified as (*a*) storage-type heaters, (*b*) instantaneous heaters, and (*c*) semi-instantaneous heaters.

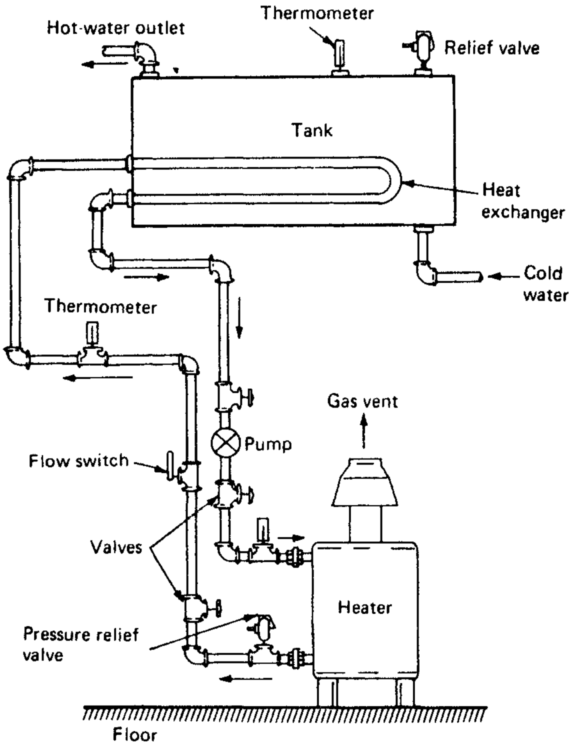

FIG. 14.2 An indirect water heater. Hot water is conveyed to a heat exchanger by a separate supply and return system. The heat exchanger, a removable tube bundle, heats the water in the tank to the desired temperature.

Storage-Type Water Heaters. A storage-type water heater, illustrated in Fig. 14.4, is composed of a horizontal or vertical storage tank, a source of heat such as an electric heating coil or heat exchanger, and various accessories for the control, operation, and maintenance of the heater. This type of heater is used (*a*) where large quantities of hot water are required at intervals, (*b*) where the required quantities fluctuate, or (*c*) where there is a limited amount of heating energy available. A circulation pump assists in preventing stratification of the water in the tank (i.e., segregation into hot layers at the top and cold layers at the bot-

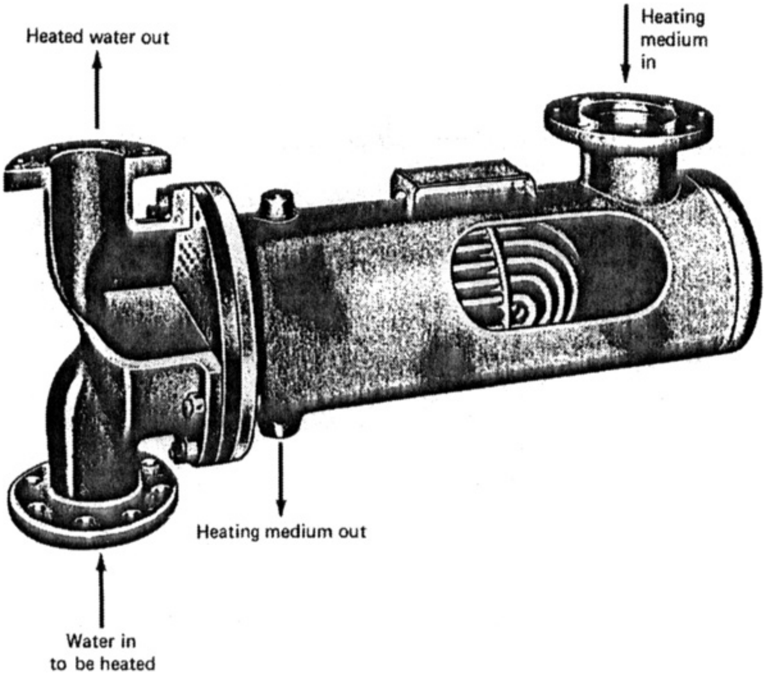

FIG. 14.3 A heat exchanger. *(Courtesy of Paterson Kelley.)*

tom) by providing constant mixing. Hot water leaves the top of the tank to the supply distribution piping upon demand from the various fixtures and apparatus. If recirculation of the hot water is provided, the cooled water is returned to the bottom of the tank by a pump.

Instantaneous-Type Heaters. In an instantaneous-type heater, water is heated almost instantaneously as it flows through tubes surrounding a heating coil. Such heaters are best suited for applications requiring a *continuous* flow of hot water. Such heaters usually are not suitable for intermittent- and fluctuating-flow applications. Figure 14.5 shows construction details of a typical small gas-fired heater of the instantaneous type used to satisfy relatively small hot-water requirements.

An instantaneous-type heater is used to provide hot water, at required maximum demand, without storage. As a result, when there is a sudden increase in demand, there may be a corresponding drop in the temperature of the supply water; when there is a sudden decrease in demand, there may be a corresponding increase in temperature, resulting in possible danger of scalding.

Instantaneous heaters should be used with care when the demand is below 10 gpm (0.63 L/s) because of the complexity of accurate temperature control at low flow rates or for intermittent flow, which may lead to violent temperature fluctuations. Heaters of this type are generally used for larger applications, and often used in multiples for continuity of service.

Semi-Instantaneous-Type Water Heaters. A heater of this type is essentially an instantaneous-type heater having a sophisticated control system with a tank of

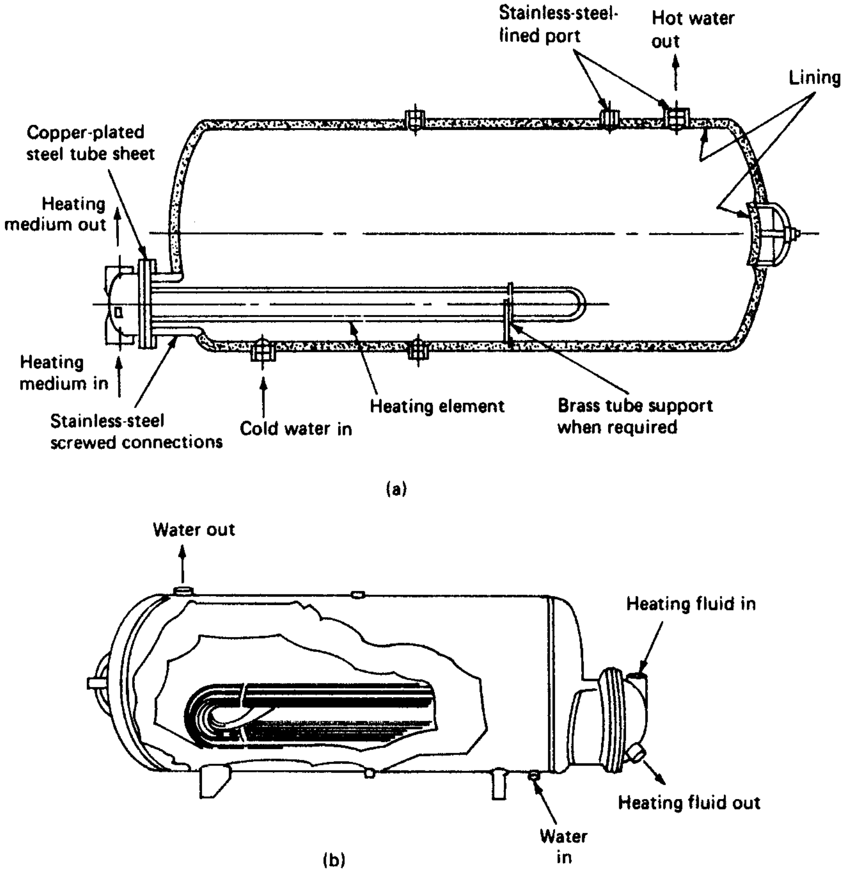

FIG. 14.4 Storage-type water heaters. The water to be heated enters the bottom of the tank and is heated by (*a*) a removable heating element or (*b*) a bundle of tubes through which a heating medium flows. Heating is controlled by an immersion-type temperature regulator inserted in the storage tank wall to measure the average temperature of the stored water. The temperature regulator allows the water to be heated when it is cold but turns off the heat when the desired temperature is reached.

limited storage capacity. Figure 14.6 shows a typical arrangement of this type of water heater. Extreme care should be taken in selecting these heaters in the smaller capacities, with flow under 10 gpm (0.63 L/s), because of the difficulty of accurate temperature control at low flow rates or for intermittent flow.

This type of heater should be considered especially when there are serious space restrictions for the installation of a water heating system. It should not be used as a point-of-use type of heater except for medium or large applications. *Point of use* generally refers to use in a room in a remote location of a building that is far from other fixtures using hot water—for example, in a single washroom located in a remote corner of a warehouse, where an instantaneous heater of the

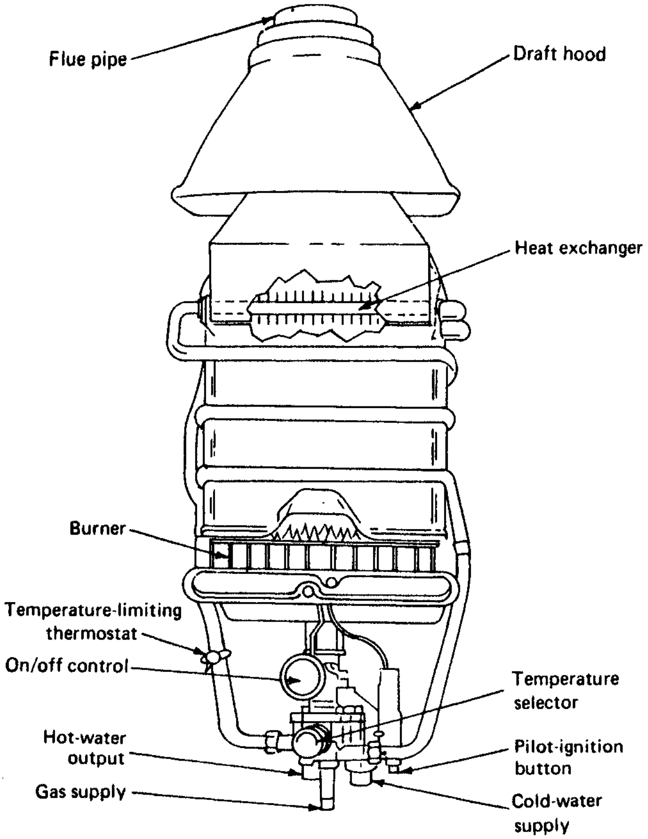

FIG. 14.5 A small gas-fired heater of the tankless, instantaneous type; the cover for the heater has been removed. When the hot water tap is turned on, cold water enters the heat-exchanger coil and is heated by a gas flame. Water-flow and temperature sensors control the height of the flame in response to the flow-rate and temperature settings. The controls include an on-off switch, a temperature-selection dial, and a pilot-light ignition control. *(Courtesy of Consumers Reports.)*

type shown in Fig. 14.5 would be suitable. Figure 14.6 shows construction details and piping arrangements for a heater of this type.

Solar Water Heaters

In a solar water heater for domestic use, the sun's heat is gathered by collectors, such as the one shown in Fig. 14.7. This heat increases the temperature of a heat-transfer fluid (such as water or a nonfreezing liquid) which flows through the pipes in the collector. The heat contained in this fluid is conveyed to the water heater, where it is transferred to the water—thereby heating it. Then the heat-

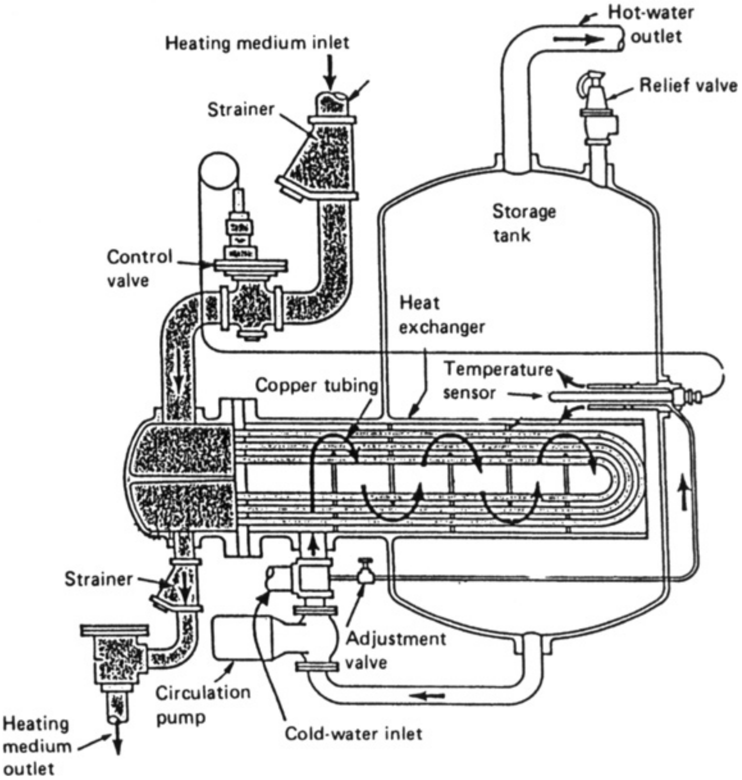

FIG. 14.6 An indirect-type semi-instantaneous water heater. A heat exchanger is partially enclosed within the storage tank. The heating medium enters the system through an inlet shown at the upper left and circulates through the copper tubing of the heat exchanger. A circulation pump forces the water being heated to flow from the bottom of the tank over the copper tubing, thereby heating the water. When the temperature of the water rises to a preset value (as measured with the temperature sensor), the control valve closes, thereby shutting off the flow of the heating medium into the heat exchanger. *(Courtesy of Paterson Kelley.)*

transfer fluid is recirculated to the collector. A simple solar water heater of this type may be used for residential applications in warm climates where there is little or no danger of freezing. It is a closed system which allows natural circulation of the heat-transfer fluid by using the difference in density between the hot and cool fluid in the tubing, when the solar collector is located above the hot-water tank.

In colder climates, solar heating systems are more complex. They require (*a*) an auxiliary source of heat for use when the solar heat is insufficient to meet the heating requirements, (*b*) a heat-transfer fluid that does not freeze, (*c*) pumps, and (*d*) a control system—all of which increase the complexity and cost of such a system, usually making it uneconomical. The relative advantages and disadvantages of the various solar water heating systems are discussed in Ref. 2.

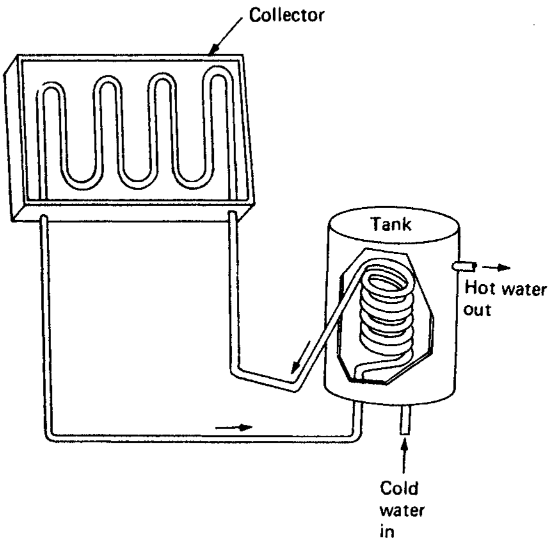

FIG. 14.7 A solar water heater. Heat from the sun raises the temperature of a heat-transfer fluid in the collector. This heat is then transferred to the water in the tank by a heat exchanger in the tank.

CIRCULATION-TYPE HOT-WATER SUPPLY SYSTEMS

A *circulation-type hot-water supply system* circulates water through a storage tank and one or several gas-fired water heaters by means of a pump. This type of system provides better heat transfer and temperature control. A circulation-type hot-water supply system is shown in Fig. 14.8.

A *hot-water recirculation system* (also known as a *return-circulation system* or an *HWRC system*) is a system in which additional piping and a return pump are added to a hot-water distribution system to return the unused hot water to the heater (to compensate for temperature losses through convection, radiation, and conduction). A recirculation-type hot-water supply system is used where the point of use is at a large distance from the heater, for example, 100 ft (30.5 m) or more, or where there would be an undue waiting time for hot water when the tap opens. A hot-water recirculation system should recirculate only enough hot water to compensate for the heat loss in the supply distribution piping between the heater and fixtures. Alternatively, the recirculation piping, pump, and system may be replaced by an electric self-limiting heater cable, with thermostatic control, applied to the hot-water supply main piping under an insulating jacket to compensate for ambient losses through the insulation and maintain the hot-water supply at the required temperature.

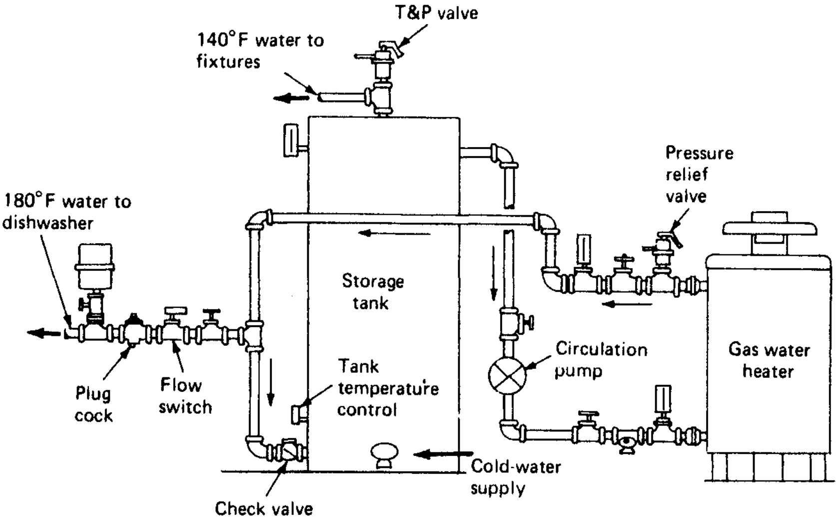

FIG. 14.8 A gas-fired circulation-type water heating system that supplies hot water at two temperatures. *(Courtesy of A. O. Smith.)*

COMPONENTS OF HOT-WATER SYSTEMS

Hot-Water Storage Tank

A hot-water storage tank must meet code requirements that depend on its size and pressure and the authority having jurisdiction. Its capacity should be selected so that 60 to 80 percent of the volume of water in the tank may be drawn off before the temperature drop (caused by the incoming cold water) becomes unacceptable. A figure of 70 percent usually is used in design calculations.

In most small installations, hot-water storage tanks are glass-lined. In large installations, the tanks may be fabricated of steel with a concrete lining. Where a protective concrete lining is used, a manhole should be provided for access so that the concrete coating can be applied on the inside of the tank and so that the concrete can be inspected periodically and any cracks can be repaired. It is important that all the openings in lined tanks be fabricated of corrosion-resistive fittings in order to protect these vulnerable (unlined) areas from failure through corrosion.

In many areas, the traditional galvanized-steel storage tanks are no longer used. Tanks made of Inconel or Monel are much too costly for commercial applications and are economically justifiable only for special projects.

Safety Devices

When water is heated in a confined volume, as the temperature increases, the water pressure increases. In a water heater, if the temperature increase is sufficiently great and if there are no safety devices, then the pressure may exceed the mechanical strength of the tank, and the tank may rupture. For this reason, safety devices are essential in a hot-water system. Such devices include various types of valves and cutoff devices. This section describes such devices as well as other components of a hot-water system.

Temperature Relief Valves; Pressure Relief Valves. Codes governing the use of safety devices in hot-water systems vary widely with locality. Utmost care must be taken to comply with local safety codes, and where there are special conditions, such as water meters, more pressure relief valves or other safety devices must be added. The principal safety devices are pressure and temperature relief valves.

A *pressure relief valve* is a type of safety valve designed to open if the pressure within the storage tank exceeds the value for which it was designed to operate safely. A pressure relief valve is located at the outlet of each heater, at the location of the maximum temperature. If the pressure is excessive, the valve opens, providing protection for the heater from possible damage and for personnel from possible injury.

Similarly, a *temperature relief valve* is a type of safety valve designed to open when the temperature of the water being heated exceeds a set value. An immersion-type sensor is inserted in the water being heated at the hottest point of the tank or heater. In general, a temperature relief valve is designed to open when the temperature within the storage tank exceeds 210°F (99°C).

There should be an air gap between the drain pipe from the outlet of a relief valve and the drain so that it is possible to check visually whether (*a*) the valve is working properly and (*b*) the valve is leaking. The relief valve should be equipped with a test lever to allow periodic checks on its operation. Such a device must have an energy-relieving capacity equal to or greater than the heating input to the heater or system that is being protected. A shutoff valve should not be installed between the pressure relief valve and the temperature relief valve or between these valves and the water heater being protected.

In relatively small hot-water systems, a pressure relief valve and a temperature relief valve may be combined in a single device, a *temperature and pressure relief valve (T&P relief valve)*, for reasons of economy. In large hot-water systems, separate valves are required for each function.

Energy Cutoff Devices. An energy cutoff device is a safety device that interrupts the flow of energy to the heater if the temperature or pressure exceeds a preset value anywhere within the water heating system. Such safety devices, which are required by national and local codes, must be correctly installed to protect the equipment and to prevent the possibility of damage or loss of life.

Pressure Gages

A pressure gage provides a visual indication of the pressure in a hot-water tank or at an appropriate point in a hot-water system (for example, before and after a pressure-reducing valve, before and after a circulation pump, etc.). Such a gage will indicate whether the pressure is excessive, as might be the case if the pressure-regulating valve on the steam supply line is not operating properly. It will also indicate whether the pressure is too low.

Thermometers

Thermometers at the inlet of a heater, and at the outlet, provide an indication of the satisfactory operation of the heater. A deviation from the usual operating temperatures is indicative of a malfunction of the equipment (or that recalibration of the thermometer is required).

Circulation Pump

The quantity of water in a coil in a heater or in a heat exchanger of a hot-water heating unit is small and would quickly turn into steam if heated under gravity-flow conditions. Therefore, to obtain (*a*) appropriate heat transfer (i.e., heating of the water) without an excessive temperature rise and (*b*) the rated capacity of the heater, water must be forced through the heating coil by a circulation pump that is correctly selected for its specific application. A flow switch prevents firing of the heater unless the circulation pump is in operation and water is flowing through the heater. This pump should be fabricated entirely of bronze or of a material that is resistive to the corrosive action of oxygen-carrying water that enters the heater from the cold-water supply system.

Isolating Valves and Drain Valves

Valves are installed in hot-water systems to isolate the flow of water to each heater or to permit any specific part or all of the system to be drained for repair or maintenance purposes.

Deliming Tees

Deliming tees are tees provided at the entry and outlet of a heater to permit the temporary installation of deliming equipment periodically. Such tees are required only in geographic regions where the water is hard and deliming is necessary. For example, deliming tees are shown at the inlets of the multiple instantaneous gas-fired circulating water heaters shown in Fig. 14.9.

Operating Controls

An *operating control* is usually an immersion-type aquastat (i.e., a sensor immersed in the water being heated) that controls (*a*) electric heating elements or (*b*) gas or oil burners; the heating is turned on when the temperature of the water falls to a set temperature; the heating is turned off when the temperature rises to a second set temperature.

Controls of this type include devices that turn a heat source on and off cyclically and devices that control the valves which admit hot water to a heat exchanger. Such controls must be carefully selected and checked to ensure that the system and its components operate as designed and follow the proper sequences, with appropriate secondary safety devices that are set slightly higher than the operating controls and that shut off the energy supply (electricity, gas, or oil) should the operating controls fail to function for any reason.

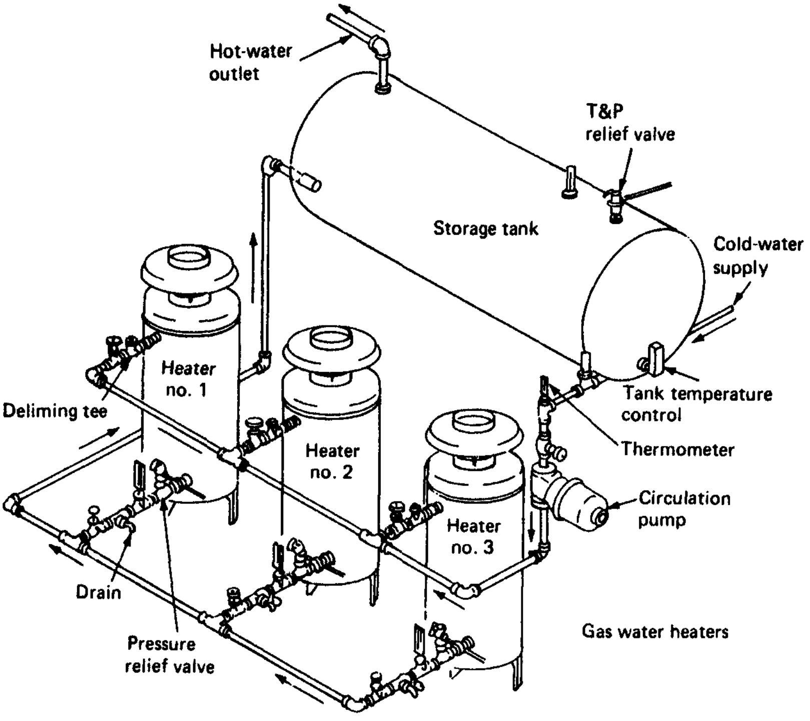

FIG. 14.9 A gas-fired circulation-type water heating system with multiple tanks. *(Courtesy of A. O. Smith.)*

Extra care must be taken in selecting controls if the hot-water system is not conventional or if the hot-water system has any special requirements.

Water Hammer Arresters

Water hammer is the noise and mechanical shock generated in a pipeline as a result of a sudden change in the rate of water flow or an abrupt stop of the water flow. A device that is installed in a piping system to absorb this sudden increase in pressure in the line is called a *water hammer arrester*. Domestic-type glass-lined storage heaters with reverse dished bottoms are susceptible to damage from water hammer. For this reason a water hammer arrester or some similar approved device should be installed to prevent failure of the storage tank. Water hammer arresters are described in Chap. 11.

Auxiliary Equipment

In addition to the equipment described above, the following components form an essential part of a hot-water system:

- *Chimneys, flues, or vents*, which should be sized and installed according to code requirements.
- *Gas piping, safety and operating controls, and vents*, which should be designed and installed according to applicable gas codes considered in Chap. 23.
- *Water piping*, which should be of adequate size, be corrosion-resistant, and comply with local codes.
- *Thermal insulation of tank and hot-water piping insulation*, which is important for both economy and personnel protection. If insulation is not installed, annual operating costs may be 10 to 15 percent higher as a result of thermal losses in the system.

WASTE-HEAT-RECOVERY HOT-WATER SYSTEMS

The increased cost of energy has led to more frequent use of equipment to recover, in part, heat that would otherwise be wasted in a building, thereby reducing the cost of heating water.

Waste heat in a building can be used to preheat cold water before it is fed to a hot-water heater. This is illustrated in Fig. 14.10, which shows a practical recovery system where the temperature difference between the warm air that is being exhausted from the building and the cold water that enters the heat exchanger is relatively small. In *preheating*, the domestic water is circulated through a first-stage heat exchanger; the water is partially heated before it is circulated through the final heater. In this way, not as much energy is required in the final heater to raise the water to the required temperature. If required, additional heat may be added by an auxiliary heating device. Where the exhaust air temperature is high, a conventional air-to-water heat exchanger may be used in the recovery system.

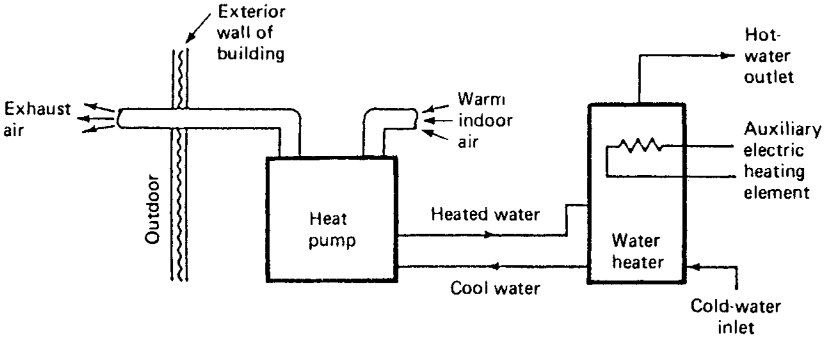

FIG. 14.10 A schematic diagram of an exhaust-heat-recovery system. Warm air within a building is forced through a heat pump, where it transfers some of its heat energy from the air to the cool water in the heat pump; then the air is exhausted to the outdoors. The heated water is then fed to a reservoir equipped with an auxiliary electric water heater, where the temperature of the water can be raised to a higher temperature by means of a heating element if the heat recovered by the heat pump does not satisfy hot water requirements. *(Courtesy of Ontario Hydro.)*

HEAT-PUMP WATER HEATER

A *heat pump* is a device that transfers heat from a cooler space or reservoir to a warmer one. By sequencing of controls, it can be used either as a very energy efficient heating device *or* as a cooling device. Figure 14.11 illustrates the operation of a heat pump designed for residential use. Warm ambient air is drawn into the top of the unit through a filter. The evaporator extracts heat from this air and transfers it to the refrigerant. The compressor compresses the hot refrigerant gas and concentrates the heat in the refrigerant. The heat is then transferred from the refrigerant by a heat exchanger to the water to be heated.

As cold water enters the tank, it is drawn to the bottom of the tank into the heat exchanger section of the heat-pump unit, where it is heated. The heated water is returned to the tank through the inlet dip tube. Heated water is drawn from the top of the tank, where it has risen after having returned from the heat-exchanger section of the heat-pump unit.

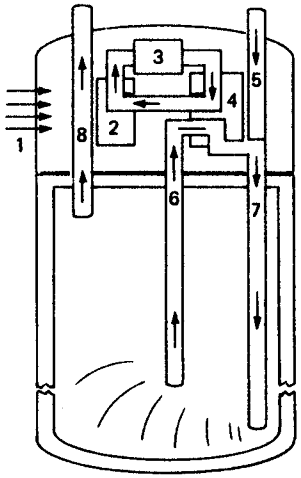

FIG. 14.11 A residential-type heat-pump water heater. *Heat is gathered as follows*: (1) Air containing waste heat enters through a filter. (2) Evaporator extracts heat from the air and transfers it to the refrigerant system. (3) The compressor concentrates heat in the refrigerant system. (4) Heat is transferred by the heat exchanger from the refrigerant to the water. *The water is heated as follows*: (5) Cold water enters the tank. (6) Water is drawn from the bottom of the tank into the heat exchanger in the heat pump unit, where it is heated. (7) Heated water is returned to the tank through an inlet dip tube. (8) Heated water is drawn from the top of the tank where it has risen after having returned from the heat pump unit. *(Courtesy of Ontario Hydro.)*

SYSTEM DESIGN CONSIDERATIONS

Available Water Pressure

In general, the available water pressure must be high enough to provide a pressure of about 15 psi (100 kPa) at the highest and most distant plumbing fixture; the available pressure must be high enough to overcome (*a*) the static head between the water supply entry and the highest floor and (*b*) the pressure loss in the piping system and equipment at maximum flow in the piping. This figure is applicable to ordinary plumbing fixtures; some fixtures (for example, flushometers) require a higher water pressure to operate correctly. If the available water pressure is not high enough to meet these requirements, the measures described in Chap. 4 must be taken. In some municipalities, the supply water pressure may be too high for ordinary purposes. Then a pressure-reducing valve or similar device should be installed, as described in Chap. 4.

Pretreatment of Water

If the water is hard, or if it contains dissolved minerals or suspended solids, it should be treated by the methods described in Chap. 1 before it is heated. Without appropriate water treatment, scale or lime may be produced, which may adversely affect the heating equipment and its performance. Provision should be made at the heater to permit deliming of the heating surfaces. If the heater and/or piping may be corroded by the water supplied to the building, some type of corrosion protection should be provided.

Corrosion

Corrosion is the gradual destruction of a metal or alloy by a chemical process such as oxidation or the action of a chemical agent. In some geographic areas, water attacks types of piping that are satisfactory elsewhere. For example, in the province of Quebec, galvanized-steel piping is no longer permitted in new domestic water distribution systems. It may only be used in repairs or replacements in existing domestic systems and in industrial process piping. This is because the local water corrodes galvanized-steel pipe so that it must be replaced in less than 5 years—resulting in excessive maintenance costs. The corrosiveness increases with water temperature and is most active on galvanized piping and/or storage tanks at a temperature between 140 and 180°F (60 and 82°C).

In some areas, types L, M, and K copper tubing are not used because the corrosivity of the hot water causes premature failure of the tubing. In other areas, stainless-steel tubing has been found to perform and last satisfactorily in apartment and office building applications at a competitive first cost. If the water conditions are particularly aggressive and if the water temperature requirements are not particularly high, chlorinated polyvinyl chloride (CPVC) plastic piping may perform satisfactorily.

Electrochemical corrosion (also known as *electrolytic corrosion*) is corrosion of a metal resulting from current in an electrolyte. The current is caused by a voltage difference between the two metal surfaces; the metal surfaces may be in the ground, in the air, or in water. In hot-water heating systems, most commonly, corrosion is the result of electric current between the anode and cathode.

Some measure of corrosion control in a hot-water system may be obtained by:

- Proper selection of materials used in the system.
- Selection and application of protective coatings on metal surfaces that are subject to corrosion.
- Use of inhibitors or water treatment to control the pH level and the suspended solids and oxygen content of the water. See Chap. 1 and Ref. 3.
- Use of cathodic protection, employing a sacrificial anode, as described in Chap. 11. The sacrificial anode must be more corrodible than the metal surface which it is to protect (for example, a hot-water storage tank), so it is usually a piece of zinc or magnesium. Corrosion is prevented by reversing the direction of current causing the corrosion. In this process the sacrificial electrode is eventually consumed and must be replaced.

Acceptable Temperature of Hot Water

Table 14.1 shows the minimum acceptable hot-water temperature at various plumbing fixtures and pieces of equipment. Since there will be heat losses in transporting the hot water from the heater to the point of use, these losses should be considered in determining the optimum temperature for water leaving the heater.

TABLE 14.1 Minimum Acceptable Hot-Water Temperature at Various Plumbing Fixtures and Pieces of Equipment

Use	Minimum temperature	
	°F	°C
Lavatory		
Hand washing	105	40
Shaving	115	45
Showers and tubs	110	43
Commercial and institutional laundry	180	82
Residential dishwashing and laundry	140	60
Commercial spray-type dishwashing as required by National Sanitation Foundation		
Single or multiple tank hood or rack type		
Wash	150 min	65 min
Final rinse	180 to 195	82 to 90
Single-tank conveyor type		
Wash	160 min	71 min
Final rinse	180 to 195	82 to 90
Single-tank rack or door type		
Single-temperature wash and rinse	165 min	74 min
Chemical sanitizing glasswasher		
Wash	140	60
Rinse	75 min	24 min

Source: Ref. 4.

To inhibit the growth of bacteria in a hot-water system, a temperature of about 140°F (60°C) or higher is recommended. If a lower temperature is required at a fixture, it can be obtained by mixing water at this temperature with cold water at the fixture.

ESTIMATING HOT-WATER DEMAND; REQUIRED HEATER CAPACITY; REQUIRED STORAGE TANK CAPACITY FOR STORAGE-TYPE HEATERS

Estimating the Demand in a Hot-Water System

As defined in Chap. 2, *demand* is the rate of flow, usually expressed in gallons per minute (or liters per second), furnished by a water supply system to various types of plumbing fixtures and water outlets under normal conditions. *Normal conditions* are those conditions which provide adequate performance while avoiding objectionable effects, such as excessive splashing or inadequate supply conditions. The *maximum demand* of a water supply system is the peak value of the demand. Methods for estimating demand are described in Chap. 2 for cold-water supply systems.

A number of methods are available for estimating the maximum demand for a domestic hot-water system. Several of these methods give conservative estimates of demand that may be applied in design, but others, based on conditions that have changed over the years, usually provide estimates that fall short of actual requirements. The *demand factor* is the ratio of the maximum demand of the hot-water heating system to the total connected load or the total of the individual requirements of all the fixtures of the system.

Table 14.2 indicates probable hot-water demand and usage for various types of building occupancies on an hourly and daily basis. Selection of equipment varies with the type of equipment used.

TABLE 14.2 Probable Hot-Water Demand and Use for Various Types of Building Occupancies

On an hourly and daily basis, normal use

Type of building	Maximum hour	Maximum day	Average day
Men's dormitories	3.8 gal (14.4 L)/student	22.0 gal (83.4 L)/student	13.1 gal (49.7 L)/student
Women's dormitories	5.0 gal (19 L)/student	26.5 gal (100.4 L)/student	12.3 gal (46.6 L)/student
Office buildings	0.4 gal (1.5 L)/person	2.0 gal (7.6 L)/person	1.0 gal (3.8 L)/person
Food service establishments:			
Type A—full-meal restaurants and cafeterias	1.5 gal (5.7 L)/max. meals/h	11.0 gal (41.7 L)/max. meals/h	2.4 gal (9.1 L)/avg. meals/day*
Type B—drive-ins, grilles, luncheonettes, sandwich and snack shops	0.7 gal (2.6 L)/max. meals/h	6.0 gal (22.7 L)/max. meals/h	0.7 gal (2.6 L)/avg. meals/day*
Apartment houses: no. of apartments			
20 or less	12.0 gal (45.5 L)/apt.	80.0 gal (303.2 L)/apt.	42.0 gal (159.2 L)/apt.
50	10.0 gal (37.9 L)/apt.	73.0 gal (276.7 L)/apt.	40.0 gal (151.6 L)/apt.
75	8.5 gal (32.2 L)/apt.	66.0 gal (250 L)/apt.	38.0 gal (144 L)/apt.
100	7.0 gal (26.5 L)/apt.	60.0 gal (227.4 L)/apt.	37.0 gal (140.2 L)/apt.
200 or more	5.0 gal (19 L)/apt.	50.0 gal (195 L)/apt.	35.0 gal (132.7 L)/apt.
Elementary schools	0.6 gal (2.3 L)/student	1.5 gal (5.7 L)/student	0.6 gal (2.3 L)/student*
Junior and senior high schools	1.0 gal (3.8 L)/student	3.6 gal (13.6 L)/student	1.8 gal (6.8 L)/student*

*Per day of operation.

Source: Ref. 4.

Table 14.3 provides reliable estimates of hot-water requirements. These values can be increased or decreased, depending on the available heating capacity and the capacity of the storage tank.

Table 14.4 provides estimates of the hot-water demand (expressed in terms of number of fixture units for various types of fixtures) for use in the design of systems that incorporate semi-instantaneous heaters.

The data given in Tables 14.2 through 14.4 are based on normal usage. These figures should be adjusted for special conditions, special requirements, or types of occupants that may influence the demand. For example, in an apartment house, the demand per apartment increases with the number of persons living in the apartment, with the hardness of the water (less hot water is used if the water is soft because of the greater ease in washing and rinsing with soft water), and with other factors. If there is specialized equipment, its demand requirements should be determined from the manufacturer.

Heating Capacity (Recovery Capacity) of a Water Heater

The *heating capacity*, also called the *recovery capacity*, of a water heater is its capacity to raise a given number of gallons per hour (liters per hour) from, say, 40 to 140°F (4.4 to 60°C); it is expressed in British thermal units per hour (kilowatts per hour). Figure 14.12 shows the relationship between heating capacity and size of storage tank for different types of building occupancies. The heating capacity

TABLE 14.3 Estimates of Hot-Water Requirements in Various Types of Buildings with Storage-Type Water Heaters

Demand is given in terms of gallons (liters) per hour per fixture, calculated at a final temperature of 140°F (60°C).

Fixture	Apartment house	Hotel	Office building	Private residence	School
Basins, private lavatory	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)	2 (7.6)
Basins, public lavatory	4 (15)	8 (30)	6 (23)		15 (57)
Bathtubs	20 (76)	20 (76)		20 (76)	
Dishwashers*	15 (57)	50–200		15 (57)	20 (100)
Kitchen sink	10 (38)	30 (114)	20 (76)	10 (38)	20 (76)
Laundry, stationary tubs	20 (76)	28 (106)		20 (76)	
Pantry sink	5 (19)	10 (38)	10 (38)	5 (19)	10 (38)
Showers	30 (114)	75 (284)	30 (114)	30 (114)	225 (850)
Service sink	20 (76)	30 (114)	20 (76)	15 (57)	20 (76)
Circular wash sinks		20 (76)	20 (76)		30 (114)
Semicircular wash sinks		10 (38)	10 (38)		15 (57)
Demand factor	0.30	0.25	0.30	0.30	0.40
Storage capacity factor†	1.25	0.80	2.00	0.70	1.00

*Dishwasher requirements should be taken from this table or from manufacturer's data for the model to be used, if this is known.

†Ratio of storage tank capacity to probable maximum demand per hour. Storage capacity may be reduced where an unlimited supply of steam is available.

Source: Ref. 4.

TABLE 14.4 Hot-Water Demand Expressed in Terms of Number of Fixture Units for Various Types of Fixtures in Buildings

For use with semi-instantaneous heaters, calculated at a final temperature of 140°F (60°C)

Fixture	Apartment house	Hotel or dormitory	Office building	School
Basins, private lavatory	0.75	0.75	0.75	0.75
Basins, public lavatory		1	1	1
Bathtubs	1.5	1.5		
Dishwashers	1.5	5 fixture units per 250 seating capacity		
Kitchen sink	0.75	1.5		0.75
Pantry sink		2.5		2.5
Service sink	1.5	2.5	2.5	2.5
Showers	1.5	1.5		1.5
Circular wash fountain				2.5
Semicircular wash fountain				1.5

Source: Ref. 4.

does not include heat losses in the hot-water system, for example, losses in the distribution piping and storage tanks. These losses should be taken into account in very large installations by increasing the calculated value of the heating capacity by a small percentage.

Procedure for Estimating the Heating Capacity (Recovery Capacity) of a Hot-Water Heating System Having a Storage Tank

Step 1. Tabulate the number of fixtures of each type in the building.

Step 2. Then multiply the number of fixtures of each type by the probable demand for each type of fixture.

Step 3. Obtain the *maximum demand* by taking the sum of the products of Step 2.

Step 4. Then obtain the *hourly heating capacity* by multiplying the maximum demand in Step 3 by the demand factor obtained from Table 14.3.

Step 5. Multiply the hourly heating capacity of Step 4 by the storage capacity factor given in Table 14.3 for the appropriate type of building to obtain the required capacity of the storage tank.

Usable Storage Tank Capacity

The usable storage capacity is usually only between about 60 and 80 percent of the total (i.e., actual) capacity of the storage tank, since hot water may be withdrawn from the tank on a peak demand faster than the water can be heated. As the cold water enters the tank after periods of large demand, the remaining water in the tank may cool down to a temperature that is not ac-

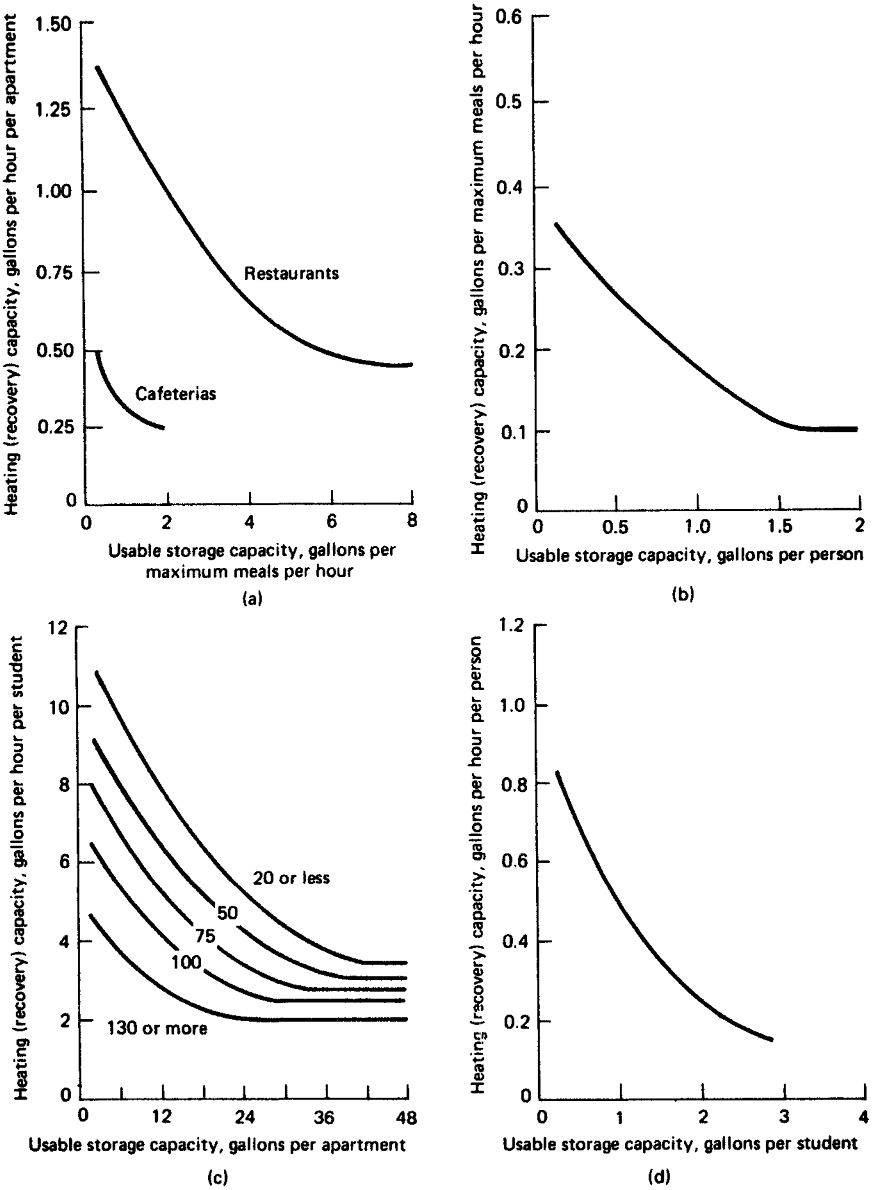

FIG. 14.12 The relationship between heating capacity (recovery capacity) and usable storage capacity for (*a*) restaurants and cafeterias, (*b*) office buildings, (*c*) apartment houses, and (*d*) high schools. *(From Ref. 4.)*

ceptable. Therefore a figure of 70 percent (i.e., a factor of 0.7) usually is used in calculations.

EXAMPLE 14.1 Determine the storage heater capacity for an apartment house having 60 lavatory basins, 60 showers, 40 kitchen sinks, and 10 laundry tubs.
Steps 1 and 2. From Table 14.3, the probable demands are as follows:

60 private lavatory basins × 2 gph (7.6 L/h) = 120 gph
60 showers × 30 gph (116 L/h) = 1800 gph
40 kitchen sinks × 10 gph (38.8 L/h) = 400 gph
40 dishwashers × 15 gph (58.1 L/h) = 600 gph
10 laundry tubs × 20 gph (77.5 L/h) = 200 gph

Step 3. The maximum demand is the sum of the probable demands: 3120 gph.
Step 4. Here the demand factor is 0.3. Therefore, the required hourly heating capacity = 3120 gph (11,810 L/h) × 0.3 = 936 gph (3543 L/h).
Step 5. The required capacity of the storage tank is

Storage tank usable capacity = 936 × 1.25 = 1170 gal (4430 L)

Since only about 70 percent of the tank capacity is usable, the actual required capacity is:

1170 gal/0.7 = 1670 gal (6327 L)

The above method is for the selection of a storage water heater; it *must not* be used for the selection of instantaneous or semi-instantaneous types of heaters.

ESTIMATING DEMAND FOR INSTANTANEOUS AND SEMI-INSTANTANEOUS WATER HEATERS

The following procedure may be used to determine maximum demand, hourly heating capacity, and the required storage capacity for instantaneous and semi-instantaneous heaters having little or no storage capacity:
Step 1. Tabulate the number of plumbing fixtures of each type that use hot water.
Step 2. Multiply the number of fixtures of each type by the number of fixture units per fixture (obtained from Table 14.4) to obtain the total number of fixture units.
Step 3. Using the total number of fixture units obtained in Step 2, determine the maximum demand in gallons per minute (liters per second) using the appropriate curve given in Fig. 14.12. The maximum demand represents the probable demand for fixtures used intermittently.
Step 4. To the demand of Step 3, add the demand for hot-water fixtures (or equipment) that operate continuously.
Step 5. Select a heater that will provide the required rise in temperature for the total demand of Steps 3 and 4.

EXAMPLE 14.2 Determine the required capacity of a semi-instantaneous water heater for a high school in which there are 6 wash fountains, 10 showers, 2 service sinks, 1 pantry sink, and 4 private lavatory basins.

Steps 1 and 2. Find the total number of fixture units from Table 14.4 by multiplying the number of each fixture type by the fixture units per fixture in the school column and adding the products.

6 circular wash fountains × 2.5 = 15.0
30 showers × 1.5 = 45.0
2 service sinks × 2.5 = 5.0
1 pantry sink × 2.5 = 2.5
4 private lavatory basins × 0.75 = 3.0
Total number of fixture units = 70.5

Select the desired temperature of the water leaving the heater, t_h. Determine the temperature of the cold water entering the heater, t_c. The difference $\Delta T = t_h - t_c$ represents the temperature rise that must be supplied by the heater.

Step 3. Determine the demand from Fig. 14.13. The enlarged section, Fig. 14.13*b*, for schools, shows that for 70.5 fixture units, the hot-water demand for fixtures that operate intermittently is approximately 15 gpm (1 L/s).

Step 4. One fixture operates continuously and has a demand of 1 gpm (0.06 L/s). Therefore, the total demand is 16 gpm (1.1 L/s).

Step 5. Select a heater that will supply this demand at the required temperature rise.

Step 8. Select the hot-water distribution system and piping.

Step 9. Determine the required capacity of the hot-water circulation pump. The circulation pump must overcome the pressure drop resulting from frictional losses through the heaters in addition to the friction losses through the piping, fittings, and accessories.

Step 10. Prepare a flow diagram of the system. A *flow diagram* of the overall system, such as the one shown in Fig. 14.14, incorporates all the various items of equipment, piping, and accessories; it provides a visual check of the system, helping to ensure that the components are located correctly and that none have been omitted.

Step 11. Size the components of the system; check the system design to ensure that it is in compliance with local and national codes and with energy conservation measures; check the system design to ensure that it conforms with architectural constraints.

Step 12. Recheck the design. The temperature of the water supplied to the high school considered in this example is 40°F (4.4°C); the desired temperature of the water leaving the heater is 140°F (60°C). This represents a temperature rise ΔT of 100°F (37.8°C). From a manufacturer's catalog, select a heater that will provide this increase in temperature for the total demand calculated in Step 4.

DUAL-TEMPERATURE SYSTEMS

In some installations (for example, in restaurants), hot water is required at two temperatures—for example, approximately 140°F (60°C) for some applications and up to 190°F (88°C) for other applications. It is uneconomical to heat the entire water supply to the higher temperature and then blend this higher temperature water with cold water to obtain water at the lower temperature. One method of supplying water at two temperatures is illustrated in Fig. 14.8. Water is heated with a gas-fired heater to the higher temperature; it is mixed in the storage tank to

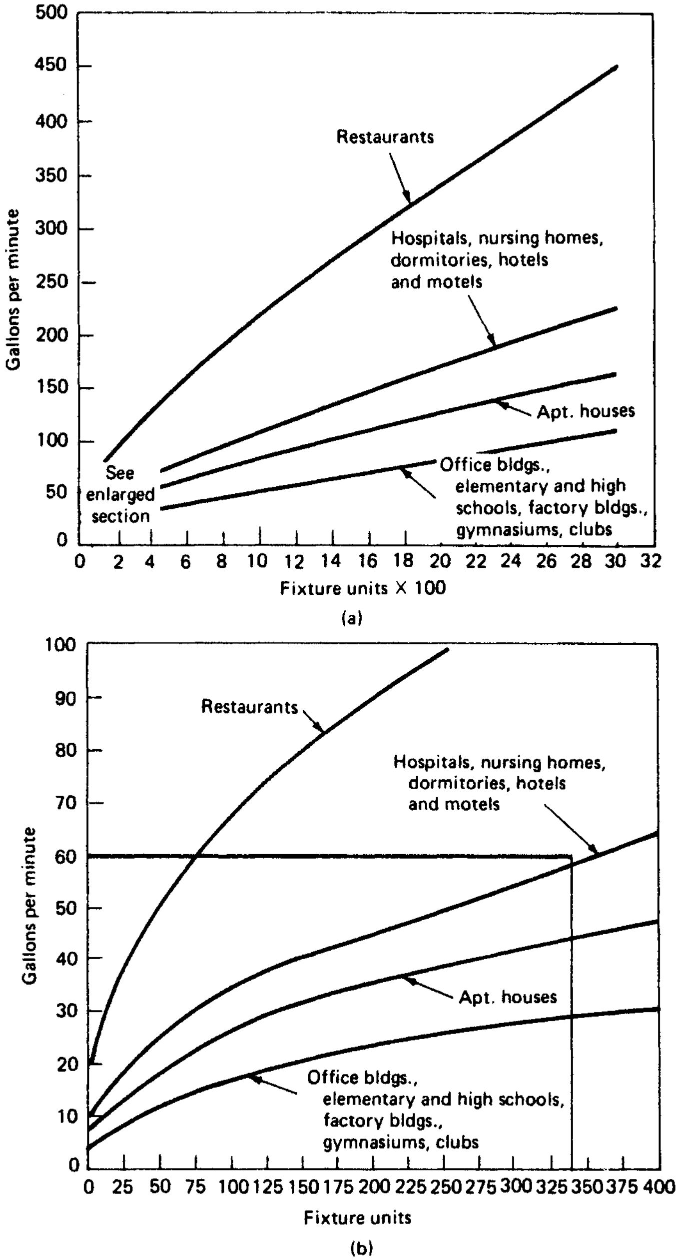

FIG. 14.13 (*a*) The relationship between estimated rate of water flow and the total number of fixture units in the hot water system for various types of buildings. These curves are modified Hunter curves, based on service water at a temperature of 140°F (60°C). (*b*) A detailed section of *a*. *(From Ref. 4.)*

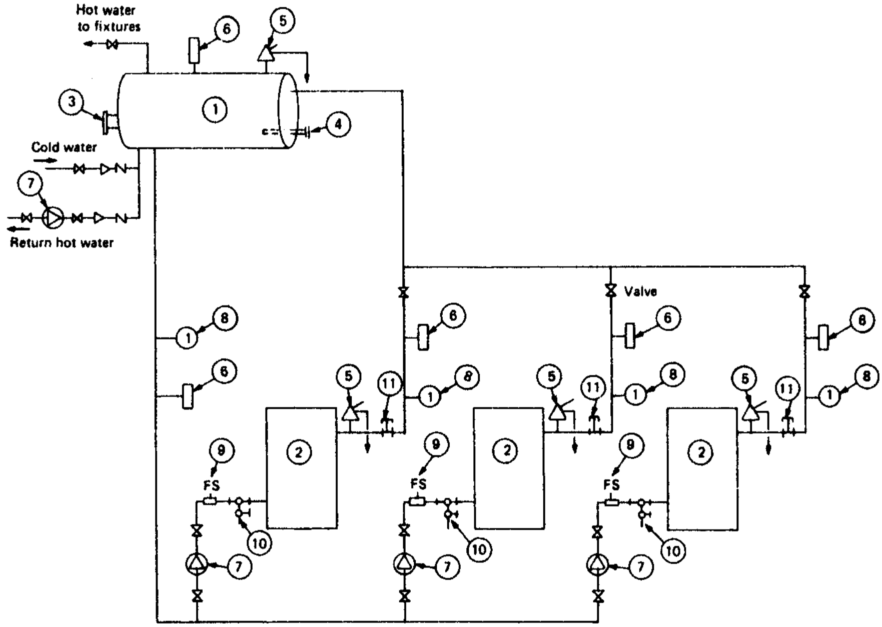

FIG. 14.14 Flow diagram for the circulating water heating system shown in Fig. 14.9, which has a horizontal storage tank and three water heaters. (1) Storage tank; (2) water heaters; (3) manhole access to tank; (4) thermostatic control for turning on and off energy supply of water heaters; (5) temperature and pressure relief valve; (6) thermometer; (7) circulation pump; (8) pressure gage; (9) flow switch; (10) drain; (11) deliming tee.

supply the lower temperature water. In effect, the system is a combined instantaneous-type system for the 180°F (82°C) water and circulation-type system for the 140°F (60°C) water.

Another method of supplying water at two temperatures (which sometimes finds application in commercial dishwashers) is to use the hot water supplied by the building system, which is at the lower temperature. The hot water from the building system is raised to the desired temperature by a booster heater located near the point of application, i.e., the dishwasher.

MIXING HOT AND COLD WATER TO OBTAIN AN INTERMEDIATE TEMPERATURE

Hot water at a high temperature is sometimes blended with cold water in order to raise the cold-water temperature. Such a method of heating usually finds application at the point of use, as in a laundry or food preparation establishment. If the blended hot water is for potable use or for food preparation, no contaminants may be in the heating medium blended with the cold water.

Suppose cold water at temperature t_c is mixed with hot water at temperature t_h to obtain a mixture of temperature t_m. The ratio $\mathfrak{R}$ of the quantity of hot water to the quantity of cold water required to yield a mixture of the required temperature is given by

$$\mathcal{R} = \frac{t_m - t_c}{t_h - t_m} \tag{14.1}$$

The temperatures are expressed in degrees Fahrenheit (degrees Celsius), and the quantities of water are expressed in gallons (liters).

EXAMPLE If t_h = 200°F (93.3°C), t_c = 40°F (4.4°C), and t_m = 170°F (76.7°C), then the ratio between the quantities of hot and cold water that is required to yield the mixture temperature is 4.3. Therefore, 4.3 gal of hot water at temperature t_h is required to heat 1 gal of cold water at temperature t_c to mixed temperature t_m; correspondingly, 4.3 L of hot water is required to heat 1 L of cold water.

PROCEDURE FOR DESIGNING A HOT-WATER SUPPLY SYSTEM

Step 1. (*a*) Determine the type of fuel and the type of heating equipment to be used for the system.
(*b*) Determine whether the local water must be pretreated and, if so, by what method.

Step 2. (*a*) Determine the quantity of the hot water that must be supplied per minute; i.e., determine the required heating capacity.
(*b*) Determine the usable storage capacity of the hot-water storage tank that will be required.

Step 3. Determine the actual capacity of the storage tank that will be required. Since only about 70 percent of the actual capacity of a hot-water storage tank is usable, to obtain the actual size that is required, divide the usable heat capacity (obtained in Step 2*b*) by 0.7.

Step 4. Determine (*a*) the location of the water heating system within the building and (*b*) any space constraints that may affect equipment election.

Step 5. Determine whether there are any specialized hot-water requirements related to user population and types of occupancy.

Step 6. Select the type of fuel to be used in heating—on the basis of fuel cost, availability, municipal ordinances, convenience, and building restrictions.

Step 7. Select heating equipment, components, and auxiliary equipment.
(*a*) Determine the number of degrees of temperature rise ΔT that is required. This is equal to the difference between the temperature of the water that leaves the heater, t_h, and the temperature of the water that enters the heater, t_c.
(*b*) Determine the rate R at which heat must be supplied in British thermal units per hour (megajoules per hour) in order to provide a temperature rise of ΔT (from Step 7*a*) for the heating capacity in gallons per hour (liters per second) in Step 2*a*:

$$R\ (\text{Btu/h}) = (\text{heating capacity in gal/min}) \times 60\ \text{min/h} \times (\Delta T\ \text{in °F}) \times 8.3\ \text{lb/gal} \times 1\ \text{Btu/(lb} \cdot \text{°F)}$$

or

$$R\ (\text{MJ/h}) = (\text{heating capacity in L/s}) \times 3600\ \text{s/h} \times (\Delta T\ \text{in °C}) \times 1\ \text{kg/L} \times 2324\ \text{J/(kg} \cdot \text{°C)}$$

Step 8. Select the hot-water distribution system and piping.
Step 9. Determine the required capacity of the hot-water circulation pump. The circulation pump must overcome the pressure drop resulting from frictional losses through the heaters in addition to the friction losses through the piping, fittings, and accessories. It must circulate the water through the heater at a rate that will provide an appropriate temperature rise.
Step 10. Prepare a flow diagram of the system. A *flow diagram* of the overall system, such as the one shown in Fig. 14.14, incorporates all the various items of equipment, piping, and accessories; it provides a visual check of the system, helping to ensure that the components are located correctly and that none have been omitted.
Step 11. Size the components of the system; check the system design to ensure that it is in compliance with local and national codes and with energy conservation measures; check the system design to ensure that it conforms with architectural constraints.
Step 12. Recheck the design.

EXAMPLE 14.3 For an office building containing 250 people and a restaurant serving 150 meals per hour, determine the quality and quantity of hot water required.

Step 1. The quality of the hot water to be supplied is *potable*. The local water has 140 grains of hardness and contains iron that discolors it. Therefore, the water must be pretreated by one of the methods described in Chap. 1 (see "Water Softening" and "Filtration").
Step 2. Assume that a minimum heating capacity is required. Since there are two types of occupancy (office and cafeteria), calculate the requirements for each and combine the results as follows.

From Fig. 14.12*b*, the minimum heating capacity for an office building is 0.1 gal/h per person (0.38 L/h per person). Therefore, for 250 people, the required flow is 250 persons × 0.1 gal/h per person (0.38 L/h per person) = 25 gal/h (95 L/h).

The required usable storage capacity (for minimum heating capacity), obtained from Fig. 14.12*b*, is 1.6 gal/person (6.1 L/person). Therefore, for 250 persons, the required storage capacity is 250 × 1.6 gal/person (6.1 L/person) = 400 gal (1514 L).

To determine the required heating capacity for the cafeteria, use Fig. 14.12*a*. The required heating capacity is 0.25 gal/h (0.94 L/h) for serving the maximum number of meals per hour. Therefore, 150 meals × 0.25 gal/h per meal (0.94 L/h per meal) = 37.5 gal/h (142 L/h). The required usable storage capacity (for minimum heating capacity), obtained from Fig. 14.12, is 1.7 gal (6.4 L) × 150 meals per hour = 255 gal (965 L).

	Required heating capacity	Usable storage
Office	25 gal/h (95 L/h)	400 gal (1515 L)
Cafeteria	37.5 gal/h (142 L/h)	255 gal (965 L)
Total	62.5 gal/h (237 L/h)	655 gal (2480 L)

Step 3. The size of the storage tank needed is equal to the usable storage capacity divided by 0.7, since only about 70 percent of the capacity is usable. Therefore, the size of the storage tank needed is

$$655 \text{ gal } (2480 \text{ L}) + 0.7 = 935 \text{ gal } (3540 \text{ L})$$

Step 4. There are no particular constraints that affect this installation.

Step 5. There are no specialized hot-water requirements other than those already considered.

Step 6. The most economic fuel in this region is natural gas, which provides 1000 Btu/ft^3 (37.26 MJ/m^3). Therefore, a gas-fired water heater will be used.

Step 7. The temperature of the water entering the heater, t_c, is 40°F (4.4°C); the temperature of the water leaving the heater is 140°F (60°C). Therefore, there is a temperature rise ΔT of 100°F (55.6°C). Thus the heater must supply 62.5 gpm (4 L/s) × 8.3 lb/gal (1 kg/L) × 60 min/h × 100°F (55.6°C) temperature rise × 1 Btu/lb (2324 J/kg) = heater output of 3,110,000 Btu/h (911 kW or 3278 MJ/h).

$$\text{Gas energy input} = \frac{\text{heater energy output}}{\text{gas burner efficiency}}$$

$$= \frac{3{,}110{,}000 \text{ Btu/h } (3278 \text{ MJ/h})}{0.80} = 3{,}890{,}000 \text{ Btu/h } (4100 \text{ MJ/h})$$

Therefore, the natural gas must be supplied to the heater at a rate of approximately 3,900,000 Btu/h (4,100 MJ/h or 1140 kW).

Instead of selecting a single gas-fired heater which has this capacity, it is better to select three gas-fired heaters, each having an input of 1,300,000 Btu/h (1370 MJ/h). The three heaters will be required only at maximum demand or peak operating periods. During the remaining time, only one or two heaters will be operated, so there is an appreciable energy savings as well as a reduction in wear and tear on the heater units. Having three units also provides the possibility of continued hot-water supply in case one unit requires maintenance or servicing.

Step 8. Since the water is not especially corrosive, type L copper represents a good choice for the hot-water supply piping system. Fittings of wrought copper or cast brass are selected. The copper tubing for hot-water recirculation (in other than small residential systems) should have a minimum nominal diameter of ¾ in (1.9 cm), and the circulation pump should have a nominal diameter of not less than ½ in (1.3 cm).

Step 9. A circulation pump must circulate water through the heaters so as to provide a temperature rise ΔT of 60°F (33°C). Since the total heating capacity of the heaters is 3,100,000 Btu/h (3278 MJ/h), if a single pump is used, its capacity in gallons per minute must be

$$\text{Capacity} = \frac{\text{output, Btu/h}}{\text{lb/gal} \times \text{min/h} \times \Delta T} \quad \text{gpm (60 L/s)} \tag{14.2}$$

$$= \frac{3{,}100{,}000}{8.3 \times 60 \times 60} = 104 \text{ gpm (6.6 L/s)}$$

Step 10. Prepare a flow diagram, similar to Fig. 14.14, showing the arrangement of all components as discussed earlier.

Step 11. Size the piping according to the methods described in Chap. 7.

Step 12. Recheck all assumptions, calculations, and steps.

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CHAPTER 15

FIRE SPRINKLER AND STANDPIPE SYSTEMS

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INTRODUCTION

A *fire suppression system* is a system used to control or to extinguish a fire in a building. Fire suppression systems are especially important because their purpose is to protect both life and property. The most common types of fire suppression systems are fire sprinkler systems and standpipe systems, but other types are also available. Such systems are described in this chapter. Fire detection and alarm systems are described in Chap. 38.

COMPONENTS OF A FIRE SUPPRESSION SYSTEM

A *fire sprinkler system* is an integrated system of underground and overhead piping, with one or more automatic water supplies, to which fire sprinklers are attached in a systematic pattern. A *fire sprinkler* is a nozzle which distributes water in a specific spray pattern. An *automatic sprinkler* is a fire sprinkler with a normally closed nozzle which can be individually opened by heat, by either melting a fusible element or rupturing a liquid-filled glass bulb. An *open sprinkler* is a fire sprinkler with a normally open nozzle. All fire sprinklers are designed to distribute water in such a way as to extinguish or control a fire. A fire sprinkler system containing automatic sprinklers is also called an *automatic sprinkler system*, which, because it reacts to fire without the need for human intervention, is considered a type of *automatic fire suppression system*. A *main* is a principal artery of a system of continuous piping to which branch lines are connected. A *branch* line is a part of the piping system to which fire sprinklers are connected. A *riser* is a water main which extends vertically one full story or more to convey water to individual floor mains and branch lines.

A *standpipe* is a pipe (usually vertical) used for the storage and distribution of water for fire extinguishing; it is generally considered to be a single vertical riser within a standpipe system, although some installations (such as shopping malls) are commonly equipped with standpipe systems which include mostly horizontal piping. A *standpipe system* is an arrangement of piping, valves, and hose connections installed in such a manner that water can be discharged through attached hose and nozzles for the purpose of extinguishing a fire. The water is discharged in streams or spray patterns. Each outlet is generally provided with a *hose valve* (i.e., a shutoff valve controlling the outlet) and a *hose connection* (i.e., a fitting permitting the connection of a fire hose).

INSTALLATION INCENTIVES

The installation of fire sprinkler systems, standpipe systems, and related fire suppression systems is generally recommended by insurance authorities, and in many cases is mandated by building codes or fire codes.

Fire Insurance

The insurance industry is historically responsible for the development and growth of the fire suppression systems industry. Fire sprinkler and standpipe systems were found to play a major role in limiting property losses due to fire in the nineteenth century, beginning with the use of perforated pipe systems in New England mills. Fire sprinkler protection has been credited with reducing the cost of fire insurance for industrial properties by a factor of 10 over the past century.

Codes and Ordinances

The better a building is protected from fire, the safer the building tends to be. The record of fire sprinkler system protection in particular is noteworthy—records indicate that there has never been a multiple loss of life of building occupants to fire in a building with a properly functioning fire sprinkler system. When confronted with the need to prevent fires that would result in large losses, states and cities have enacted building codes requiring the installation of fire suppression systems. For new construction, the installation of fire sprinkler systems is commonly mandated by building codes for buildings which, because of a combination of construction and occupancy characteristics, present a hazard which must be mitigated. Standpipe systems are generally required in large or tall buildings in which the fire must be fought internally rather than from the exterior.

Codes have also encouraged the installation of fire sprinkler systems on a voluntary basis through the use of construction alternatives or "sprinkler tradeoffs," i.e., concessions permitting other traditional fire protection measures to be reduced if sprinkler systems are installed. These alternatives (for example, reductions in the required fire resistance rating of building components or increases in travel distances to the nearest fire exits) are justified on the basis of the ability of an automatic fire suppression system to make up for other fire protection deficiencies, thereby maintaining or increasing the overall level of fire safety. A wide variety of state and local ordinances supplement building codes that require fire sprinkler systems in many new and existing buildings. In many communities, fire sprinkler systems are required by law in single-family dwellings.

INSTALLATION STANDARDS

The design and installation of fire sprinkler and standpipe systems is usually carried out in conformity with the following basic standards promulgated by the National Fire Protection Association: Standards NFPA 13 (*Installation of Sprinkler Systems*) and NFPA 14 (*Installation of Standpipe Systems*).[1] Standard NFPA 13, in turn, makes reference to other fire sprinkler standards dealing with the protection of special hazards or occupancies (such as high-piled storage warehouses and aircraft hangars) and single-family dwellings.

The use of both NFPA 13 and NFPA 14 usually is mandated by the applicable building code. Some codes, however, include specific exceptions or supplementary requirements to the NFPA standards.

For both sprinkler and standpipe systems, a number of different system types can be identified according to characteristic functions and applications.

TYPES OF FIRE SPRINKLER SYSTEMS

Wet-Pipe Sprinkler Systems

A *wet-pipe sprinkler system*, illustrated in Fig. 15.1, is the most common of four basic types of fire sprinkler systems. It consists of a network of pipes containing

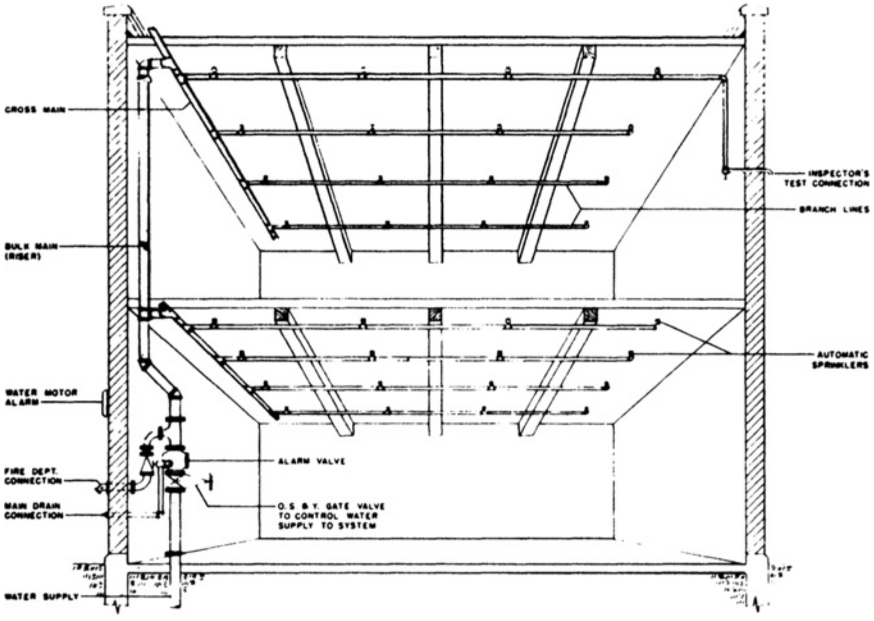


FIG. 15.1 A typical wet-pipe sprinkler system.

water under pressure. Automatic sprinklers are connected to the piping such that each sprinkler protects an assigned area of coverage. Heat applied to any sprinkler causes that single sprinkler to operate, permitting water to discharge over its area of coverage.

Dry-Pipe Sprinkler Systems

A *dry-pipe sprinkler system*, illustrated in Fig. 15.2, is the second most common basic type of fire sprinkler system. It is similar to a wet-pipe sprinkler system except that water is held back from the piping network by a special dry-pipe valve. Under normal conditions, pressurized air or nitrogen within the system keeps the dry-pipe valve closed. The operation of one or more automatic sprinklers will allow the air pressure to escape, causing the dry-pipe valve to open, which then permits water to flow into the piping to suppress the fire. Dry-pipe sprinkler systems are used where there is a danger of freezing the water in the piping. They are also used where noise isolation is considered especially important. This is because vibration and solidborne noise can be transmitted by the water in a wet-pipe sprinkler system.

Deluge Sprinkler Systems

A *deluge sprinkler system*, illustrated in Fig. 15.3, is a type of fire sprinkler system that uses open sprinklers. A special deluge valve holds back the water from

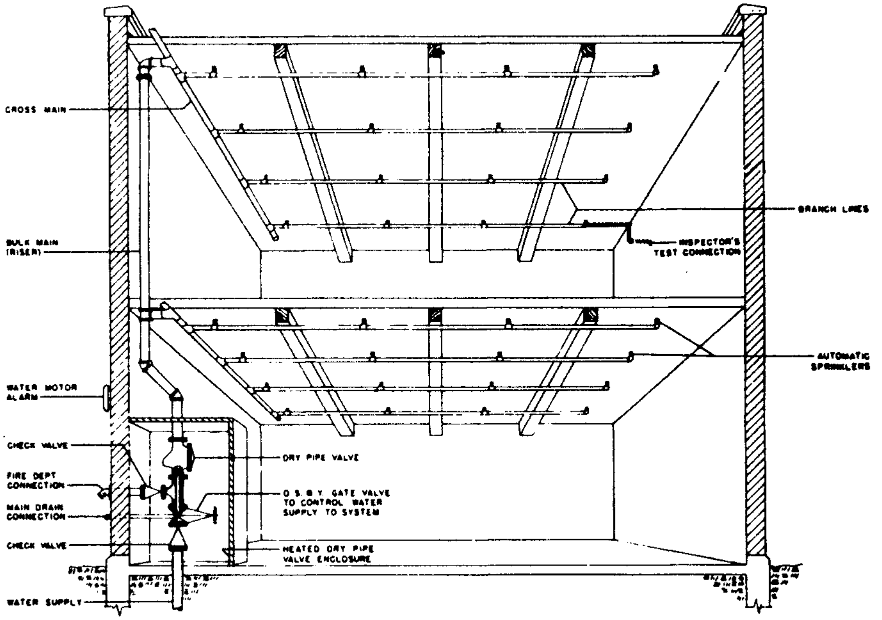


FIG. 15.2 A typical dry-pipe sprinkler system.

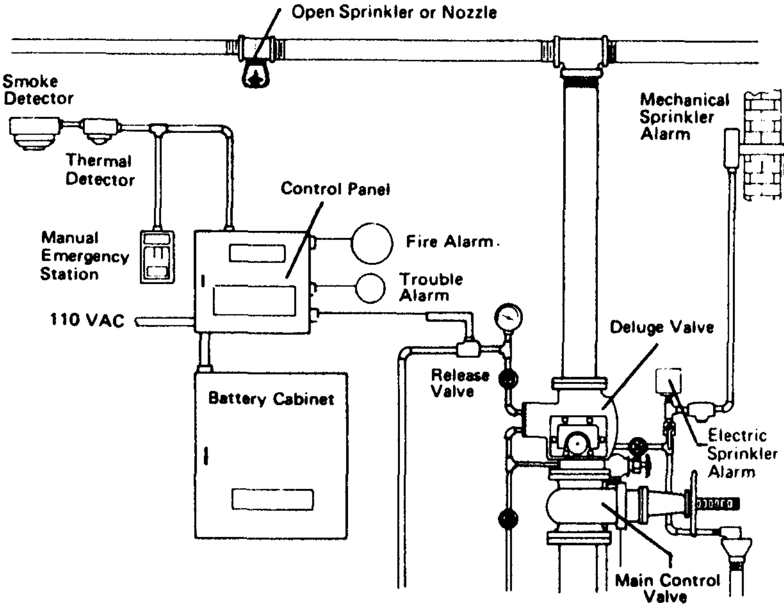


FIG. 15.3 A typical deluge sprinkler system.

the piping under normal conditions, and a separate fire detection system is used to activate the system under fire conditions. The fire detection system opens the deluge valve, which then admits water into the piping network, and water flows simultaneously from all of the open sprinklers. Deluge sprinkler systems are used for protection against rapidly spreading high-hazard fires.

Preaction Sprinkler Systems

A *preaction sprinkler system*, illustrated in Fig. 15.4, is similar to a deluge sprinkler system except that automatic sprinklers are used, rather than open sprinklers. There is no water in the piping under ordinary circumstances. A small air pressure is usually maintained in the piping network as a check on whether the piping system remains watertight; a decrease in air pressure is an indication of a leak. As with a deluge system, a separate fire detection system is used to activate a deluge valve, admitting water to the piping. Because automatic sprinklers are used, however, the flow of water from the system does not take place unless heat from the fire has also activated one or more sprinklers. Preaction sprinkler systems are generally used where there is special concern that accidental discharge of water may cause considerable damage to the area being protected.

Antifreeze Sprinkler Systems

An *antifreeze sprinkler system* is similar to a wet-pipe sprinkler system except that the piping contains an antifreeze solution instead of water. These systems are used as an alternative to dry-pipe sprinkler systems only for small systems or

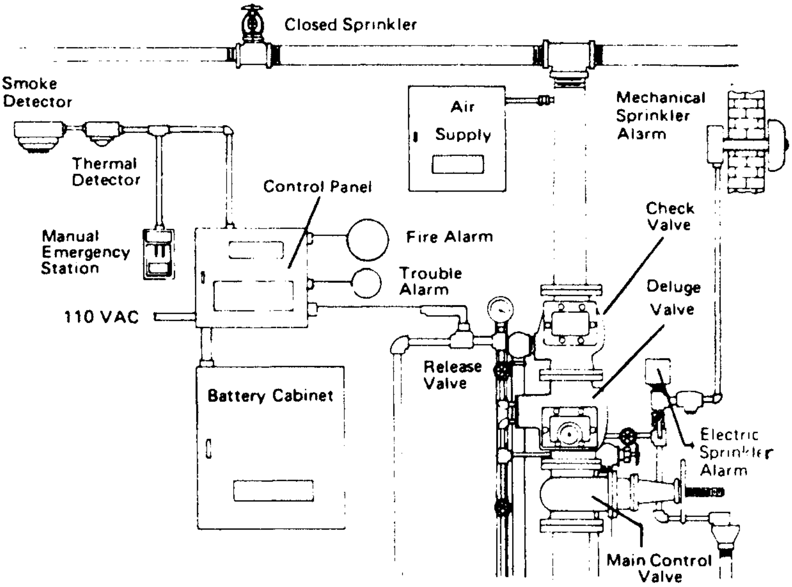


FIG. 15.4 A typical preaction sprinkler system.

parts of systems. Such systems are used where water in a wet-pipe sprinkler system would be subject to freezing, as in an extension of a wet-pipe system into an unheated loading dock area. Only specific types of antifreeze solutions are permitted by NFPA 13. Great care must be taken regarding the interface of the antifreeze system and public water supplies to avoid a cross-connection, as discussed in Chap. 13. The antifreeze solutions permitted by the standard are heavier than water, and a special "antifreeze loop" configuration of piping is used to add antifreeze to the system and to test the antifreeze solution.

Multipurpose Piping Sprinkler Systems

A *multipurpose piping sprinkler system* is a system in which the piping serves a non-fire-protection purpose in addition to serving the fire sprinkler system. Standard NFPA 13 permits such systems only in accordance with special rules. These include a requirement that the system be a "closed system," with no water used for domestic or other purposes, and that the water supply path to every fire sprinkler on the system be direct, without flowing through auxiliary equipment. In the most common type of multipurpose sprinkler system, the piping in the system is used to circulate the water within a building for a series of water-source heat pumps.

Exposure Protection Systems

An *exposure protection system* is a sprinkler system which protects the exterior of a building or object from the hazard of exposure to an adjacent fire. Such systems usually employ open sprinklers, although some use automatic sprinklers. If open sprinklers are used, the systems are activated either manually or by a separate fire detection system as in a deluge sprinkler system.

Residential Sprinkler Systems

A *residential sprinkler system* is a type of wet-pipe sprinkler system which employs *residential sprinklers* (i.e., a type of automatic sprinkler with special response and distribution characteristics). Residential sprinklers (originally developed for the protection of single-family dwellings) are designed to use a small amount of water to its greatest effectiveness against a growing fire so as to maintain life safety in the room of fire origin. As compared with standard automatic sprinklers, residential sprinklers respond faster to fires, and they direct more of their water spray to the periphery of their area of coverage.

Large-Drop Sprinkler Systems

A *large-drop sprinkler system* is a type of wet-pipe or preaction sprinkler system which employs *large-drop sprinklers*; such automatic sprinklers have the special ability of producing large water droplets in their water sprays. The large droplets are capable of penetrating high-velocity fire plumes, making large-drop sprinkler systems effective against fires in highly combustible high-piled storage.

Early-Suppression–Fast-Response (ESFR) Sprinkler Systems

An *early-suppression–fast-response (ESFR) sprinkler system* is a type of wet-pipe sprinkler system employing *ESFR sprinklers*, which are a type of automatic sprinkler with high thermal sensitivity and fire plume penetration abilities. Unlike the large-drop sprinkler, the ESFR sprinkler utilizes the velocity of the spray particles to help penetrate high-velocity fire plumes and also uses the fast-response features of a residential sprinkler. In combination, the fast-response and plume penetration abilities of the ESFR sprinkler system allow it to be used very effectively against fires in high-piled storage and similar occupancies where fire protection is difficult.

OCCUPANCY HAZARD CLASSIFICATIONS

A fire sprinkler system is not designed on the basis of the expected frequency of fires in a building. Instead, the design is based on the expected severity of a fire, should one occur. With the exception of the special residential systems, large-drop systems, and ESFR sprinkler systems, each of the above types of fire sprinkler systems can be designed to provide protection against a range of fire severities. This is recognized in a system of hazard classifications.

Methods of Hazard Classification

A *light-hazard sprinkler system* is a fire sprinkler system designed to handle fires in occupancies where the quantity and/or combustibility of contents is low and fires with relatively low rates of heat release are expected. Such occupancies typically include churches, school classrooms, hospitals, museums, nursing homes, offices, residential areas, library areas other than book stacks, restaurant seating areas, and unused attic spaces.

An *ordinary-hazard Group 1 system* is a fire sprinkler system designed to handle fires in occupancies where the quantity of combustibles is moderate, the combustibility of contents is low, stock piles of combustibles do not exceed 8 ft (2.4 m), and fires with moderate rates of heat release are expected. Such occupancies typically include automobile parking garages, bakeries, beverage and dairy manufacturing areas, canneries, electronic plants, laundries, and restaurant service areas.

An *ordinary-hazard Group 2 system* is a fire sprinkler system designed to handle fires in occupancies where the quantity of combustibles is moderate, the combustibility of contents is moderate, stock piles of combustibles do not exceed 12 ft (3.7 m), and fires with moderate rates of heat release are expected. Such occupancies typically include library stack room areas, mercantile occupancies, machine shops, print shops, textile manufacturing plants, and wood-product assembly plants.

An *ordinary-hazard Group 3 system* is a fire sprinkler system designed to handle fires in occupancies where the quantity and/or combustibility of contents is high, and fires with high rates of heat release are expected. Such occupancies typically include feed mills, paper and pulp mills, piers and wharves, repair garages, tire manufacturing areas, and warehouses other than those containing storage piled over 12 ft (3.7 m).

An *extra-hazard Group 1 system* is a fire sprinkler system designed to handle fires in occupancies where the quantity and combustibility of contents is very high and dust, lint, or other materials are present, introducing the likelihood of rapidly developing fires with high rates of heat release. Such occupancies typically include sawmills and areas used for die casting, metal extruding, manufacturing of plywood and particle board, rubber processing, and upholstering with plastic foams.

An *extra-hazard Group 2 system* is similar to an extra-hazard Group 1 system, except that (*a*) moderate to substantial amounts of flammable or combustible liquids are present or (*b*) the combustible material may be excessively shielded from the water spray of fire sprinklers. Such occupancies typically include areas used for flammable-liquid spraying, flow coating, open oil quenching, solvent cleaning, varnish and paint dipping, and mobile home manufacturing.

A *high-piled storage system* is a fire sprinkler system specifically designed to protect warehouse storage greater than 12 ft (3.7 m) in height. For the protection of high-piled storage, a different approach is used to determine protection requirements, involving classification according to the protected commodity. Basic commodity classifications are as follows:

> *Class I commodities* are noncombustible products on combustible pallets, in ordinary cartons, or in ordinary paper wrappings, with or without pallets.
>
> *Class II commodities* are noncombustible products in wood crates, solid wooden boxes, or multiple-thickness paperboard cartons, with or without pallets.
>
> *Class III commodities* are ordinary combustible materials containing little or no plastic.

Class IV commodities are products containing considerable amounts of plastic components or packaging.

Stored plastics are further classified as to type and form.

TYPES OF STANDPIPE SYSTEMS

Wet Standpipe Systems

A *wet standpipe system* is a standpipe system in which (*a*) the piping is filled with water and (*b*) water pressure is maintained in the system at all times by the water supply. This is the most common type of standpipe system.

Dry Standpipe Systems

A *dry standpipe system* is a standpipe system in which the piping is *not* normally filled with water. There are several different possible arrangements of a dry standpipe system.

One type of dry standpipe system is similar to a dry-pipe sprinkler system, in which the piping contains air under pressure. Opening a hose valve permits the release of air pressure, allowing a dry-pipe valve to open, which in turn admits water into the standpipe system.

A second type of dry standpipe system uses a deluge valve to admit water to the standpipe system following manual operation of remote control devices located at each hose connection to the standpipe system.

Another type of dry standpipe system, sometimes referred to as a *fire department standpipe system*, is a standpipe system having no permanent water supply. Water must be supplied by the fire department by pumping water from street hydrants through the fire department connection.

A *dry filled standpipe* is a standpipe system which normally is filled with water through a small water supply connection. Since it has no permanent automatic water supply, however, this type of system is considered equivalent to the fire department standpipe system. Some building codes permit water from the fire sprinkler system to provide the water to fill a dry filled standpipe. The water in a dry filled standpipe system provides a supervisory function, verifying the integrity of the piping against leaks.

Combined Fire Sprinkler–Standpipe Systems

The fire sprinkler and standpipe system installation standards NFPA 13 and NFPA 14 permit the use of a single *combined riser* to supply both fire sprinkler system mains and standpipe system outlets. In a building with complete fire sprinkler protection, the water supply requirement is generally the same as the larger of (*a*) fire sprinkler demand or (*b*) standpipe system demand. Typically the standpipe system demand is greater. In a building with only partial fire sprinkler system protection, the water supply requirement is generally greater than for the standpipe system alone because water may flow in the partial fire sprinkler system, even though it is not helping to provide protection in the area of the fire.

Specific rules regarding combined water supply requirements are contained in NFPA 14.

STANDPIPE SYSTEM CLASSES OF SERVICE

The *class of service* of a standpipe system depends on the intended user of the system during a fire. The intended use determines the system design requirements for the various classes of service:

> *Class I service* is intended for use by the fire department or trained fire brigades. This class of service provides 2½-in (6.5-cm) hose outlets fed from large risers, with water supplies arranged so that two hose streams can be fed simultaneously from a single riser, each provided with 250 gpm (15.8 L/s) at a minimum flowing pressure of 65 psi (448 kPa).
>
> *Class II service* is intended for use by untrained building occupants. This class of service provides 1½-in (4-cm) outlets with attached hose, usually in hose cabinets. In general, 100 ft (30.5 m) of hose is attached to each outlet, with hose stations located so that all building areas can be reached by the hose with a 30-ft (9.1-m) trajectory. A 100-gpm (6.3-L/s) supply is provided at a minimum flowing pressure of 65 psi (448 kPa). If approved by the authority having jurisdiction, hose as small as 1 in (2.5 cm) may be used in light-hazard occupancies.
>
> *Class III service* is a combination of Class I and II service and is intended for both building occupants and the fire department. This class of service provides separate 2½-in (6.5-cm) and 1½-in (4-cm) outlets, although it is permissible to provide a 2½-in (6.5-cm) outlet with a 1½-in (4-cm) adapter. Water supply requirements are the same as for Class I systems. The same type of hose is provided as for a Class II system, although in buildings equipped throughout with a fire sprinkler system, the requirement for hose and hose cabinets is generally waived.

TYPICAL FIRE SPRINKLER SYSTEM CONNECTIONS

Alarms

Standard NFPA 13 requires local water flow alarms on all fire sprinkler systems having more than 20 fire sprinklers. Such an alarm is intended to provide notice that one or more fire sprinklers has actuated. While not an evacuation alarm, it indicates that water is flowing and appropriate action should be taken. On small wet-pipe sprinkler systems, the alarm is usually initiated by an *alarm check valve* in the system riser; this is a valve that is a combination alarm device and check (one-way-flow) valve. The alarm check valve contains a main sealing element (termed a *clapper*) that permits flow only in the downstream direction. When flow takes place through the valve, the clapper lifts off its seat, permitting a small amount of water to flow through alarm ports toward an electric alarm switch or mechanical water-activated alarm gong. When flow ceases, the clapper returns to its seat, preventing the alarm from continuing to sound. A *retard chamber*, a hollow container, is placed in the line between the alarm ports and the alarms to collect and drain away intermittent water flow caused by surges in pressure of the water supply system.

For large wet-pipe sprinkler systems such as those in high-rise buildings, alarm annunciation is usually provided on a floor-by-floor basis, with paddle-type water flow switches called *water-flow indicators*.

For dry-pipe sprinkler systems, a *dry-pipe valve* is used to initiate an alarm in the same way as an alarm check valve. Most dry-pipe valves are of the *differential type*, which permit the air within a system to hold back a water supply, even though the pressure of the water is 6 times greater than that of the air. In this type of valve, the clapper latches open when it lifts off its seat. This prevents the buildup of water above the clapper, which could freeze in the piping. The latching of the clapper also prevents an action known as *water columning*, in which the pressure resulting from a column of water above the clapper holds the clapper in the closed position, thereby preventing the system from functioning properly.

Test Connections

Each sprinkler system must be provided with an inspector's test connection which simulates the opening of a single fire sprinkler. A nozzle from a fire sprinkler is generally controlled by a valve at an accessible remote point in the topmost story. In addition, for multistory buildings where water flow alarms are provided on each floor, a test connection must be provided for each alarm device.

In general, drains are also used as test connections, permitting the carrying out of flow tests to ensure that water supplies and connections are in proper order.

Drain Connections

In order to permit system repairs and alterations, each sprinkler system must be provided with a main system drain, located on the system side (downstream side) of the system control valve. The following minimum sizes of the main drain (as well as any sectional drains provided) are based on the size of the riser or main feeding the fire sprinkler system or section of the system:

Riser or main size	Minimum drain size
2 in (5 cm) or smaller	¾ in (2 cm)
2½ to 3½ in (6.5 to 9 cm)	1¼ in (3 cm)
4 in (10 cm) or larger	2 in (5 cm)

Fire Department Sprinkler Connections

A *fire department connection*, such as the one illustrated in Fig. 15.5, is a device, mounted close to the ground on the exterior wall of a building, which provides inlet connections for fire hoses to help supply the interior sprinkler system. Fig-

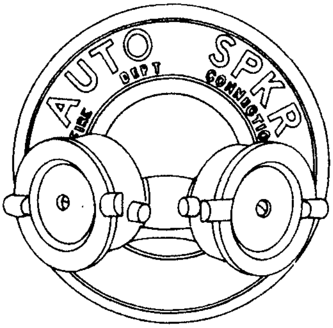


FIG. 15.5 A fire department connection for a sprinkler system. A wye connection, called a *siamese connection*, is illustrated.

ure 15.6 shows how it is joined to the sprinkler system. Such a connection is considered a desirable auxiliary supply, but not a primary or secondary water supply. Typically, the fire department connection is a wye with two inlets (called a *siamese connection*). Unless the authority having jurisdiction specifically permits omission of the fire department connection, it must be provided on any system containing more than 20 fire sprinklers.

The location of the fire department connection on the fire sprinkler system can vary. On a single-riser wet-pipe system, it is generally positioned on the system side (downstream) of the control and alarm valve. On a single-riser dry-pipe system, it is positioned on the system side of the control valve, but on the supply side (upstream) of the dry-pipe valve. On a multiple-riser system, the fire department connection is located on the supply side of the individual riser control valves, but on the system side of the main water supply control valves. A single fire department connection can serve multiple risers. Some building codes contain specific requirements for location of fire department connections with regard to street frontages.

Figure 15.7 shows typical riser and fire department connection arrangements.

Hose Connections

A hose 1½ in (4 cm) in diameter may be attached to fire sprinkler system piping as an aid in fire fighting. Such hose connections are not considered part of a

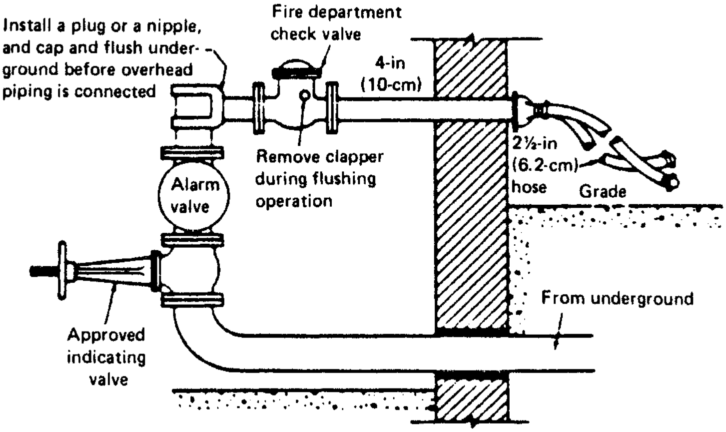


FIG. 15.6 A fire department connection joined to the sprinkler system also is used to flush underground piping. Water may be discharged through the open end of a 4-in pipe or through a Y or siamese connection with the hose as shown. *(Courtesy of NFPA.[2])*

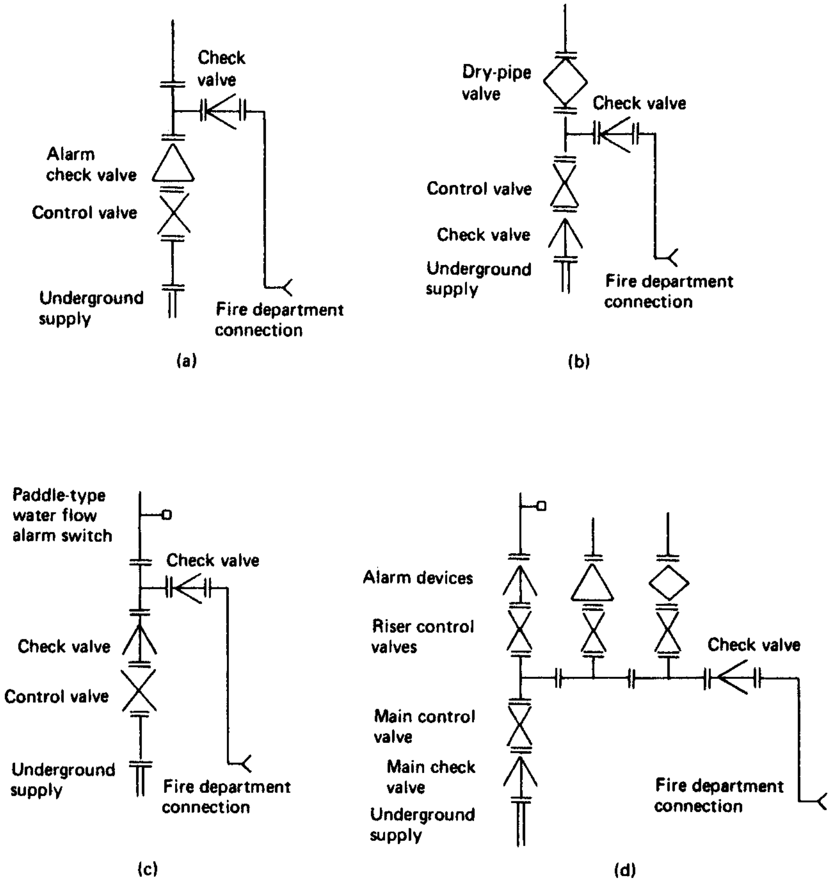


FIG. 15.7 Typical riser and fire department connection arrangements. (*a*) A single riser with an alarm check valve. (*b*) A single riser with a dry-pipe valve. (*c*) A single riser with a water-flow alarm. (*d*) A multiple riser system. The main control valve is optional.

standpipe system, and they differ from standpipe system hose connections both in the size of hose valve inlets and in the water supply requirements. The water demand for such a hose must be added to the fire sprinkler system demand; the added demand is 50 gpm (3.15 L/s) per hose station for up to two hose stations, at the flowing pressure available to the sprinkler system.

Supervisory Devices

A fire sprinkler system *supervisory device* is a device that signals abnormal conditions which could render protection inoperative or ineffective. While water flow alarms provide warning of the actual occurrence of fire or other trouble conditions such as broken piping, supervisory devices guard against the following types of conditions:

- Closed water supply control valves
- Low water levels in water supply tanks
- Low temperatures of water in storage tanks or ground level reservoirs
- Low or high water levels in pressure tanks
- Low or high air pressures in pressure tanks
- Low or high air pressures in dry-pipe sprinkler systems
- Outage of the electric power to the pumps
- Inappropriate pump operation
- Failure of fire detection system for activation of deluge or preaction sprinkler system

The most common type of supervisory device is the ***tamper switch***, i.e., an electric switch mounted directly on a fire sprinkler system main water control valve. Turning the valve wheel or handle from the open position closes the switch and results in a signal.

Pressure-Regulating Devices

A *pressure-regulating device*, i.e., a device that limits pressure under both flow and no-flow conditions (described in Chap. 4), is required at each outlet for portions of sprinkler systems where it is probable that the water pressure may exceed 175 psi (11,400 kPa). Pressure gages are required on both the inlet and outlet sides of the device. A relief valve not less than ½ in (1.2 cm) is required on the discharge side.

TYPICAL STANDPIPE SYSTEM CONNECTIONS

Fire Department Standpipe Connections

The rules governing the use of fire department connections for a standpipe system are similar to the rules for fire sprinkler systems. One or more fire department connections are required for each Class I or Class III service standpipe system. Class II service standpipe systems do not require fire department connections.

Fire Hose and Fire Hose Racks

Each fire hose connection provided for occupant use (Class II and Class III service) must be equipped with not more than 100 ft (30.5 m) of lined, collapsible or noncollapsible 1½-in (4-cm) fire hose. Various types of hose connections are illustrated in Fig. 15.8. Hose smaller than 1½ in (4 cm) used for Class II service must be noncollapsible. All 1½-in (4-cm) hose must be equipped with a rack or

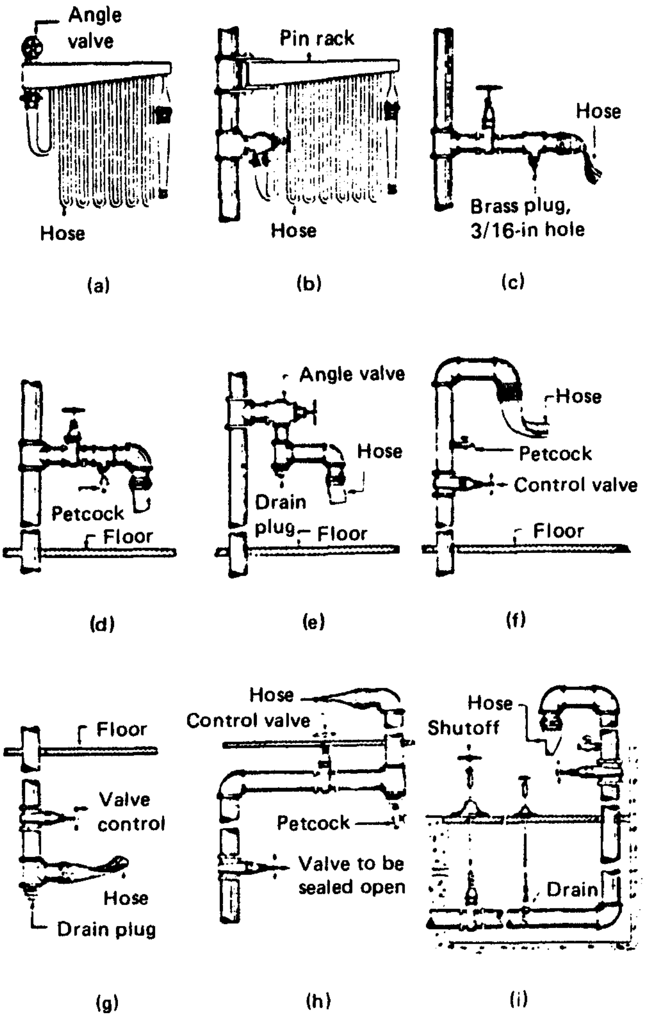


FIG. 15.8 Various types of hose connections. (*a*) Angle globe valve, pin rack or valve nipple, no drip; (*b*) angle globe valve, without drip, pin rack fastened to riser; (*c*) gate valve and drip; (*d*) same as *c* with downturned outlet; (*e*) angle valve with drain; (*f*) connection for top story; (*g*) connection for basement; (*h*) roof connection valve in heated story; (*i*) valve control for unheated buildings. (*Courtesy of NFPA.*[2])

some other approved storage facility. If smaller hose is provided, a continuous-flow reel must be used to store the hose.

Combined Fire Sprinkler–Standpipe Systems

In combined fire sprinkler–standpipe systems, when the building is protected throughout with fire sprinklers, standard NFPA 14 permits omission of the 1½-in

(4-cm) hose for use by building occupants, subject to the approval of the authority having jurisdiction. If the hose is omitted, each standpipe outlet must be equipped with a 2½-in (6-cm) hose valve with a 2½- × 1½-in (6- × 4-cm) reducer, and a cap with attachment chain.

Pressure-Reducing Devices

Pressure-reducing devices are required where flowing pressures at any hose valve outlet exceed 100 psi (690 kPa). For pressures just above this level, disks with restricting orifices are often used for this purpose. Where system pressures exceed 150 psi (1035 kPa), a warning sign is required at each such outlet. Where system pressures exceed 175 psi (1200 kPa), a *pressure-regulating device*, a device which limits pressure under both flow and no-flow conditions (described in Chap. 4), is required to be installed at each hose valve outlet. The device is required to limit pressure at the hose valve outlet to a pressure not exceeding 100 psi (690 kPa).

FIRE SPRINKLER SYSTEM DESIGN CRITERIA

Types of Sprinklers

Many types of sprinklers are available, including those which are used for specialized hazards (residential, large-drop, and ESFR). These types may be classified according to special orientation, functional, decorative, and other characteristics, as shown in Table 15.1. They are described as follows and illustrated in Fig. 15.9.

TABLE 15.1 Classification of Types of Sprinklers

Orientation	Special types
Upright	Decorative:
Pendent	Ceiling:
Sidewall:	Recessed
Vertical sidewall	Flush
Horizontal sidewall	Concealed
Old-style (conventional)	Ornamental:
Intermediate (in-rack)	Plated
	Painted (factory-applied only)
Special function	Fast response:
Dry sprinklers:	Residential
Dry pendent	Quick response
Dry upright	ESFR
Corrosion-resistant	Large drop
	Extended coverage

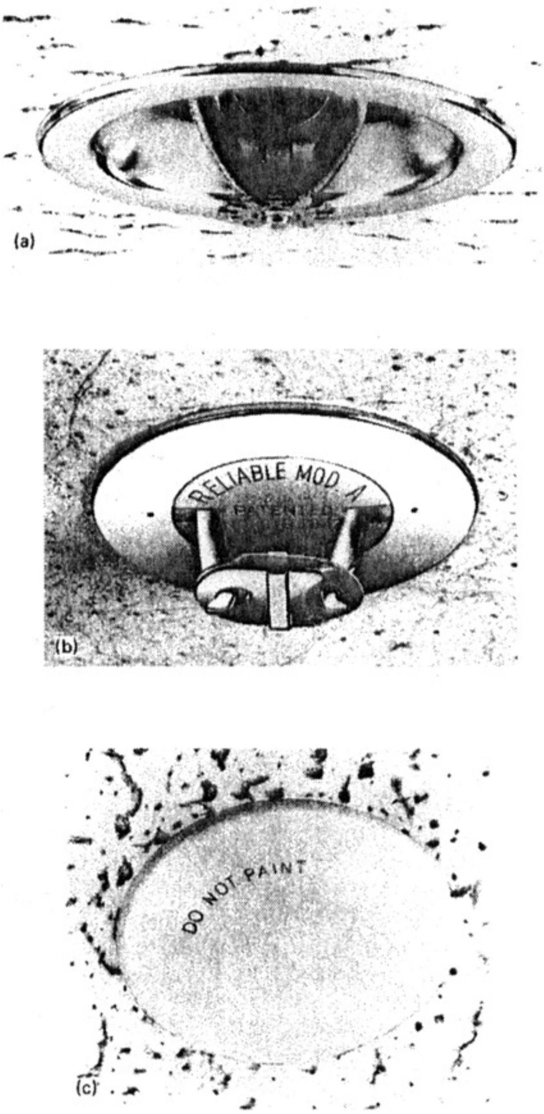


FIG. 15.9 Various types of sprinklers. (*a*) Ceiling—recessed; (*b*) ceiling—flush; (*c*) ceiling—concealed; (*d*) ceiling—concealed; (*e*) pendent—with in-rack shield; (*f*) horizontal sidewall; (*g*) vertical sidewall.

Ceiling sprinklers. Sprinklers of special design, intended for installation in ceilings. This type includes recessed, flush, and concealed sprinklers.

Concealed sprinklers. Recessed sprinklers with cover plates.

Corrosion-resistant sprinklers. Sprinklers intended to resist corrosive environments. They are provided with a special type of coating or plating.

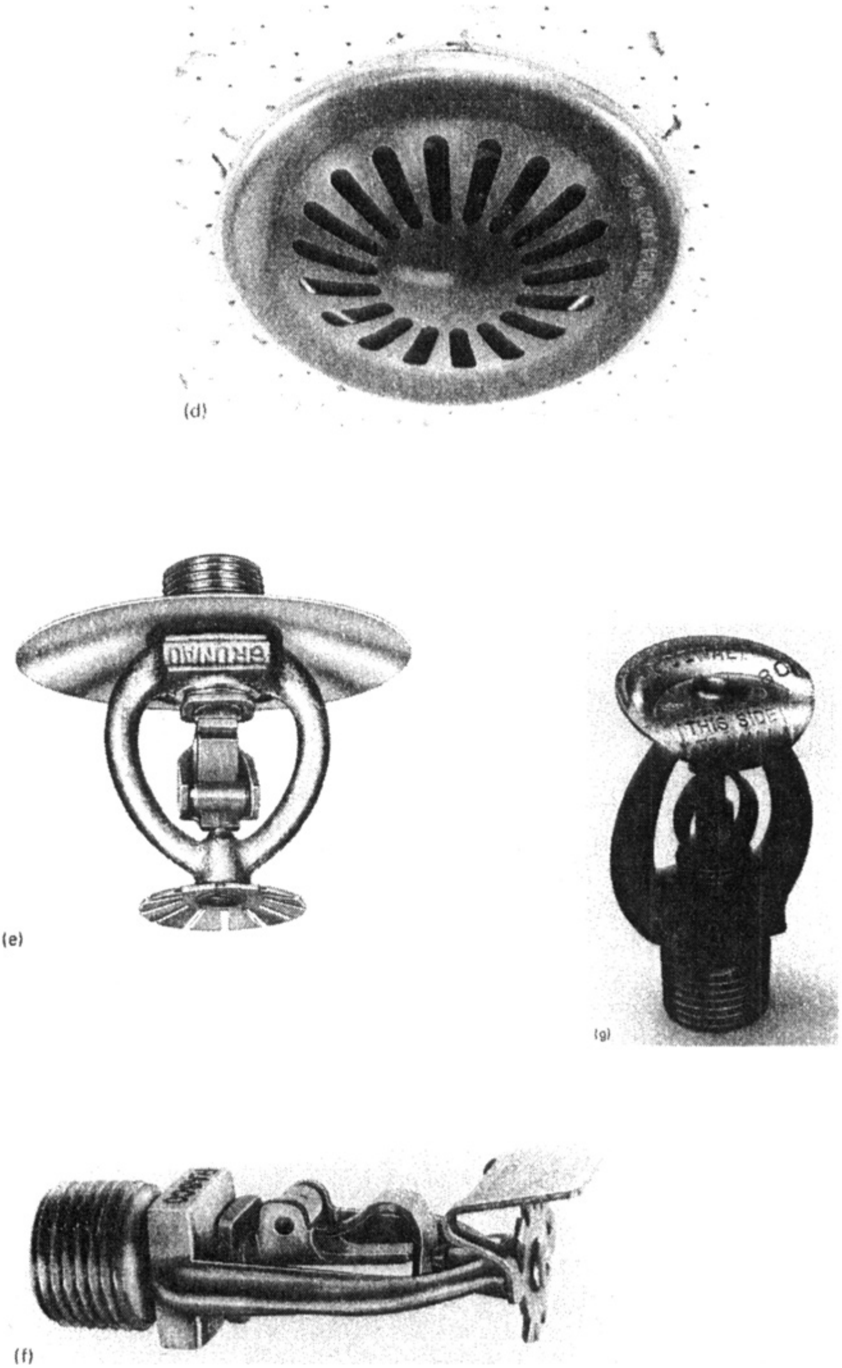


FIG. 15.9 *Continued.*

Decorative sprinklers. Sprinklers designed with ceiling aesthetics as a priority. This type includes ornamental and ceiling sprinklers.

Dry sprinklers. These are sealed assemblies consisting of a length of air-filled or nitrogen-filled pipe equipped with an automatic sprinkler. They are available as either dry upright or dry pendent sprinklers and are used to extend wet-pipe sprinkler systems into areas subject to freezing. They are also used if pendent sprinklers are required on a dry-pipe sprinkler system, since drops to ordinary pendent sprinklers cannot be drained readily following operation of the dry-pipe sprinkler system.

Horizontal sidewall sprinklers. These are sprinklers located on sidewalls in which the nozzle discharges in a horizontal direction against a deflector. (See "Sidewall sprinklers.")

Intermediate-level sprinklers (in-rack sprinklers). These sprinklers are of the pendent type or upright type, with shields attached. The shields are intended to protect the fusible-element or glass-bulb actuating elements of the fire sprinklers from the water spray of fire sprinklers located at higher elevations.

Old-style sprinklers (conventional sprinklers). This type of sprinkler was used in the U.S.A. prior to the 1950s and remains in common use in Europe. These sprinklers can generally be used either in an upright position or in a pendent position. The sprinklers commonly used in the U.S.A. are referred to in Europe as *spray sprinklers* because of their special umbrellalike spray pattern.

Ornamental sprinklers. Such sprinklers are painted or plated by the manufacturer.

Pendent sprinklers. Sprinklers of this type are designed to be installed below the piping, with the water stream directed downward against a *deflector,* which is a flat toothed disk that develops the sprinkler spray pattern.

Recessed sprinklers. These are pendent sprinklers that have been placed into cups recessed into the ceiling.

Sidewall sprinklers. Such sprinklers are designed to discharge a spray pattern resembling one-quarter of a sphere to protect the floor area beneath a fire sprinkler on a wall.

Upright sprinklers. This type of sprinkler is designed for installation above the piping and protects the floor area below the piping. The water from the nozzle is directed upward against a *deflector* and redirected onto the floor below.

Vertical sidewall sprinklers. These are sidewall sprinklers in which the nozzle discharges in a vertical (upward or downward) direction against a deflector. (See "Sidewall sprinklers.")

Extent of Coverage

In general, to comply with NFPA 13, all building areas must be provided with fire sprinkler protection, with the exception of the following areas:

- Noncombustible concealed spaces.
- Combustible concealed spaces formed by studs or joists with less than 6 in (15 cm) between the inside or near edges.
- Combustible concealed spaces formed by bar joists with less than 6 in (15 cm) between the roof or floor deck and ceiling.

- Combustible concealed spaces formed by ceilings attached directly to or within 6 in (15 cm) of the bottom of wood joists.
- Combustible concealed spaces formed by ceilings attached directly to the underside of composite wood joists.
- Combustible concealed spaces filled entirely with noncombustible insulation, or spaces filled with such insulation to the bottom edges of joists.
- Combustible concealed spaces over small rooms not exceeding 50 ft^2 (4.6 m^2) in area.
- Combustible concealed spaces in which all combustibles have a flame spread index less than 25 and the materials have been demonstrated not to propagate fire in the form in which they are installed in the space.
- Concealed spaces in which the only combustibles are insulation materials with a total heat content not exceeding 1000 Btu/ft^2 (11,356 kJ/m^2).
- Noncombustible stair shafts except at the top and under the bottom landing. (If the stair shaft serves more than one fire area, fire sprinklers are also required at each floor landing.)
- Spaces under exterior roofs and canopies not used for storage or handling of combustibles if less than 4 ft (1.2 m) wide or if of noncombustible construction.
- In hotels only, from small closets surfaced with noncombustible or limited-combustible materials, and from bathrooms not exceeding 55 ft^2 (5.1 m^2) with noncombustible plumbing fixtures and with noncombustible or limited-combustible wall and ceiling surface materials.
- In areas where the presence of substantial amounts of water-reactive materials or other substances would create a dangerous condition, or similar areas designated by the authority having jurisdiction.

Temperature Ratings

Each automatic sprinkler has a nominal temperature rating which indicates its approximate operating temperature. For design purposes, automatic sprinklers are assigned the following temperature classifications which regulate their use:

> *Ordinary-temperature sprinklers* are sprinklers rated between 135 and 170°F (57 and 77°C). They are intended for use in areas where the maximum ceiling temperature is not expected to exceed 100°F (38°C). Glass-bulb sprinklers of this temperature classification are identified by a red- or orange-colored liquid.
>
> *Intermediate-temperature sprinklers* are sprinklers rated between 175 and 225°F (79 and 107°C). They are intended for use in areas where the maximum ceiling temperature does not exceed 150°F (66°C). Glass-bulb sprinklers of this temperature classification are identified by a yellow- or green-colored liquid; fusible-element sprinklers are identified by a white frame color code. Individual sprinklers are required to be of intermediate temperature classification if in close proximity to heating ducts, under skylights, or in unventilated attics.
>
> *High-temperature sprinklers* are sprinklers rated between 250 and 300°F (121 and 149°C). They are intended for use in areas where the maximum ceiling temperature does not exceed 225°F (66°C). Glass-bulb sprinklers of this temperature classification are identified by a blue-colored liquid, and fusible-

element sprinklers are identified by a blue frame color code. Individual sprinklers are required to be of high-temperature classification if in close proximity to unit heaters or other sources of high heat.

Intermediate and high-temperature sprinklers are also permitted to be used throughout ordinary-hazard, extra-hazard, and most high-piled storage occupancies.

Higher temperature classifications of fire sprinklers are also available for special purposes, such as providing protection within exhaust ducts of commercial cooking equipment.

Spacing and Positioning of Fire Sprinklers

Standard NFPA 13 contains detailed rules regarding spacing and positioning requirements for fire sprinklers. The two most important factors in sprinkler spacing are hazard classification and type of ceiling construction. Maximum allowable coverage area per sprinkler varies between 90 ft^2 (8.4 m^2) for pipe-schedule extra-hazard systems and 400 ft^2 (37.2 m^2) for special-listed extended-coverage sprinklers. The maximum distance permitted between adjacent sprinklers is generally 15 ft (4.6 m), although this varies from 12 ft (3.7 m) for extra-hazard occupancies to as high as 20 ft (6.1 m) for special-listed extended-coverage sprinklers in light-hazard occupancies. If adjacent sprinklers are placed closer together than 6 ft (1.8 m), baffles are required between the sprinklers so the water spray from one does not prevent the other from operating. Except for ceiling sprinklers (flush, recessed, and concealed), sprinklers are required to be located so that the deflectors are a minimum of 1 in (2.5 cm) below the ceiling or bottom of close-spaced open wood joists. The maximum allowable distance of deflectors below the ceiling varies from 6 in (15 cm) for fire sprinklers below close-spaced open wood joists up to 22 in (56 cm) for fire sprinklers located directly below beams in paneled ceilings which can effectively trap heat.

Size of Fire Sprinkler Systems

Out of concern for the maximum area which might be unprotected at any point in time because of system maintenance or modifications, NFPA 13 limits the maximum size of a fire sprinkler system on any one floor. For light- and ordinary-hazard systems, the limit is 52,000 ft^2 (4836 m^2). For systems protecting high-piled storage or extra-hazard occupancies, the limit is 40,000 ft^2 (3720 m^2), except that pipe-schedule extra-hazard systems are limited to 25,000 ft^2 (2325 m^2). When a single system protects occupancies containing both light- or ordinary-hazard areas and high-piled storage or extra-hazard areas, the portions of high-piled storage or extra-hazard (hydraulically designed) systems may be up to 40,000 ft^2 (3720 m^2) within a total system area of up to 52,000 ft^2 (4836 m^2).

STANDPIPE SYSTEM DESIGN CRITERIA

Number of Risers

Since hose stations are generally located immediately on or adjacent to risers, the number of risers is determined by the required spacing of hose stations. For Class

I, Class II, and Class III service, the number of hose stations must be such that all portions of each story of a building are within 30 ft (9.1 m) of a nozzle when attached to not more than 100 ft (30.5 m) of hose. For Class II service with hose less than 1½-in (4-cm) nominal diameter, the number of hose stations must be such that all portions of each story of a building are within 20 ft (6.1 m) of a nozzle when attached to not more than 100 ft (30.5 m) of hose.

Location of Risers

Standpipe risers are required to be located within noncombustible fire-rated stair enclosures. In buildings with large areas where not all standpipes can be located within stair enclosures, additional standpipe risers are permitted to be installed in pipe shafts, at interior columns, or in other appropriate locations.

Zones

Standpipe risers are generally limited to vertical zone heights of 275 ft (84 m), although single-zone heights of up to 400 ft (122 m) are permitted when all pipe, fittings, and devices are rated for not less than the maximum system pressure. For higher buildings, multiple zones are used. Each zone requiring pumps must be provided with a separate pump, although use of pumps arranged in series is permitted. In high buildings where upper zones cannot be supplied through the fire department connection, another means of water supply must be provided. This usually is in the form of high-level water storage.

FIRE SPRINKLER SYSTEM PIPING

Types of Piping

The types of piping permitted for fire sprinkler systems inside buildings are summarized in Table 15.2, along with allowable joining methods. *Special-listed* piping products are those which have been investigated by a nationally recognized laboratory and determined to be suitable for use in fire sprinkler systems. The listing provisions generally contain specific limitations on their use.

Underground piping serving fire suppression systems is governed by National Fire Protection Association Standard 24, *Private Fire Service Mains and Their Appurtenances*. Materials suitable for such use include lined cast-iron or lined ductile-iron pipe, lined steel pipe, asbestos-cement pipe, fiberglass-filament-wound epoxy pipe, polyethylene pipe, polyvinyl chloride (PVC) pipe, reinforced concrete pipe, or other listed piping material.

Pipe Sizing

Fire sprinkler system piping is sized in one of two ways. The traditional manner of pipe sizing is accomplished through a *pipe schedule*, a table corresponding to the hazard classification of the system, which dictates the maximum number of fire sprinklers which can be served by any particular size of pipe. The larger the pipe diameter, the more fire sprinklers which can be served downstream. Pipe

TABLE 15.2 Types of Piping and Joining Permitted for Fire Sprinkler Systems

Material	Material specifications	Joining methods
Steel pipe:		
Standard (Schedule 40)	ASTM A53, A120, A135, or A795	Threaded fittings, listed cut-groove fittings, welding, listed roll-groove fittings, listed plain-end fittings
Thin wall (Schedule 10)	ASTM A53, A120, A135, or A795	Listed roll-groove fittings, welding, listed plain-end fittings
Special listed	Per listing	Per listing
Copper tube (K, L, M)	ASTM B75, B88, or B251	Brazing, soldering with 95/5 solder for wet systems only in light-hazard occupancies or ordinary-hazard Group 1 concealed-piping systems
Special-listed nonmetallic pipe:		
Polybutylene	Per listing	Per listing (heat-fusion method)
Chlorinated polyvinyl chloride (CPVC)	Per listing	Per listing (solvent cement method)

schedules have been available for more than a century, and have varied somewhat through the years.

Beginning in the 1970s, piping for most fire sprinkler systems began to be sized through *hydraulic design*, an approach which uses hydraulic principles to estimate directly the pressure losses through the piping system. This approach ensures that the expected operating sprinklers will be provided with sufficient water at sufficient pressure. To carry out hydraulic design, a *sprinkler demand*, or estimate of required water use, must be determined. For most systems, sprinkler demand is determined in accordance with an approach permitted within NFPA 13 using *area-density curves*, developed for each hazard classification, which estimate the floor area over which automatic sprinklers will open, on the basis of a given range of water application rates. The standard also permits a *room design method*, in which the number of automatic sprinklers expected to open is not expected to exceed those in any one building compartment, provided that a sufficient degree of fire resistance is provided between compartments. Some types of fire sprinklers have minimum flow and pressure requirements assigned to them as part of their laboratory listings, and the ability of the fire sprinkler system to supply such sprinklers properly must be verified through hydraulic design. For deluge sprinkler systems and other systems employing open sprinklers or nozzles, hydraulic design is absolutely necessary to confirm proper water application rates.

Minimum acceptable nominal pipe diameters permitted by standard NFPA 13 out of concern for long-term corrosion and plugging are 1 in (2.5 cm) for ferrous piping and ¾ in (1.9 cm) for copper tube.

Hanging Piping

The national installation standard NFPA 13 includes considerable detailed guidance relative to hanger spacing and sizing based on pipe sizes. The standard also allows an alternative approach to the design of hangers and their support structures, by which any hanger and installation method is acceptable if certified by a registered professional engineer for the following:

1. Hangers are capable of supporting 5 times the weight of the water-filled pipe plus 250 lb (113 kg) at each point of piping support.
2. Points of support are sufficient to support the sprinkler system.
3. Ferrous materials are used for hanger components.

The building structure itself must be capable of supporting the load of the water-filled pipe plus 250 lb (113 kg) applied at the point of hanging. The weight of 250 lb (113 kg) is intended to represent the extra loading which would occur if a relatively heavy individual were to hang on the piping.

Trapeze hangers (see Fig. 11.9) can be used where structural members are not conveniently located for providing direct support. This can occur where sprinkler system piping is run parallel to but separated from structural members such as joists or trusses. Since trapeze hangers are considered part of the support structure, requirements for these hangers within NFPA 13 are based on the ability of the hangers to support a load equal to the weight of 15 ft (4.6 m) of water-filled pipe plus 250 lb (113 kg) applied at the point of hanging. An allowable stress of 15,000 psi (103,400 kPa) is used for steel members. Tables are provided, one of which presents required section moduli based on the span of the trapeze and the size and type of pipe to be supported; another gives the available section moduli of standard pipes and angles typically used as trapeze hangers. When the tables are used, NFPA 13 permits the effective span of the trapeze hanger to be reduced if the load is not at the midpoint of the span. The equivalent length L of trapeze is determined from the formula

$$L = \frac{4ab}{a + b} \qquad (15.1)$$

where a = distance from one support to the load and b = distance from the other support to the load.

Earthquake Protection

General protection of piping against earthquakes is discussed in Chap. 9. Several types of protection for fire sprinkler systems are required in areas where the probability of earthquakes is significant:

- Flexibility and clearances are added to the system where necessary to avoid the development of stresses which could rupture the piping.
- Excessive flexibility is not permitted, since the momentum of unrestrained piping during shaking could result in breakage of the piping under its own weight or on collision with other building components.
- Bracing is required for mains and for the ends of branch lines.

The basis of calculating loads for earthquake braces is the assumption that the normal hangers that support the system are capable of sustaining vertical forces and horizontal force a_h is given by

$$a_h = 0.5g \tag{15.2}$$

where g is the acceleration of gravity.

Since the braces can be called upon to act in both tension and compression, it is necessary to size the brace member not only to sustain the expected force applied by the weight of the pipe in its zone of influence but also to avoid a member which could fail as a long column under buckling.

The ability of the brace to resist buckling is determined through an application of Euler's formula with a maximum slenderness ratio of 200:

$$\frac{l}{r} \leq 200 \tag{15.3}$$

where l = length of the brace and r = least radius of gyration for the brace.

Special care must be taken in the design of earthquake braces to ensure that:

- The load applied to any brace does not exceed the capability of the fasteners of that brace to hold to the piping system or the building structure
- The braces are attached only to structural members capable of supporting the expected loads

STANDPIPE SYSTEM PIPING

Types of Piping

The types of piping and fittings permitted for use in standpipe systems are basically the same as those permitted for use in fire sprinkler systems (Table 15.2), except that no steel or nonmetallic pipe has been given a special listing for standpipe use. All copper tube used in standpipe systems must be brazed.

Pipe Sizing

Like fire sprinkler systems, standpipes may be sized according to either (*a*) a pipe schedule or (*b*) hydraulic calculations. Under the pipe schedule, the minimum nominal size of pipe is 4 in (10 cm) for Class I and Class III service and 2 in (5 cm) for Class II service. The pipe size must then increase in diameter according to the distance (either vertical or horizontal) from the farthest hose outlet to the water supply. The diameter must also increase to accommodate increased water supply requirements created by the tie-in of additional risers.

If the standpipe is sized according to hydraulic calculations, standpipe risers for Class I or III service can be as small in nominal diameter as 4 in (10 cm). In a building completely protected with a fire sprinkler system and served by a combined fire sprinkler–standpipe system, there is no minimum size for hydraulically designed risers. If the building is not completely protected with fire sprinklers, the minimum size for a combined fire sprinkler–standpipe riser is 6 in (15 cm).

Hanging and Earthquake Protection

Standpipe riser supports must be provided at the lowest floor level, at each alternate floor level, and at the top of the risers. Supports above the lowest floor level must restrain the pipe against upward movement, as well as against the force of gravity when mechanical flexible fittings are used to join the pipe. Clamps employing set screws are not permitted. For horizontal runs of pipe, hangers must meet the same performance criteria as fire sprinkler system hangers. Similarly, the earthquake protection requirements for standpipe systems are the same as the NFPA 13 requirements for fire sprinkler systems in areas subject to earthquakes.

WATER SUPPLY REQUIREMENTS

Fire Sprinkler Systems

The water supply requirements for fire sprinkler systems differ, depending on pipe schedule or hydraulic calculations. For pipe-schedule systems, the following water supply quantities must be available at the base of the system riser, at a minimum pressure 15 psi (103 kPa) plus the pressure needed to overcome elevation losses to the highest sprinkler on the system:

Light hazard	500 to 700 gpm (32 to 44 L/s)
Ordinary-hazard Group 1	700 to 1000 gpm (44 to 63 L/s)
Ordinary-hazard Group 2	850 to 1500 gpm (54 to 95 L/s)

The lower figure is the minimum flow rate including hose stream allowance ordinarily acceptable. The higher figure is considered a sufficient flow rate where conservatism appears justified. For pipe-schedule systems with hazard classifications beyond ordinary-hazard Group 2, the authority having jurisdiction must determine the necessary water supply flow rate.

For hydraulically designed systems, the water supply flow rate and pressure is determined as a result of (*a*) the original sprinkler demand, (*b*) the pressure losses resulting from friction through the piping, (*c*) turbulence through the fittings, (*d*) elevation of the system, and (*e*) the need to provide an allowance for the possibility of simultaneous hose stream use. For hose streams inside a building, an amount of 50 gpm (3 L/s) is added to the sprinkler demand at the pressure of the sprinkler system for each of the first two hose stations. The remainder of the hose stream allowance may be added to the sprinkler demand at a yard hydrant or at the connection of the system to the city water main. The total hose stream allowance for a hydraulically designed system is

Light hazard	100 gpm (6 L/s)
Ordinary-hazard Group 1	250 gpm (16 L/s)
Ordinary-hazard Group 2	250 gpm (16 L/s)

Ordinary-hazard Group 3	500 gpm (32 L/s)
Extra-hazard Group 1	500 gpm (32 L/s)
Extra-hazard Group 2	1000 gpm (63 L/s)

In general, the total water supply requirements for hydraulically designed systems are lower than the water supply requirements for pipe schedule systems. For this reason, and because pipe sizes may be reduced in hydraulically designed systems, they are usually more economical to employ. This may not be the case where low-pressure municipal water is available in large quantity.

Standpipe Systems

The total water supply required for a Class I or Class III service standpipe system increases with the number of standpipe risers within a fire area. For the first riser, a supply of 500 gpm (32 L/s) is required at the topmost outlets at a minimum pressure of 65 psi (448 kPa). For each additional riser, the water supply is increased by 250 gpm (16 L/s) up to a maximum of 2500 gpm (158 L/s).

The total water supply for a Class II service standpipe system is not affected by the number of risers. The total water supply requirement is 100 gpm (6 L/s) at a minimum pressure of 65 psi (448 kPa).

Combined Fire Sprinkler–Standpipe Systems

If a building is completely equipped with fire sprinkler system protection, the water supply for a combined fire sprinkler and standpipe system need only be sized to accommodate the larger of the separate fire sprinkler or standpipe system requirements. Generally, the standpipe system has the larger water supply requirement, although in a small building of relatively high hazard the fire sprinkler system water supply requirement can be the larger, since the fire sprinkler system water supply requirement also includes a hose stream allowance.

If the building is only partially protected by a fire sprinkler system, the standpipe system water supply requirement must be increased by an amount equal to the fire sprinkler water supply requirement, or by simply adding 150 gpm (9.5 L/s) for light-hazard occupancies or 500 gpm (32 L/s) for ordinary-hazard occupancies.

WATER SUPPLY ARRANGEMENTS

Municipal Supplies

The most common and efficient source of water supply for fire sprinkler and standpipe systems is the public water main. The capability of a public water supply with regard to capacity and pressure is usually determined through hydrant flow tests, in which the pressure of the system is monitored as relatively large amounts of water flow from the hydrants. The pressure of the system with no water flowing (other than that used normally for domestic and industrial purposes) is termed the *static pressure*. With a known amount of water flowing from the system, a *residual pressure* is the pressure associated with that particular flow.

In some situations, water or health authorities require the installation of a *backflow prevention device* (described in Chap. 13), a device intended to protect the quality of the public water supply against contamination from connection to a fire sprinkler or standpipe system. These devices are generally required when the fire suppression system is simultaneously supplied from an open body of water or other potential source of contamination but are not required on a system with all water supplied solely from the public water mains.

Fire Pumps and Booster Pumps

A *fire pump* is a pump specially listed by a nationally recognized testing laboratory for use in a fire suppression system. These pumps are generally horizontal centrifugal pumps, although vertical turbine pumps are also used where the water supply source is below the level of the pump, as in a supply from a well or open body of water. A *booster pump* is used to boost the pressure of an available water supply to pressures suitable for use with fire suppression systems, provided the available supply is of sufficient capacity. Pumps for fire protection service are powered by either electric motors or diesel engines or, in rare cases, by steam turbines. Insurance company requirements for some high-value properties sometimes dictate that one pump of each type (electric and diesel) be provided to improve reliability. Some building codes require that emergency power be made available to electric-driven fire pumps for fire sprinkler systems in high-rise buildings and other key applications.

Water Tanks

Water tanks are used in fire suppression systems where there is no public water or where the public water supply does not have sufficient capacity to adequately supply the fire suppression system. For fire sprinkler systems with low water demand requirements, as in small- or light-hazard occupancies, the water supply can often be provided by *pressure tanks*, described in Chap. 4. Such tanks contain water as well as pressurized air and use the force of the pressurized air to supply the fire sprinklers. The air pressure p_i to be maintained in the pressure tank is

$$p_i = \frac{p_f + 15}{a} - 15 \tag{15.4}$$

where p_i = tank pressure, psi
p_f = pressure required by the fire sprinkler system at the outlet of the tank as determined by calculations, psi
a = fraction air in the tank

Usually a is equal to 0.33, with the water filling two-thirds of the tank volume. Sometimes, however, it is necessary to increase the proportion of air so as to maintain a high pressure as the last water leaves the tank while at the same time not exceeding the pressure rating of the tank under normal conditions.

A *gravity tank*, described in Chap. 4, is a tank which provides pressure to the system through elevation. A *suction tank* is a ground level or below-ground tank used in conjunction with a fire pump to provide water to fire sprinkler or standpipe systems.

Required Tank Capacity. The required capacity of a tank depends on the minimum duration requirements imposed by NFPA 13 and 14. These requirements are summarized in Table 15.3.

TABLE 15.3 Water Supply Duration Requirements for Standpipe and Fire Sprinkler Systems

	Standpipe systems	
Class I	30 min	
Class II	30	
Class III	30	
	Fire sprinkler systems	
	Pipe schedule	Hydraulically designed
Light hazard	30–60 min	30 min
Ordinary hazard, Group 1	60–90	60–90
Ordinary hazard, Group 2	60–90	60–90
Ordinary hazard, Group 3	60–120	60–120
Extra hazard, Group 1		90–120
Extra hazard, Group 2		120

Note: Where a range is shown, the lower duration is normally acceptable if water flow alarm signals are received by a fire brigade or continuously staffed station. Where no figures are shown, the duration is determined by the authority having jurisdiction.

For example, consider a combined sprinkler and standpipe system in a light-hazard building that is provided with complete sprinkler coverage; the building has two standpipe risers. According to the above discussion under "Combined Fire Sprinkler–Standpipe Systems," the standpipe demand is 750 gpm (47.3 L/s). The additional sprinkler demand is zero since the total sprinkler demand, including hose stream allowance, is no more than 700 gpm (44 L/s). Since the demand must be satisfied for a duration of 30 min, the required storage capacity of the system is

$$750 \text{ gpm} \times 30 \text{ min} = 22{,}500 \text{ gal } (85{,}200 \text{ L})$$

If the same building is equipped with an ordinary-hazard Group 1 pipe schedule sprinkler system, the total water demand, including hose stream allowance, may be as much as 1000 gpm, in which case the minimum required storage capacity is

$$1000 \text{ gpm} \times 60 \text{ min} = 60{,}000 \text{ gal } (230{,}000 \text{ L})$$

RELATED FIRE PROTECTION SYSTEMS

In addition to fire sprinkler and standpipe systems, there are a number of specialized fire protection systems which are used for the protection of specific hazards or locations:

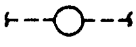
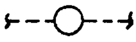
> *Halon extinguishing systems* are total flooding systems sometimes used for the protection of small high-value areas considered susceptible to water damage. Fairly expensive, they require a well-confined building area to contain the extinguishing gas.
>
> *Carbon dioxide extinguishing systems* are sometimes used for building areas containing flammable liquids or electrical equipment.
>
> *Dry or wet chemical extinguishing systems* are commonly used for spot protection of hazards associated with range hoods and other cooking equipment.

REFERENCES

1. NFPA Standard 13 (1989), NFPA Standard 14 (1986), and NFPA Standard 24 (1987), National Fire Protection Association, Batterymarch Park, Quincy, MA 02269.
2. *NFPA Fire Protection Handbook*, 16th ed., National Fire Protection Association, Batterymarch Park, Quincy, MA 02269, 1986.

APPENDIX 15.1: STANDARD FIRE PROTECTION SYMBOLS FOR ARCHITECTURAL AND ENGINEERING DRAWINGS*

Automatic Sprinkler System Symbols

Referent (synonyms)	Symbol
Sprinklers	
Sprinkler, general	
Upright sprinkler	
Pendent sprinkler	

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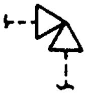
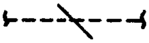
Automatic Sprinkler System Symbols (*Continued*)

Referent (synonyms)	Symbol
Sprinklers (*Continued*)	
Upright sprinkler, nippled up	
Pendent sprinkler, on drop nipple	
Sprinkler, with guard	
Sidewall sprinkler	
Outside sprinkler	
Special spray nozzle	
Piping, valves, control devices, hangers	
Sprinkler piping and branch line	———

Automatic Sprinkler System Symbols (*Continued*)

Referent (synonym)	Symbol
Piping valves, control devices, hangers (*Continued*)	
Sprinkler riser	
Valve (general)	
Angle valve (angle hose valve)	
Check valve (general)	
Alarm check valve	
Dry-pipe valve	
Dry-pipe valve with quick-opening device —accelerator or exhauster	
Deluge valve	
Pipe hanger	

PART 2

DRAINAGE SERVICES

CHAPTER 16

SANITARY DRAINAGE SYSTEMS

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INTRODUCTION

A *drainage system* is a system of piping within private or public premises that conveys sewage (i.e., any liquid waste containing animal, vegetable, or chemical wastes in solution), rainwater, or other liquid wastes to an approved point of disposal; it does not include the mains of a public sewer system. *Sanitary sewage* (also called *domestic sewage*) is sewage that contains human excrement and liquid household wastes.

This is the first of four chapters describing building sanitary drainage systems (the subject of this chapter), vent systems (Chap. 17), components used in drainage systems and vent systems (Chap. 18), and storm-water drainage systems for buildings (Chap. 19).

This chapter first discusses the fundamental principles of the flow of water in drainage piping. This is followed by a section devoted to the sizing of drainage systems. The final section deals with practical considerations in the design of sanitary drainage systems.

Sanitary drainage systems must provide for the safe, sanitary disposal of sewage from all fixtures in a building. Where public sewer systems are available, building systems should be connected thereto for reliability of service and protection of health and safety. Where public sewer systems are not available, adequate approved private treatment and disposal systems must be designed and constructed in lieu thereof. Suitable provisions should be made to prevent backflow of sewage into buildings.

The sanitary drainage system should be designed, constructed, and maintained to guard against fouling, deposit of solids, and clogging, and with adequate cleanouts so arranged that the pipes may be readily cleaned. The system should be designed to provide an adequate circulation of air in all pipes with no danger of siphonage, aspiration, or forcing of trap seals under conditions of ordinary use. Each vent terminal of the sanitary drainage system should extend to the outer air and be so installed as to minimize the possibilities of clogging and the return of foul air to the building. No substance which will clog or accentuate clogging of pipes, produce explosive mixtures, destroy the pipes or their joints, or interfere unduly with the sewage-disposal process should be allowed to enter the sanitary drainage system. Proper protection should be provided to prevent contamination of food, water, sterile goods, and similar materials by backflow of sewage. Where necessary, the fixture, device, or appliance should be connected indirectly with the sanitary drainage system.

Systems should be designed and installed so that they may be readily maintained in a safe and serviceable condition from the standpoint of both mechanics and health. Piping should be designed and installed with due regard to preservation of structural members and prevention of damage to walls and other surfaces through fixture usage. Plumbing systems should be subjected to such tests as will effectively disclose all leaks and defects in the work or material.

FLOW OF WATER IN DRAINAGE PIPING

This section deals with the principles of hydraulics that are relevant to flow of water in drainage piping in buildings. Such principles concern physical and mechanical properties of water and their application in engineering design of drainage piping systems.

The physical and mechanical properties of water include its density, scouring action, uniform and turbulent flow conditions, and frictional resistance.

Energy principles include potential and kinetic energy, static and velocity heads, and pressurized flow from fixture outlets. Friction is an essential energy consideration in limiting velocity of flow through drainage piping flowing partially full.

These properties and principles have specific application with regard to gravity flow in sloping drains and vertical drains, velocity of flow for scouring action, hydraulic jump at the bases of vertical drains, and quantity rates of flow in fixture drains and branch drains.

Gravity Flow in Sloping Drains

Gravity flow in long, sloping horizontal drains of a plumbing system is comparable to flow in open channels in which the flowing water is not completely enclosed by walls and has a free surface exposed to atmospheric pressure. Under such circumstances, flow is not dependent on pressure applied to the water but instead is caused just by the amount of gravitational force induced by the slope of the drain and of the water surface therein.

In an open channel or sloping horizontal drain of constant shape and size, and of extensive length, flow has a chance to adjust itself and reach a state of equilibrium which is termed *uniform flow*. For this condition, the slope of the water surface in the drain matches the slope of the drain, and the friction head loss (in feet of water column per foot of drain length) is equal to the slope of the drain (in feet per foot).

One of the most widely used equations for determining the rate of uniform flow in sloping horizontal drains is as follows:

$$V = \frac{1.486 \times R^{2/3} S^{1/2}}{n} \qquad (16.1)$$

and

$$Q = \frac{A \times 1.486 \times R^{2/3} S^{1/2}}{n} \tag{16.2}$$

where V = velocity of flow, ft/s
Q = quantity rate of flow, ft^3/s
A = cross-sectional area of flow, ft^2
R = hydraulic mean depth of flow, ft
S = hydraulic slope of the surface of flow, ft/ft
n = a coefficient or factor that depends on the roughness of the pipe surface, degree of fouling in service, and pipe diameter

The hydraulic mean depth of flow, in feet, frequently termed *hydraulic radius*, is the ratio of the cross-sectional area of flow, in square feet, to the wetted perimeter of pipe surface, in feet. Values for the hydraulic mean depth vary for different degrees of fullness of flow. For a drain flowing half full, the cross-sectional area of flow is equal to $3.14D^2/8$, the wetted perimeter is equal to $3.14D/2$, and the hydraulic mean depth is equal to $D/4$. Similarly, for a drain flowing full, the cross-sectional area of flow is equal to $3.14D^2/4$, the wetted perimeter is equal to $3.14D$, and the hydraulic mean depth is equal to $D/4$. Thus it can be seen that these values coincide for half-full and full flow.

Tabulated in Table 16.1 for half-full flow and in Table 16.2 for full flow in sloping horizontal drains are values for (1) R the hydraulic mean depth of flow, in feet; (2) corresponding values for the two-thirds power of R; and (3) A, the cross-sectional area of flow, in square feet.

Values for S, the hydraulic slope of the surface of flow, in feet per foot, and for $S^{1/2}$ are tabulated in Table 16.3 for several of the common slopes used for horizontal drains in plumbing systems.

The values of n vary with the roughness of the pipe surface and the diameter of the pipe. The degree of fouling of the pipe interior in service also must be con-

TABLE 16.1 Values of R and A for Half-Full Flow

Pipe size, in	$R = D/4$, ft	$R^{2/3}$	A (area of flow), ft^2
1¼	0.0288	0.0940	0.00520
1½	0.0335	0.1040	0.00706
2	0.0417	0.1200	0.01090
2½	0.0521	0.1396	0.01704
3	0.0625	0.1570	0.02455
4	0.0833	0.1910	0.04365
5	0.1040	0.2210	0.06820
6	0.1250	0.2500	0.09820
8	0.1670	0.3030	0.17460
10	0.2080	0.3510	0.27270
12	0.2500	0.3970	0.39270
15	0.3125	0.4610	0.61350

TABLE 16.2 Values of R and A for Full Flow

Pipe size, in	$R = D/4$, ft	$R^{2/3}$	A (area of flow), ft^2
1¼	0.0288	0.0940	0.01040
1½	0.0335	0.1040	0.01412
2	0.0417	0.1200	0.02180
2½	0.0521	0.1396	0.03408
3	0.0625	0.1570	0.04910
4	0.0833	0.1910	0.08730
5	0.1040	0.2210	0.13640
6	0.1250	0.2500	0.19640
8	0.1670	0.3030	0.34920
10	0.2080	0.3510	0.54540
12	0.2500	0.3970	0.78540
15	0.3125	0.4610	1.22700

TABLE 16.3 Values for Slope

Slope, in/ft	S, ft/ft	$S^{1/2}$
⅛	0.0104	0.102
¼	0.0208	0.144
½	0.0416	0.204
¾	0.0625	0.250

sidered in plumbing system drains. Recommended values to apply for the coefficient n are as follows:

> For sanitary drains of galvanized-iron pipe and cast-iron soil pipe, well aligned and supported, and with normal amount of fouling in service, assume n equals 0.012 for 1¼- and 1½-in sizes; 0.013 for 2-, 2½-, and 3-in sizes; 0.014 for 4-in size; 0.015 for 5- and 6-in sizes; and 0.016 for 8-in and larger sizes.
>
> For storm drains of ordinary sewer pipe after average uneven settlement and fouling, assume n equals 0.013 for all sizes.

Applying Eqs. (16.1) and (16.2) and appropriate recommended values for n, the uniform flow velocity and capacity of horizontal galvanized-iron or cast-iron drains of the sanitary system, laid at a slope of ¼ in/ft (2.1 cm/m) and flowing full at no pressure, may be found to have the rates shown in Table 16.4.

Similarly, for storm drainage systems, the uniform flow velocity and capacity of horizontal galvanized-iron and cast-iron drains, laid at a slope of ¼ in/ft (2.1 cm/m) and flowing full at no pressure, may be found to have the rates shown in Table 16.5. Additional data are given in Table 19.6 for storm drain pipes having a larger diameter.

The flow capacities shown in Tables 16.4 and 16.5, for drains flowing full

TABLE 16.4 Uniform Flow Velocity and Capacity of Galvanized-Iron and Cast-Iron Drains of Sanitary Systems at Full Flow

¼ in/ft (2.1 cm/m) Slope

Pipe diameter		Velocity		Capacity	
in	cm	ft/s	m/s	gpm	L/s
1¼	3.13	1.67	0.51	7.82	0.49
1½	3.75	1.85	0.56	11.7	0.74
2	5.0	1.98	0.60	19.4	1.22
2½	6.25	2.30	0.70	35.2	2.22
3	7.5	2.59	0.79	57.2	3.61
4	10.0	2.91	0.88	114	7.19
5	12.5	3.15	0.96	193	12.2
6	15.0	3.58	1.09	315	19.9
8	20.0	4.07	1.24	637	40.2

TABLE 16.5 Uniform Flow Velocity and Capacity of Galvanized-Iron and Cast-Iron Drains of Storm Drainage Systems at Full Flow

¼ in/ft (2.1 cm/m) Slope

Pipe diameter		Velocity		Capacity	
in	cm	ft/s	m/s	gpm	L/s
2	5.0	1.72	0.52	17.4	1.10
2½	6.25	1.99	0.61	31.5	1.99
3	7.5	2.25	0.69	51.3	3.24
4	10.0	2.74	0.84	111	7.00
5	12.5	3.16	0.96	201	12.7
6	15.0	3.58	1.09	327	20.6
8	20.0	4.35	1.33	705	44.5

when laid at a slope of ¼ in/ft (2.1 cm/m), may be used to establish the quantity rates of flow corresponding to other degrees of pipe fullness and for other pipe slopes. For example, for half-full flow, the quantity rate of flow for each size would be just one-half as much as those tabulated for full flow. For slopes of ⅛, ½, and ¾ in/ft, the respective quantity rates of flow would be 0.707, 1.414, and 1.73 times as much as those shown in the tables for ¼ in/ft slope.

Flow capacities and velocities under conditions of uniform flow are those which will prevail where flow has sufficient time to adjust itself and achieve a state of equilibrium. Such capacities and velocities may be considered the minimum which will occur in drains regardless of the velocity at which flow enters. High entrance velocity, such as occurs at the bases of stacks and leaders, produces surges in flow for a considerable distance downstream. Under conditions of surging or unsteady flow in horizontal drains of relatively short length, flow capacities and velocities may be appreciably higher without creating any hydrostatic head in the drain. Hence any increase in capacity or velocity of flow due to surging or unsteady flow conditions provides an added factor of safety when design is based on uniform flow conditions.

Velocity of Flow for Scouring Action

Drainage piping should be designed so as to afford scouring action in the piping when conveying sewage at the maximum rates of discharge which may be anticipated from fixtures connected thereto. The most important factor in achieving scouring action is sufficient velocity of flow. A velocity of 2 ft/s (0.61 m/s) is recommended as the minimum necessary to produce scouring action in piping conveying sewage. This velocity has the minimum amount of traction or erosive force required for lifting or scrubbing from the pipe surface loose particles, including sand, grit, and small pebbles, and carrying them along with the stream. However, a velocity of at least 4 ft/s (1.22 m/s) is recommended for drainage piping conveying greasy wastes, for such piping is subject to deposits of grease which may accumulate as a lining of congealed solids. Higher velocity is needed in this case to produce increased erosive action and to reduce the amount of time the greasy wastes are in contact with relatively cold drainage piping.

In Tables 16.4 and 16.5, which state the velocity and capacity attained under uniform flow conditions in horizontal drains laid at a slope of ¼ in/ft (2.1 cm/m), it may be seen that several of the pipe sizes yield velocities less than 2 ft/s (0.61 m/s) at full flow. These velocities will prevail where the pipe length is sufficiently long that flow has a chance to adjust itself and become uniform. Hence long runs of small-size pipe should be avoided. For short runs of fixture drains, the velocity attained under uniform flow need not be observed, as higher velocity generally will occur owing to the additional velocity gained in dropping from the fixture outlet to the horizontal portion of the fixture drain. Using the equation, $V = (2gh)^{1/2}$, the velocity attained by a body in a free fall of 1 ft (0.3 m) is equal to $(2 \times 32.2 \times 1)^{1/2}$, or 8.03 ft/s (2.45 m/s). Owing to friction in flowing from the waste outlet of a fixture through the outlet tailpiece and fixture trap, the actual velocity of flow entering the horizontal portion of the fixture drain after a fall of 1 ft is only a fraction of that which may be attained in free fall, generally about one-third as much. But this is more than the recommended minimum of 2 ft/s (0.61 m/s) and may be considered adequate for short runs of fixture drains.

Similarly, in stacks, the minimum velocity required for scouring action is almost always attained with ease, including that required for greasy wastes. In vertical drains, the velocity induced by gravity is limited only by the friction developed between the interior surface of the pipe and the flowing liquid and is more than adequate for all practical purposes. Hence the incidence of stoppage of drainage stacks is relatively nonexistent.

Gravity Flow in Vertical Drains

When a small amount of water is discharged into a large vertical drainage pipe, flow tends to cling to the pipe wall and may descend with a slightly spiral motion. As the amount of water discharged into the vertical drain is increased, flow forms a uniformly thick sheet of water on the pipe wall, encloses a core of air in the center of the pipe, and descends without any spiral motion. This condition of flow prevails for volume rates up to a rate where flow occupies from one-fourth to one-third of the cross-sectional area of the vertical drain.

Beyond this rate, flow tends to diaphragm across the cross section of the pipe and form slugs of water, which in turn break up as increased air pressure develops in the lower section of the pipe. Frequent and persistent formation and breakage of slugs of water in flow down vertical drains produce rapid oscillations in air pressure and accompanying objectionable noise. This poses a practical limit on the rate of flow which may be accommodated by a vertical drain, such as a drainage stack in a building, without producing objectionable effects.

Flow from a horizontal drain, upon entering a vertical drain through a branch or other fitting, is subjected to gravitational acceleration and gains velocity in falling in the vertical drain. Velocity increases until the frictional resistance developed by the water flowing in contact with the pipe wall and air core becomes equal to the accelerating force of gravity. Thereafter, the velocity remains constant as flow descends further down the vertical drain.

The distance below the fitting through which flow enters the vertical drain to the point where flow reaches *constant* or *terminal velocity* depends on the quantity rate of flow, the diameter of the vertical drain, and the vertical velocity resulting from the type of fitting through which flow enters. Some vertical velocity results from the downward curvature of the entrance fitting, long sweeps and Y-branch fittings yielding more vertical entrance velocity than quarter bends and sanitary T branches.

The terminal velocity and terminal length for flow in stacks of cast-iron soil pipe may be computed by means of the following formulas:

$$V_t = 3.0\left(\frac{q}{d}\right)^{2/5} \tag{16.3}$$

and

$$t = 0.052V_t^2 \tag{16.4}$$

where V_t = terminal velocity of flow in drainage stack, ft/s

L_t = terminal length below stack-branch fitting through which flow enters, ft

q = quantity rate of flow in drainage stack, gpm

d = diameter of drainage stack, in

The flow capacity of stacks can be expressed in terms of the stack diameter and a specific fraction of the stack's cross-sectional area which may be permitted to be occupied by water at terminal velocity. This is expressed in the following formula:

$$q = 27.8r_s^{5/3}d^{8/3} \tag{16.5}$$

where q = flow capacity of the drainage stack, gpm

r_s = specific fraction of the stack's cross-sectional area permitted to be occupied by water at terminal velocity

d = diameter of drainage stack, in

One recommendation (regarding a limit which should be applied as the specific fraction of a stack's cross-sectional area permitted to be occupied by water flowing at terminal velocity in a drainage stack) is to limit water area to 6⁄24 that of the stack, in which case flow in the stack relatively matches the uniform flow capacity of horizontal drains, flowing full, at a slope of ¼ in/ft (2.1 cm/s), as shown in Tables 16.4 and 16.5. Another is to permit 7⁄24 of the cross-sectional area of the stack to be occupied by water at terminal velocity. When these limits are applied to the preceding equation, it may be reduced to the following:

If r_s is 6⁄24,

$$q = 2.76d^{8/3} \tag{16.6}$$

If r_s is 7⁄24,

$$q = 3.56d^{8/3} \tag{16.7}$$

These two equations may be used to compute rates of flow in drainage stacks corresponding to what may be deemed recommended flow capacities for various sizes. Such capacities are shown in Table 16.6.

Hydraulic Jump at Base of Vertical Drains

At the base of a vertical drain, flow enters the horizontal drain at relatively high velocity. For a 3-in (7.6-cm) drainage stack flowing at recommended practical capacity, the terminal velocity of flow is about 10.2 ft/s (3.11 m/s). As flow enters a long sweep fitting at the base of the stack and is diverted from vertical to horizontal direction, the water is subjected to centrifugal force and is pressed against the lower curved surface in the fitting. This results in what may be termed *shooting* flow, or high-velocity flow, having the form of a sheet of water of relatively uniform thickness in contact with the lower curved surface in the base fitting.

Such high-velocity and sheet forms of flow cannot be maintained in the horizontal drain because of the frictional resistance of the horizontal pipe surface and

TABLE 16.6 Computed Drainage Stack Capacity

Diameter of drainage stack		Capacities at recommended fractions of drainage stack fullness			
		r_s = 6⁄24		r_s = 7⁄24	
in	cm	gpm	L/s	gpm	L/s
1¼	3.13	5.0	0.32	6.5	0.41
1½	3.75	8.1	0.51	10.5	0.66
2	5.0	17.5	1.10	22.6	1.43
2½	6.25	31.8	2.01	41.0	2.59
3	7.5	52.1	3.29	67.2	4.24
4	10.0	111.0	7.00	143.0	9.02
5	12.5	202.0	12.7	261.0	16.5
6	15.0	336.0	21.2	423.0	26.7
8	20.0	709.0	44.7	915.0	57.7

the shallow slope of the horizontal drain. For a 3-in (7.6-cm) horizontal drain laid at a slope of ¼ in/ft (2.1 cm/m), the velocity maintained under uniform flow conditions at full or half-full flow is just 2.59 ft/s (0.79 m/s). Hence the velocity of flow entering the horizontal drain is approximately 4 times as much as may be maintained therein.

The transition from high to low velocity in the horizontal drain produces a *hydraulic jump* in flow a short distance downstream from the base fitting of the stack, the distance varying with the entrance velocity, depth of water in the horizontal drain, roughness of the pipe surface, diameter of the pipe, and slope of the drain. For cast-iron drains of usual sizes, the distance from the stack base fitting to the jump in flow varies to approximately 10 times the diameter of the stack. A typical hydraulic jump is illustrated in Fig. 16.1.

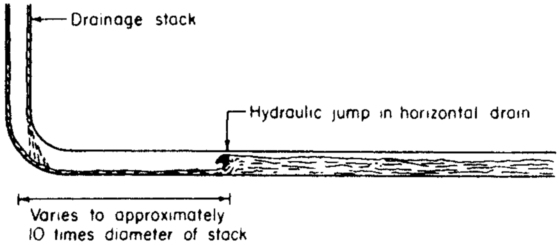

FIG. 16.1 Hydraulic jump at the base of a stack.

At the hydraulic jump, the depth of flow rises sharply and may completely fill the horizontal pipe at flows approaching drainage stack capacity. Less jump occurs when the horizontal drain is larger in size than the stack and also when the horizontal drain is increased in slope. Downstream from the jump in flow, unsteady or surging flow conditions continue until frictional resistance gradually reduces the velocity of flow to that maintained at uniform flow conditions.

In horizontal offsets of drainage stacks, the same hydraulic jump effect occurs in the horizontal section adjacent to the base fitting for the upper section of the drainage stack. If the stack is relatively large and flow from fixtures above the offset is relatively small, the jump in flow in the stack offset may be appreciably less than that produced in the horizontal drain at the bottom of the drainage stack.

Quantity Rate of Flow in Fixture Drains

The quantity rate at which flow should be conveyed by a fixture drain is the same as the rate at which liquid waste is discharged into the drain from the waste outlet of the fixture. Flow from a fixture waste outlet is comparable with flow from a water supply orifice discharging under flow pressure. However, in this case, the orifice diameter is that of the minimum flow area existing in the waste-outlet fitting and tailpiece, and the flow pressure is that due to the height of water in the fixture above the level of the minimum flow area. Thus the quantity rate of flow discharged from a fixture into a fixture drain decreases as the water level drops in the fixture.

A formula expressing the quantity rate of flow discharged by a fixture and to be conveyed by its fixture drain is as follows:

$$q_d = 13.17 d_o^2 \sqrt{h_m} \qquad (16.8)$$

where q_d = quantity rate of flow discharged from fixture waste outlet in practice, gpm

d_o = orifice diameter of waste outlet, in

h_m = head measured above orifice of waste outlet, ft of water column

As flow jets from the orifice of the fixture waste outlet, additional velocity is gained in dropping from the outlet through vertical sections of the fixture drain, thereby producing a corresponding decrease in cross-sectional area of flow.

Quantity Rate of Flow in Branch Drains

The quantity rate of flow to be conveyed by a horizontal branch drain is the sum of flows received simultaneously from the various fixture drains connected thereto. For this amount of flow to be conveyed without any development of hydrostatic pressure in the horizontal drain, its design may be based on the assumption that uniform flow conditions will prevail where the horizontal branch drain is of extended length. However, in relatively short horizontal branch drains, such as those from a group of fixtures discharging into a stack branch fitting, the high velocities of flow from fixture drains produce surging flow conditions and appreciably higher capacities and velocities of flow than are produced under uniform flow conditions.

In no case should the quantity rate of flow conveyed by a branch drain exceed the flow capacity of the drainage stack or main drain into which it discharges. Also, where branch drains discharge into stacks, the quantity rate of flow in the branch drain should not cause excessive interference with flow in the stack so as to produce back pressure in the branch drain. Thus the permissible flow capacity of a branch drain should be related to the probable simultaneous rate of flow in the stack. This in turn is related to the total load on the stack and to the number of branches discharging into the stack.

SIZING OF DRAINAGE PIPING

This section deals with the application of principles of hydraulics in sizing drainage piping so as to achieve the performance required of plumbing fixtures, fixture drains, sanitary drainage stacks, branches and building drains, storm drainage systems, and combined storm and sanitary building drains.

The specific criteria used in each sizing application are presented in detailed discussion for each section of drainage piping systems. The criteria define the limits for adequacy of performance.

Fixture Drains

In establishing proper sizes for fixture drains, consideration should be given to the diameter of the orifice in the waste-outlet fitting and tailpiece, the size of the trap, and the desired velocity of flow for proper fixture drainage and scouring action in the fixture drain. Fixtures generally have discharge orifices sized to provide suitable rates of drainage. In no case should the fixture drain size be reduced to less than that of the discharge orifice, for to do so would cause a reduction in the rate of fixture discharge. Instead, the size of the fixture trap and the fixture drain should be slightly larger than that of the discharge orifice so that they will not affect the discharge rate adversely after a moderate degree of fouling in normal service. Similarly, the size of the fixture drain should not be smaller than that of the fixture trap, so as to avoid constriction of flow and resultant increased fouling in the fixture trap.

Where fixtures discharge greasy wastes, low velocity of flow in fixture drains increases the incidence of stoppage development therein. For such fixtures, it is recommended that the size of the fixture trap and drain should be the minimum commercial size available and larger than the size of the discharge orifice. In this way, maximum scouring effect may be achieved to minimize fouling of the fixture drain.

Hence minimum fixture drain sizes may be assumed to be the same as the minimum sizes permitted for the fixture traps of the various kinds of plumbing fixtures.

Sanitary Drainage Fixture Units

A method of assigning fixture unit values to plumbing fixtures was originally proposed in 1923 by R. B. Hunter of the National Bureau of Standards. The suggested values were designed for application in conjunction with the probability of simultaneous use of fixtures so as to establish maximum permissible drainage loads, in terms of fixture units rather than in numbers of specific types of fixtures or gallons per minute of drainage flow, for each of the various parts of sanitary drainage systems. Since the original proposal, various changes have been made. Fixture unit values presently recommended for assignment to various kinds of plumbing fixtures which discharge into sanitary drainage systems are stated in Table 16.7. They are provided as a means for computing sizes of soil, waste, and vent piping based on the loading effects produced by the discharge of many different kinds of plumbing fixtures commonly installed in buildings.

In general, the sanitary drainage fixture unit value assigned to a particular fixture is based on the average volume discharged and the average rate of discharge for the fixture. This value is determined from the fixture's total discharge flow, in gallons per minute, divided by 7.5, or, in other words, its total discharge flow in cubic feet per minute. The integer closest to the flow rate, in cubic feet per minute, is taken as the fixture unit value. Thus the sanitary drainage fixture unit is a factor so chosen that the drainage load-producing effects of different plumbing fixtures are expressed approximately as multiples of that factor.

Design Load for Sanitary Drainage System

Except in the case of fixtures in which water is retained for use and discharged afterward, the rate at which water leaves fixtures and enters the sanitary drainage system is the same as the rate at which water is supplied to the fixtures. For relatively large systems where fixtures are supplied directly from public water

TABLE 16.7 Sanitary Drainage Fixture Unit Values

Fixture or group	Trap size in	Trap size cm	Fixture units
Residential:			
Automatic clothes washer, domestic	2	5.0	3
Bathroom group consisting of a water closet, lavatory, and bathtub or shower stall:			
Flushometer valve closet			8
Tank-type closet			6
Bathtub (with or without overhead shower)	1½	3.75	2
Bidet	1¼	3.13	1
Dishwasher, domestic	1½	3.75	2
Floor drain	2	5.0	3
Floor drain	3	7.5	5
Floor drain	4	10.0	6
Food-waste grinder, domestic	1½	3.75	2
Kitchen sink, domestic	1½	3.75	2
Kitchen sink, domestic, with dishwasher	1½	3.75	2
Kitchen sink, domestic, with food-waste grinder	1½	3.75	2
Kitchen sink, domestic, with dishwasher and food-waste grinder	2	5.0	2
Kitchen sink and wash (laundry) tray with single 1½-in (3.8-cm) trap	1½	3.75	2
Kitchen sink and wash (laundry) tray with separate 1½-in (3.8-cm) traps	1½	3.75	3
Kitchen sink and wash (laundry) tray with food-waste grinder	2	5.0	4
Lavatory, common	1¼	3.13	1
Laundry tray (1 or 2 compartments)	1½	3.75	2
Shower stall, single head	2	5.0	2
Sink, bar, private	1½	3.75	1
Water closet, tank-type, trap arm only	3	7.5	4
Public toilet rooms:			
Urinal, pedestal, trap arm only	3	7.5	6
Urinal, pedestal, siphon-jet blowout	3	7.5	6
Urinal, stall, washout	2	5.0	4
Urinal, wall [2-in (5.0-cm) min. waste]	1½	3.75	4
Water closet, flushometer valve, trap arm only	3	7.5	6
Industrial:			
Interceptors for grease, oil, solids, etc.	2	5.0	3
Interceptors for sand, auto wash, etc.	3	7.5	6

TABLE 16.7 Sanitary Drainage Fixture Unit Values (*Continued*)

	Trap size		Fixture units
Fixture or group	in	cm	
Lavatory, multiple-type (wash fountain or wash sink)	1½	3.75	2
Showers, gang (one unit per head)	2	5.0	2
Commercial:			
Dishwasher, commercial	2	5.0	2
Food-waste grinder, commercial	2	5.0	3
Receptors (floor sinks) indirect waste receptors for refrigerators, coffee urn, water stations, etc.	1½	3.75	1
Receptors, indirect waste receptors for commercial sinks, dishwashers, airwashers, etc.	2	5.0	3
Sink, bar, commercial [2-in (5.0-cm) min. waste]	1½	3.75	2
Sink, commercial, with food-waste grinder	2	5.0	3
Sink, commercial (pot, scullery, or similar type)	2	5.0	4
Sink (flushing-rim type, flush valve supplied)	3	7.5	6
Sink (service type with trap standard)	3	7.5	3
Sink (service with P-trap)	2	5.0	2
Washing machines, commercial	2	5.0	3
Medical:			
Dental unit or cuspidor	1¼	3.13	1
Dental lavatory	1¼	3.13	1
Lavatory (surgeon's, barber shop, beauty parlor)	1½	3.75	2
Sink (surgeon's)	1½	3.75	3
Miscellaneous:			
Drinking fountain	1¼	3.13	½
Mobile-home-park traps (one for each trailer)	3	7.5	6
Trap size 1¼ in (31.3 mm) or less	1¼	3.13	1
Trap size 1½ in (37.5 mm)	1½	3.75	2
Trap size 2 in (50 mm)	2	5.0	3
Trap size 2½ in (62.5 mm)	2½	6.25	4
Trap size 3 in (75 mm)	3	7.5	5
Trap size 4 in (100 mm)	4	10.0	6

mains, the rate at which water enters the water supply distributing system and the rate at which sewage leaves the building drainage system are the same except for a small amount of water consumed by occupants. Hence there is relative equivalency between the water supply demand load and the sanitary drainage discharge load for which the respective systems are designed.

This ultimate equivalency is the basic premise upon which values have been assigned to express the load-producing effects of fixtures, both in water supply fixture units and in sanitary drainage fixture units. Although the values assigned to fixtures for water supply purposes differ from those for sanitary drainage, the same design load in gallons per minute corresponding to a given number of fixture units is applicable to the main lines of both systems, with one proviso. The design load for sanitary drainage systems should be determined from the number of sanitary drainage fixture units and the corresponding water supply demand load, in gallons per minute, as indicated in the charts (Fig. 7.8 and Table 2.3), applicable to systems equipped predominantly with flush valves (flushometers). The reason for this is simply that the discharge rate of water closets equipped with flush tanks is sufficiently comparable with that of flush-valve–equipped water closets as to warrant use of the demand rates applicable to systems equipped with flush valves (flushometers).

Drainage Stacks and Branches

Based on the computed drainage stack flow capacity for stacks flowing $7/24$ full at terminal velocity, the corresponding number of fixture units may be determined from design load charts or tables so as to establish the total load which may be placed on a tall drainage stack. For example, the computed flow capacity of a 4-in (10-cm) stack flowing at $7/24$ full is 143 gpm (9.02 L/s). From design load charts or tables, it may be found that this rate of flow is equivalent to 500 fixture units.

This is the total load which may be received from all branches on a 4-in (10-cm)-tall stack. However, to avoid excessive interference between flow entering the stack and that coming down the stack, it is necessary to limit the amount of flow which may be allowed to enter the stack at each of the branches. Thus, in a building of just a few stories in height, the amount of flow entering the stack through a branch may be greater than would be permissible in a building of many stories.

Table 16.8 for sizing drainage stacks provides different permissible loadings for stacks of 3 stories or less in height and for stacks more than 3 stories in height. Included in the table are the maximum loads permitted on any horizontal fixture branch of a short stack and at any 1 story of a stack more than 3 stories in height.

Sanitary Building Drains

Sanitary building drains should be designed to flow only partially full so as to provide an air space in the upper portion of the pipe through which air may flow and relieve pressure therein to available branches. A general recommendation in this case is to design such drains to flow at from one-half to three-quarters of the quantity rate of discharge which may be calculated for uniform flow conditions in sloping horizontal sanitary drains flowing full.

In relatively low buildings of extensive area, the condition of flow in the sanitary building drain may approach uniformity within the building, and for such buildings, it is recommended that the drain be designed to convey liquid flow at one-half its full-flow capacity under such conditions. This permits the drain to flow at one-half depth for maximum liquid load.

In buildings of the multistory type, the condition of flow in the sanitary building drain usually is different because of the high velocity at which discharges are received from drainage stacks. Considerable turbulence and surging flow occur in

TABLE 16.8 Maximum Permissible Loads for Sanitary Drainage Piping
In terms of fixture units

Pipe diameter		Any horizontal fixture branch	One stack of 3 stories or less in height	Stacks more than 3 stories in height		Building drain, and building drain branches from stacks			
						Slope, in/ft (cm/m)			
in	cm			Total for stack	Total at 1 story	1/16 (0.5)	⅛ (1.0)	¼ (2.1)	½ (4.2)
1½*	3.75	3	4	8	2	np	np	np	np
2*	5.0	6	10	24	6	np	np	21	26
2½*	6.25	12	20	42	9	np	np	24	31
3	7.5	20†	48‡	72‡	20†	np	np†	42†	50†
4	10.0	160	240	500	90	np	180	216	250
5	12.5	360	540	1100	200	np	390	480	575
6	15.0		960	1900	350	np	700	840	1000
8	20.0			3600	600	1400	1600	1920	2300
10	25.0			5600	1000	2500	2900	3500	4200
12	30.0					3900	4600	5600	6700

*No water closets permitted.
†Not over two water closets permitted.
‡Not over six water closets permitted.

such cases. Under such conditions, flow is conveyed by the building drain at velocities higher than those which prevail for uniform flow conditions. For such buildings, it is recommended that the drain be designed to convey liquid flow at three-fourths the quantity rate of flow corresponding to full-flow capacity under uniform flow conditions. The higher capacity may be permitted because of the higher velocities of surging flow and correspondingly higher capacities for drains flowing at one-half depth.

Table 16.8 may be used for sizing sanitary building drains. The value shown therein for an 8-in (20-cm) drain laid at a slope of ¼ in/ft (2.1 cm/m) corresponds to a design load, in gallons per minute, equal to the half-full flow rate for such a drain flowing at uniform flow conditions. The values shown for smaller sizes reflect an allowance made for the effects of surging flow. Similar allowances have been made for each given size of drain reflecting the effect of surging flow on the relative capacities of drains at different degrees of slope.

Combined Storm and Sanitary Building Drains

Where sanitary building drains are connected to storm building drains so as to form a combined storm and sanitary drain, an equivalency basis is necessary to convert the fixture unit load of the sanitary system to that of the storm drainage system in square feet of drained area. As the flow in the storm drainage system during maximum rainfall periods generally is far in excess of the flow in the sanitary drainage system at peak load, the sizing of a combined drain should be based on the storm-drain design, and sanitary drainage fixture units of load should be converted to terms of equivalent square feet of drained area.

A method of converting such load units has been recommended. As a minimum, 1000 ft^2 (92.9 m^2) of drained area should be deemed equivalent to all sanitary drainage fixture unit loads that are less than 256 units. It may be seen from the water supply system demand load charts and Table 2.3 that each additional fixture unit above 256 corresponds to an additional load of 0.2 gpm (0.0126 L/s). At a maximum rainfall rate of 4 in (10 cm)/h, rain is collected at a rate of 1 gpm (0.063 L/s) on 24 ft^2 (2.33 m^2) of drained area and at a rate of 0.2 gpm (0.0126 L/s) on 3.9 ft^2 (0.36 m^2) of drained area.

Consequently, each fixture unit of sanitary drainage load in excess of 256 such units should be deemed equivalent to 3.9 ft^2 (0.36 m^2) of drained area. The total drained area equivalent to the number of sanitary drainage fixture units should be added to the total storm drainage area to determine the load on the combined system, and the appropriate size of combined drain then may be selected from the tables applicable for sizing horizontal storm drains.

PRACTICAL CONSIDERATIONS IN THE DESIGN OF DRAINAGE SYSTEMS

Each building in which plumbing fixtures are installed should be provided with a sanitary drainage system for conveying sewage from the fixtures to an adequate and approved means for sewage disposal, such as a public sanitary or combined sewer where available. Where a public system is not available, an approved private sewage disposal system must be provided. Such private systems must conform to regulations of the health authority having jurisdiction in the area. No sewage should be discharged into sewers intended for storm water only, nor be disposed of onto the ground or into a public waterway. Sewage or other waste which may be deleterious to surface or subsurface waters should not be discharged into the ground or into a waterway unless first rendered harmless through subjection to treatment in accordance with standards acceptable to the authority having jurisdiction.

Wherever public sanitary or combined sewers are available for disposal of sewage from a building, it is recommended that the sanitary drainage system of the building be connected to the public system. This is the most satisfactory method of ensuring disposal of sewage without health hazard or nuisance. No other known method affords the same convenience, reliability, capacity, and trouble-free service for the life of any given building.

In areas where public sanitary or combined sewers have been installed, it is almost always found that public sewer district authorities have regulations which require that the sanitary drainage systems of buildings be connected to the public systems when such buildings are not too distant therefrom. Availability may be considered to be just 100 ft (30.5 m) in the case of a one- or two-family dwelling and as much as 500 ft (152 m) for other types of building occupancies. In general, wherever it is practical to do so, it is advisable to connect to public sanitary or combined sewers as the most economical method of disposing of sewage.

The disposal of radioactive wastes should conform to applicable regulations of the health authority having jurisdiction. Not all such wastes pose the same degree of hazard: some require little or no special treatment and precautions, while others may be too hazardous for disposal into the sanitary drainage system. State health authorities regulate the use of radioactive materials and permit such materials to be used only by licensed and qualified laboratories and their personnel. The manner of disposal to be applied to each particular radioactive substance is carefully prescribed by state authorities in accordance with federal safety standards.

Building Sewers

Building sewers should be designed and installed in accordance with regulations of the authority having jurisdiction in the particular area in which they are to be located. Regulations in different areas may vary greatly because of local conditions, such as capacity limitations of the public sewer system or the public sewage treatment plant, potential infiltration of groundwater into public sewers, maintenance procedures established by sewer authorities in accordance with local sewer conditions, soil conditions below ground, public roadway construction and maintenance standards, roadway traffic and loadings, underground structures and utility piping systems located beneath public roadways, and numerous other conditions singular to given areas in which building sewers may be installed.

A great variety of regulatory agencies exercise jurisdiction over the design and installation of building sewers, such as a public sewer district authority, public highway and sewer department, local board of health, public safety department, and other governmental agencies appropriately designated by law and charged with such duties and responsibilities.

Local health agencies usually exercise jurisdiction over building sewer installations which convey sewage to private sewage disposal systems located on the premises with the building. In this case, the health agency may appropriately serve as the single agency exercising jurisdiction over private sewage disposal systems, building sewers, and plumbing systems for buildings.

Existing building sewers are not recommended for use in conjunction with new building plumbing systems or major alterations of existing systems unless it has first been definitely determined by thorough inspection and test that the existing building sewer is in good condition, watertight, in proper alignment, and of adequate size and capacity to perform satisfactorily under the loads to be conveyed from the building. The costs involved in making a proper determination in the case of existing building sewers usually are high and are difficult to justify, especially in view of the fact that sewers tend to settle unevenly and become unevenly aligned after years of service unless originally installed of highly durable piping and bedded in hard-packed natural soil. Generally, it is recommended that new building sewers be provided for new building plumbing systems and major alterations of existing systems.

Fixture and Equipment Connections to Sanitary Drainage System

The most sanitary method for conveying liquid wastes and sewage from fixtures to a safe disposal terminal is to connect the waste outlets of the fixtures directly to the sanitary drainage system of the building. With this method, once the wastes are discharged into the system they flow by gravity to the disposal terminal through a watertight and gastight system of piping designed to provide safe, rapid disposal of sewage and to prevent the escape of any sewer gases and odors from the piping system into habitable spaces in the building.

This method should be applied for all fixtures and equipment which discharge liquid wastes, except for certain specific fixtures and equipment which require special types of connections for a variety of reasons. For example, regardless of how well designed a sanitary drainage system may be, the interior of the piping will become lined with deposits of solid matter, and a stoppage condition eventually can develop and cause backup of sewage into fixtures. Backup of sewage into certain specific fixtures and equipment cannot be permitted.

Fixtures and equipment used for storage, preparation, or processing of food or drink, sterile goods, or similar materials must be provided with *air breaks*, that is, physical disconnections, at their waste outlets. The air breaks should be adequate to prevent contamination of the contents of such fixtures and equipment from any possible backup of sewage from either direct or indirect waste piping and should be located within 2 ft (0.61 m) of the waste outlet of the fixture or equipment and on the inlet side of the fixture trap. Hence the waste outlets of all sterilizers, food refrigerators, and food compartments must be protected against contamination from sewage by means of air breaks at their waste outlets.

Refrigerators, ice boxes, or receptables wherein food is stored, when provided with waste outlets, should be drained by means of drip pipes which discharge through an air break either into a floor drain or sink approved for such use or into a safe pan, or receptor, which is equipped with a bell trap, preferably, or ordinary type trap and which discharges into the sanitary drainage system by means of an indirect waste pipe.

Fixtures and equipment which have interior surfaces which are not readily accessible to permit effective cleaning and restoration of sanitary conditions therein, after having been flooded by backup of sewage from the sanitary drainage system, should not be connected directly to the system. Instead, they should be connected to indirect waste pipes, which are permitted to convey liquid waste but exclude any human waste, and should discharge therefrom into a fixture approved for such use. This method applies especially to automatic laundry machines equipped with squirrel-cage type tumblers which cannot be removed readily for complete cleaning of the interior of the machine after being flooded by backup.

Drinking fountains discharge wastes at such a low rate of flow as to be little more than drippage. In addition, the wastes contain very little or no organic matter. In view of this, relatively no sanitary hazard exists when such fixtures discharge indirectly into a fixture approved to receive such indirect wastes. Consequently, it is permissible for drinking fountains, including electric water cooler drinking fountain units, to be connected to indirect waste pipes. This is a generally accepted alternative method which may be more economical in some particular installations.

Portable household appliances, such as portable laundry and dishwashing machines which are not intended to be permanently connected to the plumbing system of a building, generally are provided with flexible discharge piping of suitable length at the end of which is a bent section which may be hooked over the rim of a fixture. The discharge of such fixtures into kitchen or laundry fixtures in dwelling units poses no additional sanitary hazard and, hence, should be permissible.

Swimming pools and wading pools having overflow connections located at an elevation below street level would be subject to backup of sewage through such connections in the event that they were connected directly to the sanitary drainage system and backup conditions occurred in the public sewer system. This should not be permitted. For such pools, all drainage outlets, including pool drains, scum gutter drains, backwash outlets from pool water filters, and floor drains which serve walks around pools, should be arranged so as to discharge by means of an indirect waste pipe, and any existing circulation pump for pool water may be used to pump wastes from the pool to an elevation suitable for gravity discharge into a fixture approved for such use.

Where drains are provided in the pits of hoistways, flooding of the pits during backup conditions in public sewer systems should be prevented. Such drains should not be directly connected to the sanitary drainage system or to the storm drainage system, but instead should discharge through an indirect waste pipe.

Certain fixtures and equipment which may be classified as business equipment rather than as building equipment provided for the needs of building occupants pose legal and practical difficulties which weigh against their being connected directly to the sanitary drainage system of a building. These difficulties resulted from the fact that such fixtures (1) were *business equipment* rather than *building equipment*, (2) were the property of the business owner rather than the property of the building owner, (3) were to be installed upon occupancy by the business to meet its needs, (4) were to be removed by the business when its occupancy in the building terminated, and (5) generally were to be installed in unusual locations, such as under bars or counters remote from walls, where the vent piping required for the direct-connection method would usually have to be exposed and thereby detract from the normal appearance and attractiveness of the business space.

Fixtures and equipment which may be classified as business equipment include bar sinks, soda fountains, counter sinks, wash boxes, spoon troughs, glass rinse sinks, barber shop and beauty parlor lavatories, commercial dishwashing machines, glass washers and silver washers, and other equipment specifically required for the business operations of a particular kind of business occupancy. Most codes contain special provisions which permit such fixtures and equipment to be connected by means of an indirect waste pipe discharging into a fixture approved for such use. This is an alternative method specifically permitted for business equipment connections. Generally, this method is the most practical and economical to apply when installing such equipment.

Objectionable Wastes

Many kinds of wastes may be detrimental to the sanitary drainage system or public sewer or sewage treatment plant. Such wastes may be classified as objectionable for one reason or another. Special precautions or methods of handling or treating such wastes may be required in order to prevent detrimental effects which might otherwise occur.

Swimming pool wastes might be considered to be objectionable if they were to be discharged into a sanitary drainage system connected to a septic tank system of sewage disposal. The great volume of waste to be handled when a swimming pool is drained may have a seriously adverse effect on the septic tank system and cause extensive flooding of the subsoil leaching field system. This should not be permitted. Under such circumstances, it is recommended that the swimming pool wastes be discharged through an independent sanitary drainage system just for that purpose and conveyed to an independent disposal system.

Industrial wastes which may be detrimental to the sanitary drainage system, or to the public sewer, or to the public or private sewage treatment plant should not be permitted to be discharged in the usual manner. Notice of the type of industrial waste which is proposed to be discharged into a public system ordinarily is required to be filed with authorities having jurisdiction prior to obtaining permission to connect the sanitary drainage system of an industrial building to the public system. If satisfactory treatment of the waste may make it unobjectionable, installation of the treatment process may render the wastes suitable for discharge into the sanitary drainage system. If proper treatment of such wastes is not provided, they should be disposed of by a method acceptable to the authority having jurisdiction.

Excessively high temperature wastes are objectionable because of the unusually large amount of drainage piping expansion and contraction effects resulting therefrom. They may cause pipe joints to be disturbed or pulled apart or cause solidly bedded piping to be strained or broken, and leakage of sewage may result from the discharge of excessively high temperature wastes into the sanitary drainage system. This should be prevented. It is generally recommended that no high-pressure steam exhaust, boiler blowoff, or similar drip pipe be directly connected to the building drainage system. Such wastes should be cooled to a reasonable temperature before they are permitted to be discharged. The recommended method of disposing of such wastes after cooling is to discharge them into a branch of the building sewer where they can mix with the total sanitary sewage flow from the building and no temperature effects can be transmitted into the piping system in the building in the event that the cooling process shuts down or is inoperative at times.

Corrosive liquids, acids, strong alkalies, or other chemicals which might destroy or injure a drain, soil, waste, or vent pipe or which might create noxious fumes should not be discharged into the regular sanitary drainage system. Such chemicals should be discharged through an independent sanitary drainage system directly to a public sewer system provided permission has been received for their discharge into the public system from the authority having jurisdiction, or such wastes should be treated by an acceptable method prior to disposal. Where such wastes are treated by passage through an approved dilution or neutralizing device for which adequate maintenance is ensured, they may be discharged into the regular sanitary drainage system of the building. However, all drains which convey untreated chemical wastes and all vents attendant upon such drains should be made of materials resistant to the corrosive action of such wastes and their fumes.

Any wastes which may cause clogging conditions in the sanitary drainage system should not be permitted to be discharged into the drainage system unless appropriate, effective means of treatment are provided to render such wastes unobjectionable. Where intercepting strainers or grease- or sediment-intercepting fixture traps may provide appropriate and effective treatment and render such wastes unobjectionable, they should be installed at the fixtures, and adequate maintenance should be ensured for such equipment.

Fixtures through which volatile oil or other flammables could be introduced or admitted into the regular sanitary drainage system of a building, by accident or otherwise, should not be connected to the regular sanitary drainage system. Instead, such fixtures should be connected to an independent sanitary drainage system discharging through an oil separator of satisfactory design and capacity. Where the oil separator discharges to the building sanitary sewer or building drain, the branch connection should be located downstream from any building trap installed therein. Where the oil separator must discharge into a private sewage disposal system, the system shall be one specially approved for such use.

Each oil separator should be provided with an individual vapor vent pipe at least 3 in (7.5 cm) in size to convey flammable vapor from the top of the separator to a suitable and unobjectionable location outside the building. It is recommended that the vapor vent terminal be located at least 12 ft (3.66 m) above grade so as to be safely distant from any source of ignition and so as to cause no objectionable odors noticeable to passersby.

Radioactive wastes should not be discharged into the regular sanitary drainage system or to a public or private sewer system or sewage treatment plant unless such wastes are specifically treated and disposed of in accordance with standards prescribed by the health authority having jurisdiction.

Drainage Systems Below Sewer Level

Where a drainage system or part of a drainage system is located at an elevation below the building sewer or public sewer, the liquids or sewage conveyed thereby should be disposed of through a subbuilding drainage system into a sump, receiving tank, or ejector equipped with automatic equipment for lifting and discharging such liquids or sewage into the building gravity drainage system. The receiving vessel and lifting equipment should be of adequate capacity and suitable design for the volume and kinds of liquids to be conveyed. In large installations where service interruption may result in flooding or unsanitary conditions, it is recommended that the lifting equipment should consist of two or more units connected in parallel arrangement.

Sumps, receiving tanks, and ejectors which receive sewage from sanitary subbuilding drainage systems should be of airtight design and should be provided with a vent to permit airflow into and from the receiving vessel. Drainage and vent piping of sanitary subbuilding drainage systems should be installed in the same manner as for gravity systems. Sumps, receiving tanks, and ejectors need not be airtight or vented if they do not receive sewage but instead receive only clear water wastes such as from boiler-room floor drains, machinery drips, storm-water drains, and subsoil drains.

Backwater Valves

Drainage systems which connect to public sewer systems are subject to backwater and flooding in the event that the public sewer becomes blocked or insufficient in capacity for the load that is imposed on it, such as may occur during an abnormally heavy storm. To prevent water from backing up into the building drainage system and flooding into the building under such circumstances, backwater valves should be installed on drainage systems wherever it is known or authorities advise that a particular part of the public sewer system may become overloaded or surcharged at times.

In such cases, the drainage piping for fixtures located at an elevation where they may be subject to flooding should be equipped with a backwater valve. An alternative to this method is to install an accessible backwater valve or a manually operated gate valve in the building drain at the point of entry inside the building and downstream from any building trap.

The design of backwater valves should provide a positive mechanical seal against backwater. When fully opened, such valves should have a flow capacity not less than that of the piping in which they are intended to be installed. All bearing parts of such valves should be of corrosion-resistant material.

Building Traps and Fresh-Air Inlets

Local authorities having jurisdiction may require, because of local conditions, that building traps be installed on or omitted from the building drain. Wherever such regulations prevail, installations should conform. However, where no regulations on the subject of building traps exist, the right to determine whether or not to equip the building's drainage system with a building trap is vested in the owner of the building, who may consider the matter on the basis of relative costs, advantages, and desirability.

While the installation of a fixture trap in the drain of each fixture provided a primary safeguard against the escape of sewer gases and objectionable odors from piping of the drainage system, this secondary safeguard was deemed a necessity during the period preceding the discovery and application of the basic principles of venting to protect the seals of fixture traps. In those days, fixture-trap seals very often were sucked into the drainage system or blown out at fixtures because of the strong, sharp air-pressure fluctuations developed within unvented drainage systems. Even now many substandard and unvented drainage systems are still in service in communities that have had plumbing regulations for a number of years. In communities that have had no regulations, substandard and unvented drainage systems are common.

Building traps provide protection in other ways, simply because such traps effectively seal off the sewer atmosphere from building drainage systems. Systems frequently must be opened to make repairs, alterations, and additions. During such work, building traps prevent the sewer atmosphere from entering building spaces where pipes are opened. Such protection has been deemed necessary in many areas because very often sewer gases are not only offensive to smell, but are also flammable or explosive.

Following its early period of development, extending from 1866 to about 1900, the design and regulation of plumbing systems progressed rapidly. It had to keep pace with new problems arising from parallel developments in other fields.

Gas manufacturing plants were established, and utility gas piping systems were laid under the streets of most large communities. Natural gas piping systems were similarly laid more recently. Some of these systems conveyed gas at very high pressures. With the advent of the automobile, gasoline selling stations were established in virtually every community, and large underground gasoline storage tanks were installed.

These underground installations caused new hazards to arise in conjunction with building drainage systems. Leakage from underground gas piping systems very often infiltrates the public sewer system and building sewers where laid under paved streets. Where the leakage is from high-pressure gas piping systems, the hazard is increased. Leakage of gasoline from defective underground storage tanks and the inadvertent discharge of flammable liquids with wastes often result in volatile and explosive gas mixtures being conveyed by public sewer systems.

Danger from explosions in public sewer systems has increased seriously with the passing of time. It is now at an all-time high. At present in some large cities, various sections of the public sewer systems are known to be almost constantly high in explosive gas content. Extensive efforts are made to locate the sources of such infiltration and to eliminate them. However, the matter of tracing such infiltration is very often nearly impossible. Further, such conditions recur from time to time, presenting a constant hazard.

Building traps provide effective protection against shock and fire damage within buildings when explosions occur in public sewer systems. The trap effectively seals off explosive gas mixtures in the public sewer, and in the event of an explosion, it acts as a shock absorber, owing to its water seal and 360° change in direction. Presently, this is considered one of the most important reasons for building trap requirements in codes. The use of building drainage systems for venting explosive gases from public sewer systems has been found to be completely inadequate in preventing gas explosions in public sewers and resultant damage within buildings connected thereto.

Durability of standard piping materials used in building drainage and vent systems is a factor that is in part dependent on the corrosivity of the atmosphere within the systems. In public sewer systems, the corrosivity of the atmosphere is subject to wide variation. This is influenced by the types of wastes the sewer authority permits to be discharged into the public system. Some systems handle just ordinary household sewage; others take in industrial wastes, including highly corrosive acid wastes. Some sewers are specially designed to handle fuming acid wastes. Municipal sewer services may be specially designed to handle the wastes from important industries around which the economic life of the community is centered.

In some communities, building traps are forbidden. This generally occurs only where the atmospheres of public sewer systems are so highly corrosive that maintenance of the systems would be excessively hazardous unless provided with additional ventilation afforded by using building drainage systems as vent stacks for the public systems. In such cases, several of the standard piping materials may have to be excluded from use in the building drainage systems because of insufficient durability, as proved by experience under service conditions.

Where building traps are provided on building drainage systems, fresh air is normally required to be supplied to the system through a fresh-air inlet connected to the building drain directly upstream from the building trap. Entrance of fresh air into the system reduces the corrosivity of the atmosphere within the system and tends to establish normal atmospheric pressure conditions in the building drain. Under these conditions, the durability of standard piping materials can be reasonably established on a standardized basis regardless of the corrosivity of the atmosphere in the public sewer system.

Where private sewage disposal systems are installed, building traps very frequently are required so as to avoid the creation of a stench nuisance in the vicinity of vent terminals. In populated areas of private home developments, especially of low ranch-type homes, the stench from septic tank systems ventilated through building drainage systems has often been found to be very objectionable and has resulted in widespread demands by residents that it be prevented. This condition is most objectionable in low or valley areas during hot, humid weather. Building traps effectively prevent such stench nuisance conditions.

Building traps are not necessary for normal operation of building drainage systems, except in one instance. This occurs in very cold regions where the winter is severe and the drainage system is connected to a public sewer system. In such cases, vent terminals of the building system are subject to frost closure because of the relatively high moisture content of the public sewer atmosphere. When frost closure occurs, building drainage systems cannot operate satisfactorily. Under such conditions, building traps are necessary for normal operation of the systems.

When building traps are installed, they offer a resistance to the flow of sewage equal to that offered by four 90° bends of the same material and radius of curvature. They also offer resistance to the flow of air through the trap equal to that of the trap's effective water seal, normally 3 in (7.5 cm) of water column for standardized building traps.

Where a building trap is provided, a fresh-air inlet must be installed so as to ventilate the building drainage system. The fresh-air inlet relieves any air-pressure rise at the building trap caused by the trap's resistance to the flow of air. Consequently, codes specify no change of minimum pipe sizes whether building traps are or are not installed.

The installation of building traps and fresh-air inlets is an item of building cost. However, it is a relatively insignificant factor amounting to no more than about one-tenth of 1 percent in the total cost of a modern private dwelling and no more than one-hundredth of 1 percent for a large multistory building. Nevertheless, building costs are important to persons who must pay them. Architects, engineers, and contractors, when called on to serve as authorized agents for building owners in areas where building traps are not required to be installed or omitted, should consider the cost that may be saved by omitting a building trap against the protective values inherent in such installations. In some areas, there may be little or no need for protection; in others, protection may be vital.

Each building trap should be equipped with two brass cleanout plugs of the same size as the trap, except that they need not exceed 4 in (10 cm) in size for larger traps. The cleanout plugs should be accessible so as to permit cleaning the trap interior and rodding upstream and downstream therefrom. Cleanout plugs should be extended to above floor level where required by the authority having jurisdiction in order to exclude from the public sanitary sewer any wastes drained from floors.

Building traps should be installed within the property line of the premises, inside the building wherever practicable, and located on the building drain within 2 ft (0.61 m) of the exterior wall of the structure. Such traps should be located downstream from all drainage branches to the system, except those provided to receive discharges from a sewage lift, oil separator, steam blowoff and condensing tank, or leader. A masonry or concrete pit, or manhole, of acceptable, approved design should be provided for access to trap cleanout plugs when they are located below ground or below a cellar floor.

A fresh-air inlet pipe should be provided on every sanitary or combined building drain equipped with a building trap, sewage sump, ejector, receiving tank, oil separator, or similar equipment. The fresh-air inlet pipe should be connected to the building drain immediately upstream from and within 4 ft (1.22 m) of such trap or equipment and should be at least one-half the diameter of the building drain at the point of connection, but not less than 3 in (7.5 cm) in size. The connection to the building drain should be made to the upper half of such drain (air-space portion), and the fresh-air inlet pipe should be extended therefrom to the atmosphere outside the building and terminated in an open end at least 6 in (15 cm) above grade. In skyscraper construction, it is recommended that the open end be terminated above the roof of a setback of the building rather than at street grade so as to avoid condensation drippage and discharge of odors which might otherwise be objectionable to passersby when the system is subject to constant downward flow of wastes and air during peak-load periods. Where fresh-air inlet pipes are terminated at grade, a perforated metal plate should be permanently installed over the end of the pipe. The plate should have an open ventilating area at least equal to the area of the fresh-air inlet pipe. In lieu of a perforated plate over the end of the fresh-air inlet pipe, a return bend may be installed with its unprotected open end at least 6 in (15 cm) above grade within the property line in an acceptable location.

Connections to Sanitary Building Drains

Sanitary building drains are designed to flow half full at peak load. To avoid backup of flow from the building drain into branches, each branch connection to the building drain should be made to its upper half or air-space portion. This may be achieved for 90° branch connections by means of a one-sixth bend and a 45° Y branch or a long-sweep one-quarter bend and a 45° Y branch. The Y-branch fitting may be rotated so that the branch is at a 45° angle above the horizontal when the one-sixth bend is to be used and at a vertical angle when the long-sweep one-quarter bend is to be used. Less invert elevation is lost with the one-sixth bend and Y combination (see Fig. 16.2).

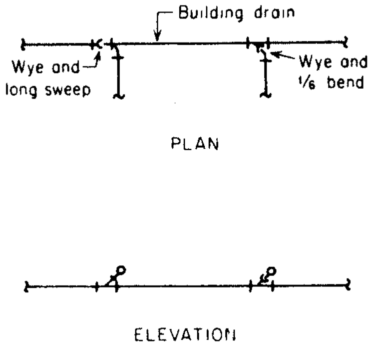

FIG. 16.2 Recommended building drain branch connections.

Branch connections made to the upper half of sanitary building drains are recommended for several additional reasons. First, they reduce the incidence of stoppages occurring in the branch drains; second, they produce less flow interference at the branch connection than would occur were the branch to be made horizontally into the building drain; third, they produce less restriction to airflow in the building drain as the result of reducing flow interference in the drain; and fourth, during periods when one or more branches from drainage stacks are not flowing, their full cross-sectional area is available to relieve pressures occurring in the building drain.

Branch Connections to Drainage Stack Offsets

Drainage stack offsets are subject to extremely turbulent waste flow conditions and excessively severe pneumatic effects when they convey even as little as one-half the load permitted for a given size of stack. Branches connected to such offsets are subject to conditions prevailing therein. They may be sufficiently severe as to blow out the trap seals of fixtures draining thereto unless special relief vents of adequate size and number are provided to control effectively any possibility of excessive air-pressure development. This is not always practical and is generally uneconomical. Consequently, it is recommended that branch connections to drainage stack offsets should be avoided, except where the portion of the stack above the offset does not serve drains from fixtures at a higher story.

Piping Installation

Horizontal drainage piping should be installed in practical alignment at a uniform downstream slope sufficient to yield a flow velocity of at least 2 ft/s (0.61 m/s) as may be determined for uniform flow conditions in piping of various sizes and materials. To attain such minimum velocity for scouring effect in horizontal drains, it is recommended that the pipe slope be at least ¼ in/ft (2.08 cm/m) for piping of 3-in (7.5-cm) diameter or smaller and at least ⅛ in/ft (10.4 cm/m) for larger piping. Lesser slope should be used only when computations clearly establish that sufficient velocity will be attained. It should be noted that standard threaded and solder-joint drainage fittings having inlet openings at a nominal 90° angle, outlets of P traps, and both inlets and outlets of running traps are designed to provide a pitch of ¼ in/ft (2.08 cm/m) in the horizontal drain.

Vent piping should be installed in practical alignment and sloped upward continuously from its lowest connection with soil or waste piping to its terminal in the atmosphere above the building roof. This is necessary so as to permit ventilation of all parts of the drainage and vent piping system by gravity circulation of air. Sags or traps in vent piping should not be permitted because condensation may collect therein and cause restricted air circulation and reduced venting capacity. Vertical drops in upward-sloping vent piping should not be permitted because such drops tend to entrap warm, moist air in the top of the *bowed* piping section, restrict air circulation, and permit accelerated corrosion of the piping.

There are certain locations in buildings where drainage and vent piping should not be installed, such as in stairways, in a hoistway, under an elevator or counterweight, or where such piping would interfere with the normal operation of windows, doors, or other building openings. Horizontal drainage piping should not be located directly above nonpressure water supply tanks, access holes of pressure water supply tanks, or floor areas used for the manufacture, preparation, packaging, storage, or display of food unless a watertight barrier is provided to intervene between the piping and such tanks or space immediately below. Leakage from such horizontal drainage piping may contaminate potable water or food under these circumstances, as has been amply evidenced by epidemics which have occurred in the past.

Unless adequate provision is made to protect soil and waste piping against damage from frost conditions, such piping should not be installed outside buildings or concealed in exterior walls in climate zones where freezing temperatures may occur. Similarly, such piping should not be installed in rooms or spaces of buildings where freezing temperatures may occur normally, such as in food freezer rooms, lockers, refrigerators, cold storage rooms, etc.

Protection against damage from external corrosion should be provided for drainage and vent piping which must be installed in or beneath cinders or other corrosive material. Although adequate protection may be afforded in many instances by application of one or more coats of suitable paints and wrapping of joints, it is recommended that piping installations in highly corrosive beds be avoided wherever possible or that the piping be encased in a special bed of chemically neutralized, noncorrosive material.

Drainage and vent piping should be installed in such a manner as to avoid damage and breakage due to strain accompanying normal expansion and contraction of the piping, as well as to building settlement. Where piping passes through foundation or bearing walls, protection should be provided by means of iron or steel pipe sleeves two sizes larger than the pipe passing through the wall or by means of masonry relieving arches directly above the top of the piping. Flexible sealing material should be caulked into the annular space between the pipes and the sleeves or arches. Where outside leaders are installed along alleyways, driveways, or other locations where piping may be exposed to damage, protection may be afforded by the installation of suitable guards, or the piping may be recessed in a wall.

Underground drainage and vent piping should be laid on a firm, natural bed of earth for its entire length or on an equally firm means of continuous support. Tunneling is not recommended as a satisfactory method for installing such piping because of the resulting misalignment of the piping when the soil above it settles down on it in time and a rut forms in the ground surface at grade level. Open trenchwork is generally recommended for such piping installations. Proper compactness of backfill should be ensured without damage to piping. Clean earth, sand, or screened gravel should be placed under, around, and above the piping to at least 1 ft (0.30 m) above it and compacted carefully. Thereafter, backfilling should be completed to grade, compacting the backfill at least every 2 ft (0.61 m). Heavy boulders and corrosive cinder fill should not be allowed in the trench as backfill material.

Drainage and vent piping aboveground should be securely supported and attached to the building construction. Where it is deemed necessary to prevent movement of the piping, it should be attached securely to an anchor rigidly affixed to the building construction. Hangers, piers, and pipe anchors should be of durable materials having adequate strength to perform their respective functions for the anticipated life of the building.

The maximum distances between supports for drainage and vent piping of various types of materials commonly used are as follows:

Vertical piping:
  Cast-iron pipe: at base and at each story
  Screwed pipe (standard pipe size): every other story, not to exceed 25 ft (7.6 m), or where fitting is installed within story
  Copper tube: every story, but not more than 10-ft (3.0-m) intervals
  Lead pipe: 4-ft (1.2-m) intervals
  Plastic pipe (DWV, rigid): 4-ft (1.2-m) intervals
  Glass pipe: every story, but not more than 15-ft (4.6-m) intervals
Horizontal piping:
  Cast-iron pipe: 5-ft (1.5-m) intervals, except that where 10-ft pipe lengths are used, 10-ft (3.0-m) intervals are acceptable
  Screwed pipe (standard pipe size): 10-ft (3.0-m) intervals
  Copper tube: 10-ft (3.0-m) intervals
  Lead pipe: on continuous metal or wood strips for entire length
  Plastic pipe (DWV, rigid): 4-ft (1.2-m) intervals
  Glass pipe: 8-ft (2.4-m) intervals

Changes in direction of drainage piping should be made by means of fittings which will permit flow to proceed without excessive reduction in velocity or other adverse effects. The use of 45° Ys, long 90° sweeps, sixth, eighth, and sixteenth bends, and combinations of such fittings and equivalent of such fittings is recommended. In the interest of economy, it is recommended that available combination fittings which are the equivalent of several individual fittings be used in place of them wherever the opportunity presents itself. Short 90° sweeps are not recommended for use in drainage piping except where it is 3 in (7.5 cm) or larger in size. Single and double sanitary tees should not be used, except in vertical drainage piping.

Running threads, bands, and saddles should not be permitted in drainage or vent piping, nor should the drilling or tapping of such piping be allowed. Experience has vividly shown that connections made by means of running threads, bands, and saddles seldom, if ever, remain tight and are prone to leakage of waste and objectionable gases and odors. Drilling and tapping of piping are disapproved generally because of the many instances in which the piping has been damaged or split, because of the inadequate pipe wall thickness available for the minimum number of threads required for joint tightness, and because of the projection of branch pipe ends into the drilled pipe.

Any method of installation, fitting, device, or connection which retards flow in drainage or vent systems to a greater degree than normal frictional resistance should not be permitted. Hence double hubs should not be used in drainage piping. Neither should a fitting having a hub facing downstream be so used. Nor should a T branch of a drainage fitting be used as an inlet branch for wastes. Heel- or side-inlet quarter bends should not be used as vent-connection fittings in drainage piping when the heel or side inlet is placed in a horizontal position. In that position, the vent connection is prone to become blocked by sewage matter which may enter and accumulate in the horizontal vent and eventually stop airflow through it.

Installation methods which may result in damage or material reduction in the durability of piping should be avoided wherever possible. For example, the expanding or swaging of 3-in (7.5-cm) lead bends and stubs, so as to connect them to 4-in (10-cm) flanges for fixtures, results in a corresponding reduction in pipe wall thickness. Numerous cases of leakage have been known to occur within a short time after installations were completed and found tight under test. Such leakage incidence should be avoided. It is recommended that 3- × 4-in (7.5- × 10-cm) lead bends and stubs having uniformly proper wall thickness be used for connections to 4-in (10-cm) floor flanges and that 4- × 3-in (10- × 7.5-cm) floor flanges be used for connections to 3-in (7.5-cm) lead bends and stubs.

For future fixture installations, provisions should consist either of plugged branch fittings in stacks or branch piping or completely installed drainage and vent piping for such fixtures, except for exposed, short fixture drain and trap connections which may be required for completion of such installations. Drainage or vent branch pipes which terminate at a distance greater than 2 ft (0.61 m) from a ventilated line of piping are considered to be "dead ends" in which inadequate air circulation conditions exist. They are subject to the development of fungi and accumulations of slime and sludge. Hence they should not be permitted except where it is necessary in order to extend the piping for a cleanout in an accessible location.

Hazardous piping should always be conspicuously identified so as to warn maintenance personnel of danger. This applies to acid waste piping systems, high-pressure steam blowoff systems, and most particularly to piping and equipment for conveying radioactive wastes. In the latter case, the piping and equipment should be conspicuously identified by adequate labeling with the standard radiation danger symbol as required by state health authorities having jurisdiction.

Expansion and Contraction of Piping

Drainage and vent piping should be installed in such manner as to avoid damage and breakage due to strain accompanying normal expansion and contraction of the piping. *The recommended design basis for sanitary drainage and vent piping aboveground in buildings is to provide accommodation for the normal expansion and contraction in length which may occur in the materials corresponding to a temperature change of 50°F (27.8°C) or a pipe temperature range from 40°F (4.4°C) to 90°F (32.2°C).*

Table 16.9 presents coefficients of linear expansion for piping materials in general use, including plastic pipe. It should be noted that ABS-DWV, type I, and PVC-DWV, type II, expand at a rate 9.4 times as much as cast iron and 5.9 times as much as copper and necessitate careful attention.

Calculations made applying this information show that a 100-ft (30.5-m) straight run of either ABS-DWV, type I, or PVC-DWV, type II, expands 3.36 in (8.53 cm) in length when subjected to temperature change of 50°F (27.8°C). For a 10-ft (3.1-m) straight run, the corresponding change in length would be approximately ⅜ in (0.95 cm). The calculations apply to piping which is free to expand.

If the piping were restrained completely so that expansion could not take place, a 50°F (27.8°C) temperature change would cause development of an axial compressive stress in the piping. The amount of such stress as calculated would be 588 psi (4054 kPa) in ABS-DWV, type I, and 825 psi (5688 kPa) in PVC-DWV, type II. Under these conditions, the pipe, acting as a column, will tend to bow between points of anchorage. Although it is highly probable that the effect of lateral deflection on the axial compressive stress in the pipe will be relatively small, it remains to be proved that no permanent deformation or failure will result when these plastic materials are subject to complete constraint of expansion over an extended period of service.

Appropriate accommodation for normal expansion and contraction effects in plastic piping systems may be provided by recognized methods in common usage. Four such methods are (1) packless expansion joints, (2) slip joints, (3) swivel joints, and (4) flexural offsets, bends, or loops.

Methods 3 and 4 may be applied in the field using available materials in appropriate arrangements. To apply them, determine first the amount of expansion

TABLE 16.9 Piping Expansion with Temperature Change

Piping material	Coefficient of linear expansion C_e	Total expansion in 100-ft (30.5-m) pipe length for 100°F (55.5°C) temperature change: ft	(m)	in	(cm)
Cast iron	0.00000595	0.0595	0.018	0.714	1.81
Steel	0.0000065	0.065	0.020	0.780	1.98
Wrought iron	0.0000068	0.068	0.021	0.816	2.07
Copper	0.0000095	0.095	0.029	1.140	2.89
Red brass	0.0000104	0.104	0.032	1.248	3.17
ABS, type I	0.000056	0.560	0.171	6.720	17.1
PVC, type I	0.000028	0.280	0.085	3.360	8.53
PVC, type II	0.000055	0.550	0.168	6.600	16.8

to be accommodated for a given straight run of piping and then determine the developed length of pipe and fittings which should be provided in the swivel joint or flexural offset, bend, or loop.

The amount of expansion to be accommodated for any given length of straight run of ABS-DWV, type I, or PVC-DWV, type II, may be established as being approximately ⅜ in (0.95 cm) per each 10 ft (3.1 m) of length. With this known, the developed length which should be provided in the swivel joint or flexural offset or loop, so as not to exceed an allowable extreme fiber stress in the piping, may be determined from equations which have been developed for this purpose. They are as follows:

For ABS-DWV, type I, piping:

$$L = 1.71\sqrt{de} \tag{16.9}$$

For PVC-DWV, type II, piping:

$$L = 1.89\sqrt{de} \tag{16.10}$$

where L = developed length of piping in expansion loop or swing joint, ft
d = outside diameter of piping, in
e = amount of expansion to be absorbed, in

An example of how this may be applied can be given. A straight run of piping, such as a building drain or a drainage stack, has a T-Y branch connection located 10 ft (3.1 m) from the point at which the straight run is anchored or restrained from movement. For a 50°F (27.8°C) temperature differential in the straight run, the amount of expansion to be accommodated at the branch connection will be approximately ⅜ in (0.95 cm). To accommodate this amount of expansion, the branch pipe must have sufficient developed length to flex or twist without being subjected to excessive strain. The developed lengths calculated in this example for various sizes of branch pipes made of ABS-DWV material are as follows: for 1¼-in (3.18-cm) pipe—1.3 ft (0.4 m) developed length; for 1½-in (3.81-cm) pipe—1.4 ft (0.43 m); for 2-in (5-cm) pipe—1.6 ft (0.49 m); for 3-in (7.5-cm) pipe—1.9 ft (0.58 m); and for 4-in (10-cm) pipe—2.2 ft (0.67 m). For PVC-DWV material, the respective lengths would be 11 percent more.

To accommodate expansion and contraction in building drains and in drainage stacks, 90° offsets may be provided. The developed length which should be provided so as to absorb safely a given amount of expansion or contraction may be calculated for a given size of piping offset in the same way as explained above.

At roof flashings for vent extensions through roofs, adequate means to accommodate the normal expansion and contraction of stacks must be provided for a satisfactory installation. Where the amount of stack expansion is relatively small, not more than about ½ in (1.25 cm), this may be accommodated by a flexible type of flashing. Where the amount of expansion is greater, this may be accommodated by means of a double-sleeve type of flashing, with the lower section surrounding the pipe and attached to the roofing in a watertight manner and the upper section attached to the pipe in a watertight manner and extending down to sleeve or slip over the lower section so as to provide a weathertight flashing. Buckling and leakage at flashings as a result of stack expansion must be avoided for a satisfactory installation.

Cleanouts in Drainage Piping

All drainage piping is subject to stoppage development at some time, and no system, regardless of how well designed, can be considered to be immune from such conditions. This has been amply demonstrated by experience. In the past when drainage piping was not required to have provisions for clearing stoppages, the piping system had to be broken into and opened for cleaning at various appropriate locations. Damage to the piping, inadequate clearing of stoppages, and improper repairs to the piping where openings were made resulted in leakage, vermin, and other objectionable unsanitary conditions in buildings. Hence adequate provision of readily accessible cleanout openings of adequate size at appropriate locations in the drainage piping system is now deemed a practical necessity.

Cleanouts should be provided on the building drain near its junction with the building sewer outside the building or at a Y-branch fitting or building trap immediately inside the building, and cleanouts should be provided at all changes in direction of the building drain greater than 45°. All horizontal drainage piping should be provided with cleanouts spaced not more than 50 ft (15.2 m) apart for piping 4 in (10 cm) or less in diameter and not more than 100 ft (30.5 m) apart for larger piping, except that for underground piping over 10 in (25 cm) in diameter, access holes of acceptable design and equipped with suitable covers should be installed at each 90° change in direction and at maximum intervals of 150 ft (45.7 m). An accessible cleanout should be provided at the base of each soil stack, waste stack, and leader. All underground traps should be provided with an accessible cleanout, except for P-traps located directly beneath and serving floor drains which are equipped with removable strainers or gratings.

The size of cleanouts should be the same as the nominal size of the pipe they are intended to serve, but they need not be larger than 4 in (10 cm). On concealed or underground piping, cleanouts should be extended so as to be accessible at the grade, floor, or wall, whichever location is the most suitable for maintenance operations. Cleanouts should be installed so that the opening is in a direction opposite to that of flow in the drain or at a right angle thereto. They also should be installed so as to permit adequate clearance for rodding. For piping 3 in (7.6 cm) and larger, at least 18 in (0.45 m) of clearance should be provided, while at least 12 in (0.3 m) of clearance should be available for smaller piping.

Wherever a fixture trap or a fixture having an integral trap which is readily removable without disturbing concealed piping is located at a part of the drainage piping where a cleanout is required, such trap or fixture may be considered to be acceptable as the equivalent of a cleanout, provided there is not more than one 90° bend in the piping to be rodded.

Combination Waste and Vent System

This special method of venting is intended as an economical means of providing adequate protection of fixture trap seals for extensive floor and shower drain installations, floor sinks and drains in large markets, laboratory and work tables in school buildings, and similar installations where individual venting of fixture drains to protect trap seals is either impractical or causes undue hardship. With this method, the waste piping is purposely oversized so as to permit it to serve as both a waste and a vent pipe to avoid excessive pneumatic effects at fixture drains.

Combination waste and vent piping systems, limited for use as a means of venting the traps of floor drains and laboratory sinks, should be permitted in conjunction with horizontal branch waste piping of an independent acid waste system, or an independent flammable oil waste system, or where deemed acceptable for other systems. Combination waste and vent piping should be two sizes larger than otherwise required for drainage only. Horizontal branch waste and vent piping should be provided with vent-pipe connections so as to permit air circulation through such horizontal branch drains.

Indirect Waste Piping

The installation and sizing of indirect waste piping should in most respects be the same as for direct waste piping. However, indirect waste piping is subject to much greater incidence of stoppage development because of the relatively slow rates at which wastes are discharged into such piping from the various types of fixtures permitted to discharge indirectly. One of the most important requirements for such piping is the provision of an accessible cleanout at each change of direction in horizontal piping, regardless of the angle at which the change is made.

Indirect waste pipes should discharge through an air break into a suitable water-supplied fixture which is directly connected to the sanitary drainage system. The air break should be provided by terminating the open end of the indirect waste pipe at least 1 in (2.5 cm) above the flood rim of the receiving fixture. The receiving fixture in each case should be of a type acceptable for such use, such as a sink or floor drain, and should be located in a well-ventilated area where the discharge of waste-pipe odors into the atmosphere at the terminal will not become objectionable.

Vent pipes need not be provided to protect the water seals of fixture traps connected to indirect waste piping. Such piping seldom is subject to severe pneumatic effects because of the low rates of flow therein. However, where indirect waste piping exceeds 15 ft (4.6 m) in developed length and conveys just drippage from refrigerators and showcases and where indirect waste piping for other fixture wastes exceeds 100 ft (30.5 m) in developed length, such piping should be extended to the atmosphere, preferably above the building roof, independent of vent piping for the regular sanitary drainage system, and terminated as required for vent extensions through roofs. Such ventilation of indirect waste piping is necessary to prevent rapid fouling of the piping due to the activity of slime molds in the absence of adequate air circulation.

Special Wastes

Special methods for discharging wastes are recommended for use in conjunction with emptying, overflow, and relief pipes of the water supply system. Such pipes should not be connected directly to the drainage system because of the possibility of contaminating the potable water supply system. They should discharge either through an air break into a fixture acceptable for such use or onto a roof. The same precautions and methods should be applied with regard to drain pipes of expansion tanks and sprinkler systems and to the discharge pipes from cooling jackets.

Drip and overflow pans and similar equipment which discharges clear water only should be discharged through an air break into a fixture acceptable for such use or onto a roof. Such equipment should not be directly connected to the regular sanitary drainage system, for in the event of a stoppage condition in the system, sewage backup could occur at the equipment and cause an unnecessary, unsanitary, and objectionable condition. This should be avoided.

Steam expansion, blowoff, condenser, and cooling tanks provided to receive and handle discharges from steam exhaust and boiler blowoff pipes should discharge through an air break into a fixture acceptable for such use or should discharge by means of a direct connection to the building sewer where permissible.

Storm-Water Disposal

Buildings should be equipped with provisions for draining water from roofs and paved areas, including yards and courts. Storm water should be conveyed to an adequate and unobjectionable system of storm-water disposal, such as a public storm or combined sewer where available. No storm water should be discharged into sewers intended for sewage only, nor should it be discharged so that water flows across public sidewalks, drains onto adjacent premises, causes erosion of soil, or forms a pond on the premises. Storm water may be disposed of into an existing stream on or adjacent to the premises or into an adequate system of dry wells constructed underground. The subject of storm-water drainage is discussed in Chap. 19.

Wherever public storm or combined sewers are available for disposal of storm water from a building, it is recommended that the storm drainage system of the building be connected to the public system. The convenience, reliability, capacity, and trouble-free performance recorded for public systems operated and maintained by public authorities have clearly established their superiority over any other method of storm-water disposal.

In most areas where public storm or combined sewers have been installed, it is mandatory that the storm-water drainage systems of buildings and premises be connected to the public system if the premises are within a reasonable distance of the system. The limits of what is deemed *availability* of the public system may vary in different areas and for different types of building occupancies. For example, a public system may be deemed available for a one- or two-family dwelling when the system is within 100 ft (30.5 m) of the premises as measured along the street. For any other type of building occupancy, the public system may be deemed available when it is within 500 ft (152 m) of the premises.

Storm-water drains which connect to a combined building sewer or building drain should be designed to prevent escape of sewer gases and objectionable odors from the combined system. This should be avoided either by means of an individual trap installed in the horizontal branch serving each leader and area drain or by means of a single trap installed on the main storm-water drain serving all leaders and area drains prior to its connection with a combined building drain, building sewer, or public sewer. Such traps should be of the same size as the horizontal drain in which they are installed, should be provided with an accessible cleanout on the inlet side, should be located within the building, and, in the case of leaders, should be located in the horizontal piping at the base of leaders.

Provisions should be made to exclude from storm drains any solid particles and objects that may otherwise cause stoppage conditions in the drains. Strainers should be installed in the inlets to leaders. They should extend at least 4 in (10 cm) above the roof or gutter surface at the leader inlet and should have a clear open area at least 1½ times that of the leader, except that for roof drains of sun decks, parking decks, and similar areas which are usually serviced and maintained, strainers may be of the flat-surface type installed level with the deck but should have a clear open area at least twice that of the leader. All openings through roofs for roof drains must be made watertight.

Storm drains in buildings may be sufficiently long so that flow has ample time to adjust itself and reach a state of equilibrium or uniform flow condition. High velocity and surges in flow entering a long horizontal drain of constant shape and slope are dissipated gradually owing to pipe friction. Thereafter, flow proceeds at a rate corresponding to uniform flow conditions for the drain.

Sizing of horizontal storm drains is based on the quantity rate of uniform flow for drains flowing full, under no pressure, after many years of service. The velocity and capacity corresponding to full flow in galvanized-iron and cast-iron storm drains laid at a slope of ¼ in/ft (2 cm/m) are shown in Table 16.5. For drains laid at other slopes, appropriate multipliers are also given in the accompanying text. These multipliers may be applied to the values tabulated for drains laid at a ¼ in/ft (2 cm/m) slope.

The maximum rate at which storm water should be conveyed from drainage areas may be assumed to be the same as the rate at which storm water may collect thereon. This is dependent on the maximum rainfall rate recorded in the region of the building installation and on the amount of storm-water collection area. For many regions in the United States, the maximum rainfall rate recorded over a 10-min period is 4 in/h (10 cm/h). At this rate, the amount of drainage area on which 1 gal (3.79 L) of storm water will collect in 1 min is 24 ft^2 (2.23 m^2).

By applying a value of 24 ft^2 (2.23 m^2) as the collection-area equivalent to 1 gpm (3.79 L/s) of maximum storm drainage flow, tables showing uniform flow capacities in gallons per minute for sloping drains flowing full can be converted to terms of maximum permissible storm drainage areas which may be served by various sizes of drains in such regions.

Subsoil Drainage

Subsoil drains installed under a cellar or basement floor or surrounding the outer walls of a building so as to drain water from such subsoil regions should be at least 4 in (10.2 cm) in size and consist of open-jointed, horizontally split or perforated piping of acceptable material. Where such piping discharges to a public sewer, subsoil drains should be connected to an accessible silt and sand intercepting trap, and the liquids therefrom should be disposed of into the storm drainage system of the building. Where the drain from the intercepting trap is connected directly to a gravity storm drainage system which discharges into a public sewer system, an accessibly located backwater valve of acceptable design should be provided in the drain at the outlet side of the intercepting trap.

CHAPTER 17

VENT SYSTEMS

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INTRODUCTION

A *vent system* is a pipe or pipes installed in a drainage system (*a*) to provide a flow of air to and from a drainage system so as to ventilate it, (*b*) to provide a circulation of air within such a system to eliminate trap siphonage and reduce back pressure and vacuum surge, and (*c*) to ensure the rapid and silent flow of waste. Thus the sanitary drainage system of a building should be provided with an attendant system of vent piping designed so as to permit gases and odors in all parts of the drainage piping to circulate up through the system and escape into the atmosphere above the building and to permit the admission and emission of air in all parts of the system so that siphonage, aspiration, or back-pressure conditions will not cause an excessive loss of trap seal under ordinary conditions of use. The sizing, arrangement, and installation of attendant vent piping should be designed so as to limit air-pressure variations in all fixture drains to a differential not exceeding 1 in (2.5 cm) of water column above or below atmospheric pressure.

Adequate circulation of air by induced head or draft through the entire drainage and vent-piping system is an effective aid in avoiding accelerated corrosion of piping which may otherwise occur from such aggressively corrosive gases as hydrogen sulfide and ammonia normally present in significant amounts in sewer gases. Where inadequate air circulation occurs in drains, fungi find conditions favorable to their growth, and they produce slime. If the slime is not scoured from the piping by flow at sufficiently high velocity, it may accumulate to the degree that a stoppage condition occurs.

The water seals of fixture traps provide a means of keeping objectionable gases and odors confined to the drainage system of the building and preventing them from escaping into rooms in which fixtures are located. To maintain water seals against being lost as a result of siphonage, aspiration, or back-pressure conditions accompanying excessive variations in pneumatic pressures in fixture drains, vent pipes should be provided so as to supply and to remove air at whatever rates may be required in order to limit air-pressure variations to a degree that the water seals can effectively resist. As the minimum required trap seal depth is 2 in (5 cm), the permissible air-pressure variation in fixture drains is appropriately limited to 1 in (2.5 cm) of water column. Consequently, this provides a practical basis upon which to size vent piping.

This chapter first defines and illustrates various terms used in vent systems. Then methods of venting are described. This is followed by a discussion of venting systems, the flow of air in vent piping, and the methods of sizing vents.

TERMINOLOGY

Air-pressure relief vent. See *Relief vent.*

Back vent. A *back vent* is sometimes used as a synonym for a *vent* or an *individual vent.*

Branch vent. A *branch vent*, illustrated in Fig. 17.1, is a vent connecting one or more individual vents with a vent stack or stack vent.

Circuit vent. A *circuit vent*, illustrated in Fig. 17.2, is a branch vent that serves two or more fixtures and extends from in front of the last fixture to a connection with a vent stack.

Common vent. A *common vent* (also called a *dual vent*) is an individual vent, defined below, that is used for two fixtures and serves as a vent for both, as illustrated in Fig. 17.3.

Combination waste and vent system. A specially designed system that enables waste piping, purposely oversized, to serve both as a waste and vent pipe to avoid excessive pneumatic effects at fixture drains.

Continuous vent. A *continuous vent*, illustrated in Fig. 17.4, is a vent that is a continuation of and in a straight line with the drain to which it connects.

Dual vent. See *common vent.*

Ejector vent. An *ejector vent* is a vent pipe used to convey air to a receiving basin that collects the discharge of sanitary waste—called an *ejector basin.*

Individual vent. An *individual vent* (also called an *individual back vent* or *revent*), illustrated in Fig. 17.5, is that part of a vent-pipe line that connects directly with any individual waste or group of wastes underneath or at the back of a fixture and extends to either a vent stack or a branch vent.

Local vent. A *local vent* is a pipe that conveys foul air from a plumbing fixture to the outer air.

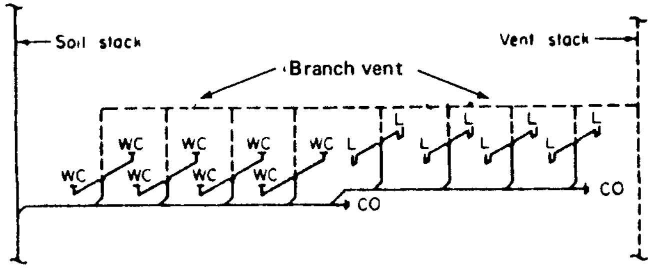

FIG. 17.1 Branch vent.

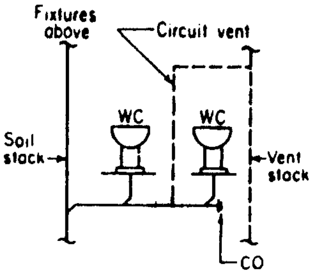

FIG. 17.2 Circuit vent.

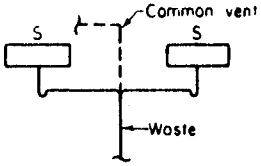

FIG. 17.3 Common vent.

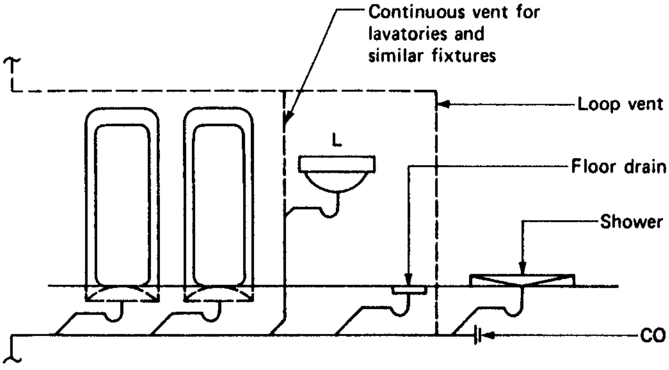

FIG. 17.4 Continuous vent.

Loop vent. A *loop vent*, illustrated in Fig. 17.6, is a branch vent serving two or more fixtures that is connected into the same stack into which the fixtures discharge.

Relief vent. A *relief vent*, illustrated in Fig. 17.7, is either (*a*) a vent which provides circulation of air between drainage and vent systems or (*b*) an auxiliary vent that connects the vent stack to the soil or waste stack in multistory buildings and is used to equalize pressure differences between them.

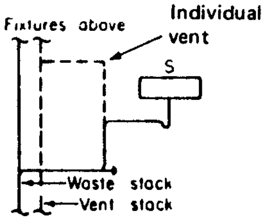

FIG. 17.5 Individual vent.

Revent. See *Individual vent.*

Soil vent. See *Stack vent.*

Stack vent. A *stack vent* (also called a *waste vent* or *soil vent*), illustrated in Fig. 17.8, is the extension of a soil or waste stack above the highest horizontal drain connected to the stack.

Stack venting. The continuous venting of a single fixture or a group of fixtures connected directly to a soil or waste stack. Thus a group of fixtures such as those from a bathroom and a kitchen can be installed without providing individual fixture vents—provided each fixture drain is independently connected to the stack and the water closet and bathtub or shower-stall drain enter the stack at the same level.

Vapor relief vent. See Chap. 5.

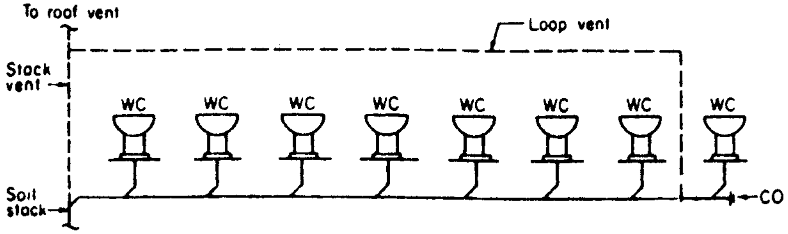

FIG. 17.6 Loop vent.

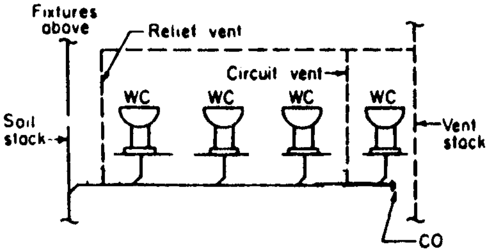

FIG. 17.7 Relief vent.

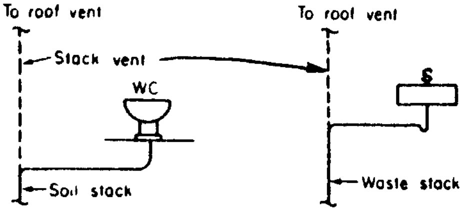

FIG. 17.8 Stack vent.

Vapor vent. Same as *local vent.*

Vent extension. A *vent extension* is a pipe from the uppermost drainage branch connection through the roof to the atmosphere.

Vent header. A *header* is a pipe of many outlets. The outlets may be parallel and may be at 90° to the centerline of the header. A *vent header*, shown in Fig. 17.9, is a header (i.e., a horizontal vent pipe) that connects the tops of vent stacks or stack vents at the header; a single vent pipe extends from the header to the open air above the roof.

Venting. The replacement of air that is carried out of a stack into the building drain and sewer by the waste water. The following methods of venting are commonly employed:

Vent pipe. A *vent pipe* is any pipe in a plumbing system used to equalize pressures and ventilate the system; it is a component of a vent system.

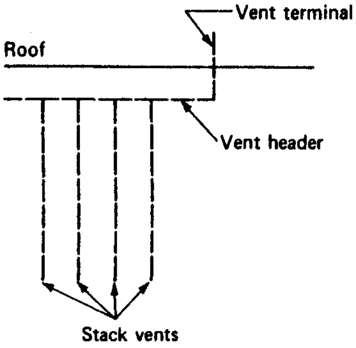

FIG. 17.9 Vent header.

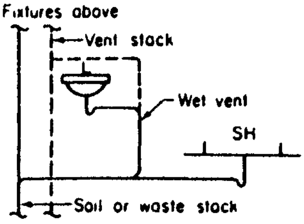

FIG. 17.10 Wet vent.

Vent stack. A *vent stack* is a vertical vent pipe serving branch vents for fixtures on two or more building stories. Also see *Stack vent.*

Wet vent. A *wet vent,* illustrated in Fig. 17.10, is a vent into which a fixture (or fixtures) other than a water closet can discharge. Thus it is a vent that also serves as a drain. Wet vents are used to reduce the vent piping required for a given installation by making individual pipes serve two purposes. Their use simplifies the drainage system and substantially reduces its cost.

Yoke relief vent, yoke vent. A *yoke relief vent,* illustrated in Fig. 17.11, is a vent connected to a soil or waste stack that continues upward to the connection with the vent stack for the purpose of reducing pressure changes in the stack.

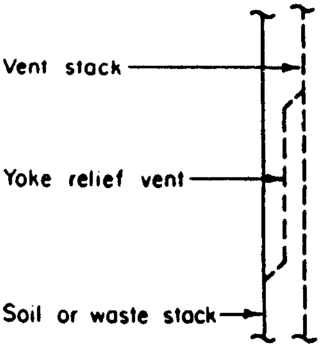

FIG. 17.11 Yoke relief vent.

Drainage Stack Vent Extensions and Vent Stacks

Each drainage stack connected to the sanitary drainage system should be provided with a vent pipe extending from the top of the highest drainage branch fitting on the stack to the atmosphere above the building roof. This vent extension of the drainage stack is necessary to permit gravity circulation of air up through the stack to the atmosphere at an unobjectionable location and to permit air to enter the top of the stack as rapidly as is required to replace the air which is dragged down by flowing water descending in the stack. Drainage stack vent extensions may be connected together as a vent header above the flood-level rims of the highest fixtures discharging into the drainage stacks, and a single vent pipe may be extended from the vent header to the atmosphere above the roof.

An attendant vent stack should be installed with each soil or waste stack which has drainage branch connections for present or future fixtures on two or more stories. The purpose of the vent stack is to prevent development of excessive air pressure in the lower region of the drainage stack by relieving air therefrom at as rapid a rate as it is carried down the drainage stack by liquids discharged by fixtures into the upper section of the stack. The most effective place for the vent-stack base to be connected, consequently, is at the bottom of the drainage stack, below the level of all drainage branch connections and, preferably, to the top of the horizontal drain immediately adjacent to the base fitting, where air-pressure rise is maximum and potential stoppage or closure of the vent connection by grease and other deposits is minimum. The recommended vent-stack base connection is illustrated in Fig. 17.12.

Each vent stack should extend undiminished in size to the atmosphere above the building roof as an independent vent extension, or it should be connected to the vent extension of the drainage stack it serves at an elevation of at least 6 in (15 cm) above the flood-level rim of the highest fixture discharging into the drainage stack or to a vent header to which the drainage stack connects.

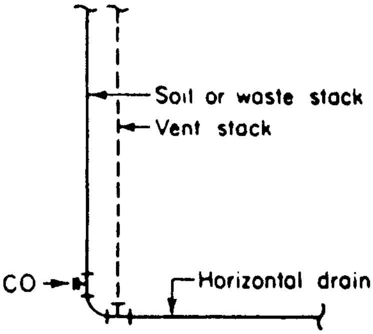

FIG. 17.12 Recommended vent-stack base connection.

Offsets in drainage stack vent extensions, offsets in vent stacks, and connections of the bases of vent stacks to the drainage stacks or the horizontal drains therefrom should be made at an angle of at least 45° to the horizontal wherever the piping is of a scale- or rust-producing type so as to avoid accumulation of scale or rust therein and resultant loss in venting capacity. Where the entire piping above such offsets is of a nonscaling type, the offset angle may be reduced, provided there is sufficient slope in the vent piping for condensation to drain back to soil or waste pipe connections.

Terminals of all extensions of drainage and vent stacks should be located so as to be unobjectionable. They should not terminate within 10 ft (3 m) of any door, window, or opening for ventilation unless the terminal is located at least 2 ft (0.61 m) above such an opening. Terminals should extend at least 6 in (15 cm) above building roofs, but where a roof is used for other than just incidental access, the terminal should be located at least 5 ft (1.5 m) above the roof. Vent extensions should not be extended through an exterior wall unless it is impractical to extend the piping through a roof. In such a case, the terminal should open downward and be equipped with a screen so as to prevent birds from nesting therein. In no case should the terminal be located beneath an eave or overhang of the building or within 10 ft (3 m) horizontally of the lot line of the premises.

On several occasions in the past, courts have been called on to decide cases arising from vent terminals, their effects with regard to adjacent new buildings, and the effects of new buildings erected adjacent to vent terminals. Such decisions may be used as a guide to proper terminal locations. They are as follows: (*a*) where a structure is to be built higher than the vent terminal of an adjacent building and thereby adversely affects the vent system of the adjacent building, or when such a vent terminal would become a potential nuisance to occupants of the higher structure, the owner of the higher structure shall, at the owner's expense and with the consent of the owner of the adjacent building, cause such vent to be extended or altered to correct the condition; and (*b*) where a vent terminal is to be installed adjacent to an existing higher building, the proposed vent terminal shall be installed by and at the expense of the owner of the lower building, in conformity with plumbing regulations, including any necessary extension of the vent terminal to a location sufficiently remote to prevent the creation of a foul-air nuisance to occupants of the higher building.

Air-Pressure Relief Vents

Drainage systems, especially those in tall buildings, are frequently found to develop extremely high and objectionable pneumatic effects in several specific portions of such piping. Special air-pressure relief vents are recommended to control, within tolerable limits, any air-pressure fluctuations that otherwise may occur at these portions of the system. They are generally specific locations where the cross-sectional area of the drain may suddenly become filled with liquid, thereby constricting the area available for passage of air through the drain at the same high-quantity rate of flow as it is dragged down into the drain by the flowing liquid. When air is dragged into a zone where airflow constriction or blockage occurs, the pressure may rise sharply and cause excessive back pressure and blowout of fixture-trap seals connected to the zone. This must be prevented.

One such zone occurs where a horizontal building drain is offset vertically, or drops at a 45° angle, more than 10 ft (3 m) in invert elevation. Airflow constriction may occur in the horizontal building drain at the base of the vertical drop in the same manner as it occurs in a horizontal drain at the base of a drainage stack. An air-pressure relief vent at least one-half the diameter of the building drain should be provided at the top of the vertical offset so as to supply such additional air to the drain as may be required by the sudden increase in liquid velocity in the vertical offset. Where a building trap or other sharp change in flow direction is provided in the building drain downstream from the vertical offset, an air-pressure relief vent should be provided at the base of and within 3 ft (0.91 m) of the vertical offset.

The relief vent connected at the base of the offset should be sized as a vent stack, considering the vertical offset in the building drain as a soil or waste stack. This lower relief vent should be branch-connected to the upper relief vent at a sufficient height so that they cannot serve to bypass sewage flow in the event of a stoppage in the vertical offset.

Another zone occurs in drainage stacks of extended height. Excessive interference with air flowing down a stack with liquids from upper stories may occur where additional liquid is simultaneously discharged into the stack at high rates of flow through lower drainage branches. This interference with the flow of air down a tall drainage stack is not unusual. Consequently, provision should be made to prevent occurrence of excessive back-pressure effects. The recommended provision for soil and waste stacks more than 10 stories in height is to provide a yoke relief vent at each tenth story of the drainage stack, counting downward from the top story. The lower end of the yoke relief vent should connect to the drainage stack by means of a Y located below the horizontal branch drain serving fixtures in that story, and the upper end should connect to the vent stack by means of a T or inverted Y located at least 3 ft (0.91 m) above the floor level (see Fig. 17.13).

An additional zone occurs in drainage stack offsets which are made at an angle of more than 45° from the vertical and are located more than 40 ft (12.2 m) below the highest drainage branch connection to the stack. Such offsets are subject to extremely turbulent flow conditions and excessively high pneumatic effects.

The recommended relief-vent provisions are as follows: either provide for the drainage stack section below the offset and for the drainage stack section above the offset the same venting provisions, such as attendant vent stacks and drainage stack-vent extensions, as would be required if they were two separate drainage stacks, or provide a relief vent at the top of the drainage stack section below the offset and a yoke vent at the base of the upper stack section (see Fig. 17.14).

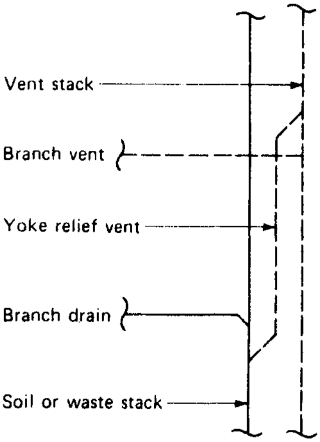

FIG. 17.13 Yoke relief vent.

Suds-Pressure Zones and Suds-Pressure Relief Vents

The soap and chemical industries have developed and marketed many new products which have replaced the use of bar soap for numerous cleaning tasks. These detergents have gained wide public acceptance and general use for a large variety of cleaning operations. Coincident with the extensive use of these new products in place of bar soap, a marked change has occurred in the characteristics of household wastes conveyed by sanitary drainage systems. A tremendous increase in the volume of suds accompanying wastes has resulted. When upper-floor fixtures and appliances discharge wastes containing detergents, the suds-producing ingredients mix vigorously with air as the wastes churn down the inner wall of the drainage stack. These suds flow down and settle into the lower sections of the drainage system. It has been found frequently upon investigation that

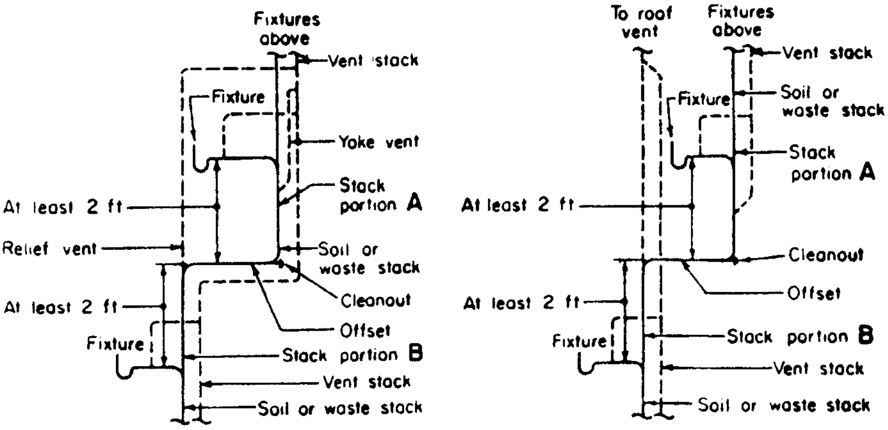

FIG. 17.14 Alternative methods of relief venting for 60° and 90° offsets in drainage stacks.

the sanitary building drain and the lower section of soil, waste, and vent stacks were laden with suds and remained in that condition for considerable periods of time.

When upper-floor fixtures discharge into a stack, the wastes churn down the inner wall of the stack and drag or force air down into the lower sections of the system. Liquid wastes are heavier than suds and easily displace and flow through the suds-laden lower drainage piping to the sewer. However, the air which is forced down into the body of suds compresses and forces them to move through any available paths of relief.

These relief paths may include the building drain, its branches, the vent-stack base connection, branch vents, and individual vents connected to the lower section of the system. These paths of relief may not be available, or they may be cut off or constricted by sudden increases in the cross-sectional area occupied by liquid flow, or they may be inadequate because of arrangement, location, or pipe size. If one or more of these conditions prevail, abnormally high suds pressure may develop in such zones and force trap seals connected to the system.

Cutoff or constriction of the cross-sectional area available for suds flow in drainage piping may occur at sharp changes of direction, such as in the horizontal drain at the base of a stack. Extreme turbulence in liquid flow occurs at such directional changes. The turbulence is accompanied by a *hydraulic jump* in the horizontal drain at a point where velocity reduction is most severe and produces a sudden increase in the cross-sectional area occupied by liquid flow. A hydraulic jump is illustrated in Fig. 16.1.

The cutoff or constriction of suds flow at the hydraulic jump creates a zone where pressure of suds can develop and extend upstream for a considerable distance unless a means of relief is provided. Where vent-stack base connections, branch vents, or individual vents are required to serve as relief paths from suds-pressure zones, very often they are found to be inadequate for such use and suds backup conditions appear at plumbing fixtures. It should be understood that the vent-pipe sizing tables given in most current codes, including nationally recognized model codes, are based exclusively on airflow capacity and give no consideration to suds flow capacity. Hence sizes determined in applying such tables may prove inadequate for suds-pressure relief.

Suds are much heavier than air, do not move with the same ease, and produce considerably more friction loss for the same rate of flow. The density of old or regenerated suds, compared with that of air, varies from a minimum of about 2.7 to a maximum of about 18.7 for various kinds of detergents in common use. On the basis of these values and appropriate assumptions, it may be calculated that for equal rate of flow and pressure drop, the vent-pipe diameter for suds relief flow should be from 21.5 to 80 percent larger than for airflow.

Two alternative methods for eliminating suds-pressure conditions in drainage systems have been devised on the basis of field tests and investigations of systems in tall residential buildings. The choice of method to apply may be based on whether a building is in the process of being designed or already existing and on the economics and difficulties involved.

The first method may be applied most advantageously in designing new systems. It is as follows: wherever a soil or waste stack is to receive wastes at an upper-floor level from sinks, laundry trays, laundry washing machines, or other fixtures in which sudsy detergents are normally used, the drainage and vent piping for lower-floor fixtures should be arranged so as to avoid connection to suds-pressure zones in and adjacent to the stack.

Suds-pressure zones should be considered to exist in the following locations:

1. *In a soil or waste stack offset of 60° or 90° serving fixtures on two or more floors and receiving wastes from fixtures wherein sudsy detergents are used:* a zone extending 40 stack diameters upward and 10 stack diameters horizontally from the base fitting for the upper stack section and a zone extending 40 stack diameters upstream from the top fitting for the lower stack section
2. *At the base of the stack:* a zone extending upward from the base a distance of 40 stack diameters
3. *In the horizontal drain from the base of the stack:* a zone extending horizontally from the base a distance of 10 drain diameters, and where a 60° or 90° offset fitting is installed in the horizontal drain, a zone extending 40 drain diameters upstream and 10 drain diameters downstream from the fitting
4. *In a vent stack having its base connected to a suds-pressure zone in the drainage stack or horizontal piping therefrom:* a zone extending from the vent-stack base connection upward to above the level of the suds-pressure zone in the drainage stack

The four suds-pressure zone locations listed are also illustrated in Fig. 17.15.

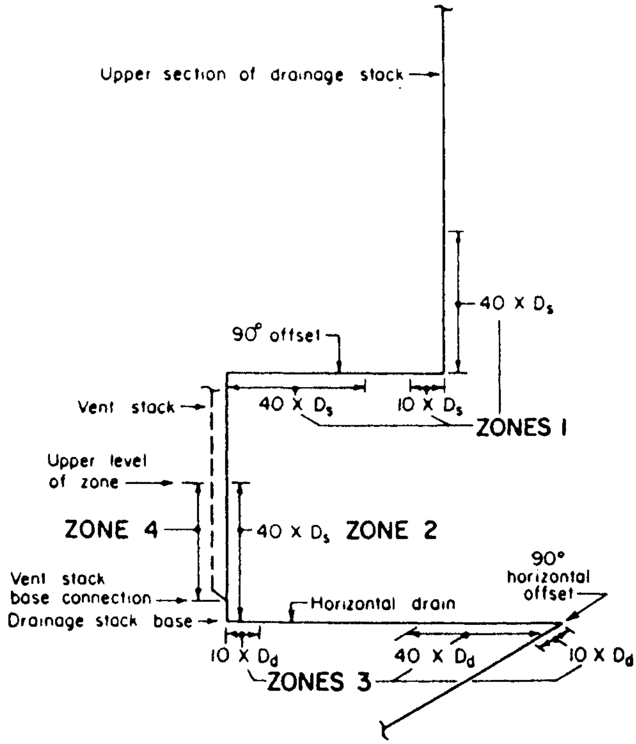

FIG. 17.15 The four suds-pressure zones.

The second method provides a practical solution which may be applied to existing systems. In such systems, where suds backup conditions develop at lower-floor fixtures connected directly to such pressure zones, it is usually found to be excessively costly, impractical, or otherwise undesirable to change the arrangement of drainage and vent piping connections for the fixtures. A more appropriate method under these circumstances is to provide suds-pressure relief vents. *A suds-pressure relief vent should be connected to each suds-pressure zone and installed so as to relieve suds pressure, therefrom to a nonpressure zone downstream from and at a lower elevation in the sanitary drainage and vent system.*

At 60° or 90° offsets in soil or waste stacks, the suds-pressure relief vent should be connected to the stack at fixture rim level just above the offset and then dropped down to a connection just below the offset so as to permit suds to overflow and run off through the suds-pressure relief vent and bypass the zone of constricted flow through the offset.

At the base of soil or waste stacks, the suds-pressure relief vent should be connected to the stack at fixture rim level just above the base of the stack and then dropped down to a connection to a nonpressure zone in the house (building) drain. This permits suds to overflow and run off through the suds-pressure relief vent and bypass the zone of constricted flow through the horizontal drain.

Figure 17.16 illustrates recommendations for relief of suds-pressure conditions at the bases of soil or waste stacks in high-rise residential buildings. Note that the suds-pressure relief-vent connection is made to the drainage stack at fixture rim level [36 in (0.91 m) maximum] so as to avoid creating a potential sewage bypass condition in the event of a stoppage occurring at the base of the stack. Note also that the size of the suds-pressure relief vent is 3 in (7.6 cm), or three-fourths the diameter of the stack in which the suds-pressure zone occurs. The suds-pressure relief vent drops down and connects to a nonpressure zone in the upper end of the house (building) drain where pressure conditions usually are minimum, although other nonpressure zones farther downstream in the house (building) drain might be found equally suitable. In most instances, this is the most practical, economical, and desirable method to apply to existing systems where suds backup conditions develop at lower-floor fixtures connected directly to suds-pressure zones.

Probably other satisfactory methods may be applied to eliminate the development of excessive suds pressure in the lower sections of sanitary drainage systems. Undoubtedly, larger pipe sizes may be applied advantageously for horizontal drains at the bases of drainage stacks and for the lower sections of vent stacks. However, this should be properly tested and developed in the field or conclusively established by computations or research.

In industrial or loft buildings of the multistory or high-rise type occupied or used for light industry, sudsy detergents are frequently used in processes such as washing, dyeing, and shrinking of cloth and textiles or washing, separating, and recovering gold and precious metals. In such cases, the disposal of sudsy industrial wastes has caused serious suds backup problems at lower-floor plumbing fixtures when the sudsy wastes were discharged into the regular drainage stacks at upper levels. *For such process wastes, it is recommended that they be disposed of by an independent waste system discharging directly into the house (building) drain at its lowest elevation (at the front wall of the building) or into the building sewer. The objectionable effects of process wastes should be avoided, and*

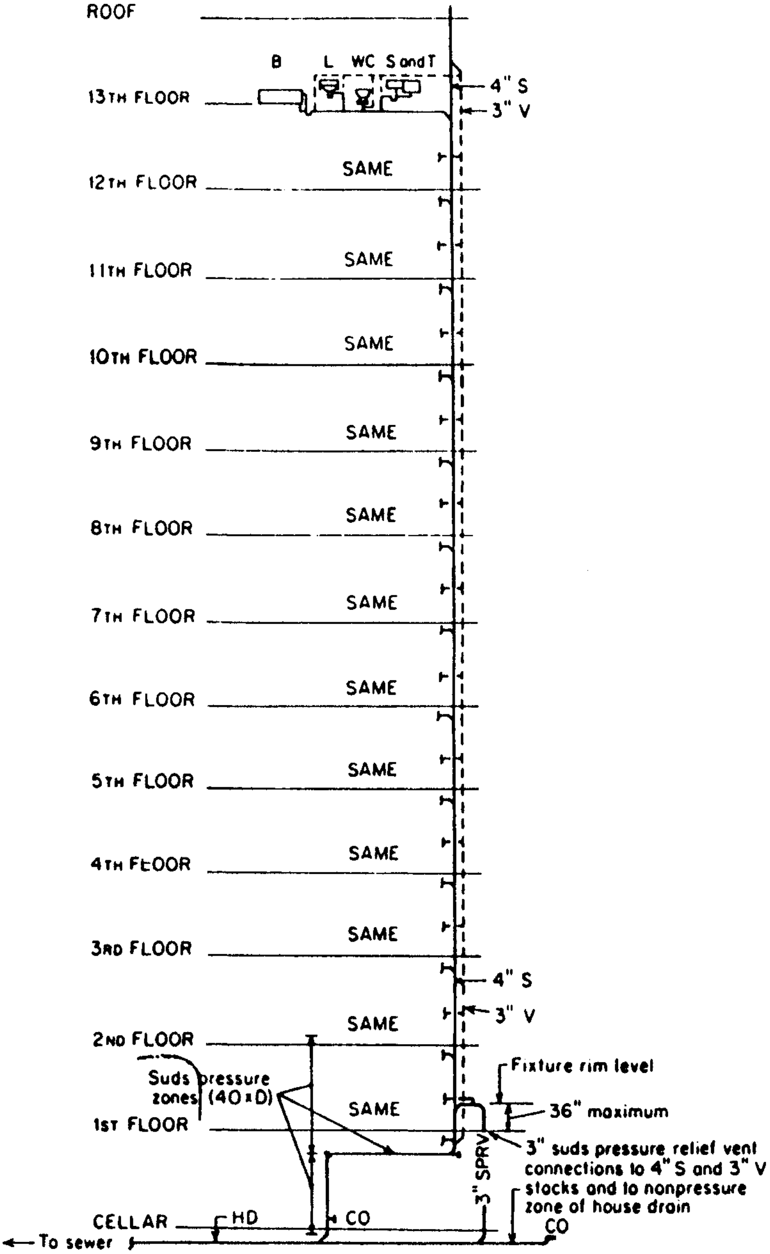

FIG. 17.16 Suds-pressure relief vent connections for high-rise stack systems.

the industrial occupancy should be prevented from adversely affecting the performance of the regular plumbing system of the building.

Air-Pressure Relief for Pneumatic Ejectors

A *pneumatic ejector* is a special type of device designed to receive and dispose of liquids and sewage from subbuilding drainage systems. This device is specially designed to apply compressed air as the means of expelling liquids and sewage accumulated in the receiver, forcing them out and up through a discharge pipe to a suitable height and discharging them into the gravity building sewer. An inlet and an outlet check valve are provided at the pneumatic ejector. Liquids and sewage enter the device at atmospheric pressure and displace air therefrom into an air-pressure relief pipe. When the ejector is filled to a predetermined level, the device operates automatically, shutting off the air-pressure relief pipe, allowing compressed air to enter the ejector and expel its liquid contents, shutting off the supply of compressed air when the liquid contents have been expelled, and opening the air-pressure relief pipe to permit air pressure in the device to drop to atmospheric pressure conditions again.

The minimum air pressure required in the device to expel liquids therefrom is the pressure equivalent to the head of liquid in the discharge pipe plus the pressure loss due to flow in the discharge pipe. After discharging, the device must be relieved from such relatively high air pressure to atmospheric pressure before additional sewage may flow by gravity into the ejector. In no case should the air-pressure relief pipe for a pneumatic ejector be connected to the attendant vent piping serving a drainage system. To do so would produce severe pneumatic effects in such a system and result in blowout of fixture trap seals.

It is recommended that the air-pressure relief pipe from a pneumatic ejector be extended independently to the atmosphere and terminated at an unobjectionable location, preferably above the building roof. The size of the vertical section of such relief piping should be adequate to avoid frost closure at the roof terminal and to permit adequate venting capacity. It is generally required that such piping be at least 3 in (7.6 cm) in diameter and that a cleanout be provided at its base so as to permit removal of any scale or deposits that may accumulate at the base of the vertical section. The size of piping from the pneumatic ejector to the vertical section should be adequate to permit pressure in the ejector to be completely relieved to atmospheric conditions within a reasonable period. This has been deemed to be just 10 s, and the minimum size recommended for such piping under usual conditions is 1¼ in (3 cm).

Fixture-Trap Vents

Adequate vent pipes should be provided to protect the water seals of all fixture traps against excessive seal loss or voidance due to siphonage, aspiration, and back pressure under conditions of normal use. Where fixtures discharge directly into drainage stacks or into branch drains which discharge into drainage stacks and the drainage stacks are provided with adequate air supply at their tops and adequate attendant vent stacks to relieve air from their bottoms, the only additional vent protection required to prevent trap seal loss for such fixtures is that which is necessary to avoid excessive self-siphonage effects when the fixture discharges and to relieve excessive pneumatic effects occurring in the branch drains when other fixtures discharge through them.

Regulations prevailing in many areas of the nation require that the drain of each individual fixture be provided with a vent pipe, connected in a prescribed manner, to protect the water seal of each fixture trap. However, in numerous other areas, alternative special methods of venting fixture traps may be permitted for groups of fixtures in various arrangements. These methods are generally known as *wet venting, stack venting, circuit and loop venting*, and *combination waste and vent system*. Recommendations regarding application of these special methods have been included in model plumbing codes, based on research reports published by the National Bureau of Standards and other research agencies. As a result, these methods may be applied for economy in vent-piping design wherever they are acceptable to the authority having jurisdiction. They are described in the following sections under their respective titles (see Figs. 17.17 to 17.20).

Blowout-type water closets and urinals, during the initial phase of their discharge, produce very sudden and heavy surges with appreciable shock effects in the fixture drain. This necessitates providing an individual vent connected to the fixture drain of each blowout-type fixture in order to avoid transmitting such effects to other fixture traps connected to the same branch drain.

To protect a fixture trap against loss of seal due to siphonage when the fixture discharges, air must be allowed to enter the fixture drain at a level above the dip of the fixture trap so as to disrupt or prevent the development of siphonic action in the fixture drain as the last of the volume of water drains from the fixture. This prevents the sloping fixture drain from acting as the long outlet leg of a gravity siphon which otherwise might occur and siphon out the last amount of water flowing into the trap. An additional factor which tends toward producing siphonage effects is the velocity head, or momentum, of the water during peak rate of flow in the fixture drain. Research has shown that even though siphonic action occurred during fixture discharge, the trap seal might be completely refilled by a sufficient amount of trickling or trailing flow at the last phase of drainage from fixtures having flat bottoms of 1 ft^2 (0.093 m^2) or more, such as sinks, laundry trays, and bathtubs.

Nevertheless, it is recommended that vent connections to fixture drains be made above the level of the dip of the fixture trap for all fixtures except floor-outlet-type water closets and urinals, which are specifically designed to produce strong siphonic action for adequate fixture performance, and service or slop sinks, which are equipped with floor-outlet trap standards and sufficiently large flat bottoms to refill the trap seal when the fixture discharges. These exceptions are recommended in view of the practical difficulties and other objections encountered in venting such fixtures in the usual manner.

A single vent pipe which connects at the junction of two fixture drains above the level of the dip of each fixture trap may serve as an individual or *common vent* to protect both traps. This type of vent is shown with other types of individual vents in Fig. 17.17.

Vent connections to fixture drains should be installed so that the developed length of fixture drain between the weir of the fixture trap and the vent connection does not result in excessive self-siphonage effects. This length varies with the type of branch fitting into which the fixture drain discharges, the slope of the fixture drain, and its diameter. In view of the permissible types of branch fittings and drain slopes, the maximum permissible developed length may be based just on the diameters of fixture drains. Recommended maximum distance of a vent connection from the weir of a fixture trap is given in Table 17.1.

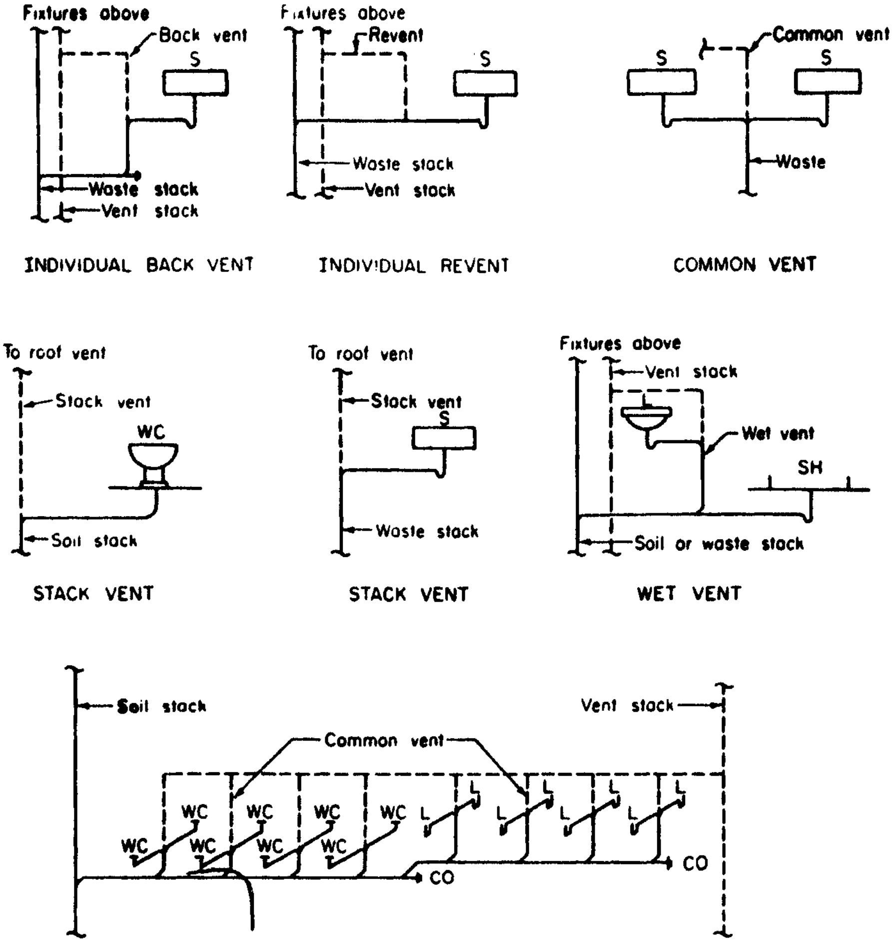

FIG. 17.17 Fixture trap vents.

TABLE 17.1 Maximum Distance of Vent from Fixture Trap

Size of fixture drain		Maximum distance of vent to trap	
in	cm	ft	m
1¼	3.18	2½	0.75
1½	3.81	3½	1.05
2	5.0	5	1.50
3	7.5	6	1.80
4	10.0	10	3.0

Vent connections should not be permitted to be made to the crown of any trap. Such vent connections have been proved to be worthless in a very short period of normal service. When wastes flow through a fixture trap, they are centrifuged against the crown of the trap, and they can enter and deposit waste matter in a vent connection attached to the crown. This results in rapid stoppage of the vent connection and failure in its capacity to provide necessary venting.

Vent piping should be installed in such a manner as to minimize the possibility of stoppage therein and especially prevent it from serving as a means of bypassing waste flow to other drains in the event of a stoppage development in the drain to which it is connected. This is necessary in order to maintain the vent piping at its maximum capacity for service.

Vent connections should be made to the top half of fixture drains and should rise at least at a 45° angle above the horizontal before offsetting horizontally. Each vent pipe connected to a fixture drain or branch drain should rise to a level at least above the flood rim level of the highest fixture discharging into the branch drain before the vent pipe connects to a branch vent, vent stack, or drainage stack vent extension.

Wet Venting

This special method of venting is intended as an economical means of providing adequate protection of fixture trap seals for a group of fixtures, such as a bathroom and kitchen group in a dwelling unit, when such fixtures discharge into a main drain or drainage stack in which only minor pneumatic effects may be anticipated. A single vent is used in this case to relieve whatever minor pneumatic effects may occur in the fixture and branch drains and to prevent excessive self-siphonage of water seals during fixture discharge.

On the top story of a building, an individually vented fixture drain of a lavatory, kitchen sink, or combination fixture may serve as a wet vent to protect the traps of a bathtub, shower stall, and water closet, provided

- Not more than one fixture unit of load is served by a 1½-in (3.8-cm) wet vent, nor four fixture units by a 2-in (5-cm) wet vent.
- The length of each fixture drain does not exceed the maximum distance permitted between a fixture trap and its vent connection.
- The horizontal branch drain connects to a drainage stack at the same level as, or below, the water-closet drain, or the horizontal branch drain connects directly to the upper half of the horizontal portion of the water-closet drain at an angle no greater than 45° from the direction of flow (see Figs. 17.18 and 17.19).

On the top story of a building, a common vent and drain for two lavatories, back-to-back, may serve as a wet vent to protect the traps of two bathtubs or shower stalls installed back-to-back, provided

- The fixtures discharge into the same horizontal branch drain.
- The length of each fixture drain does not exceed the maximum distance permitted between a fixture trap and its vent connection.
- The wet vent is at least 2 in (5 cm) in size, as illustrated in Fig. 17.19.

Below the top story of a building, an individually vented fixture drain of a lavatory or a common vent and drain for two lavatories, back-to-back, may serve as a wet vent to protect the traps of one or two bathtubs or shower stalls, provided

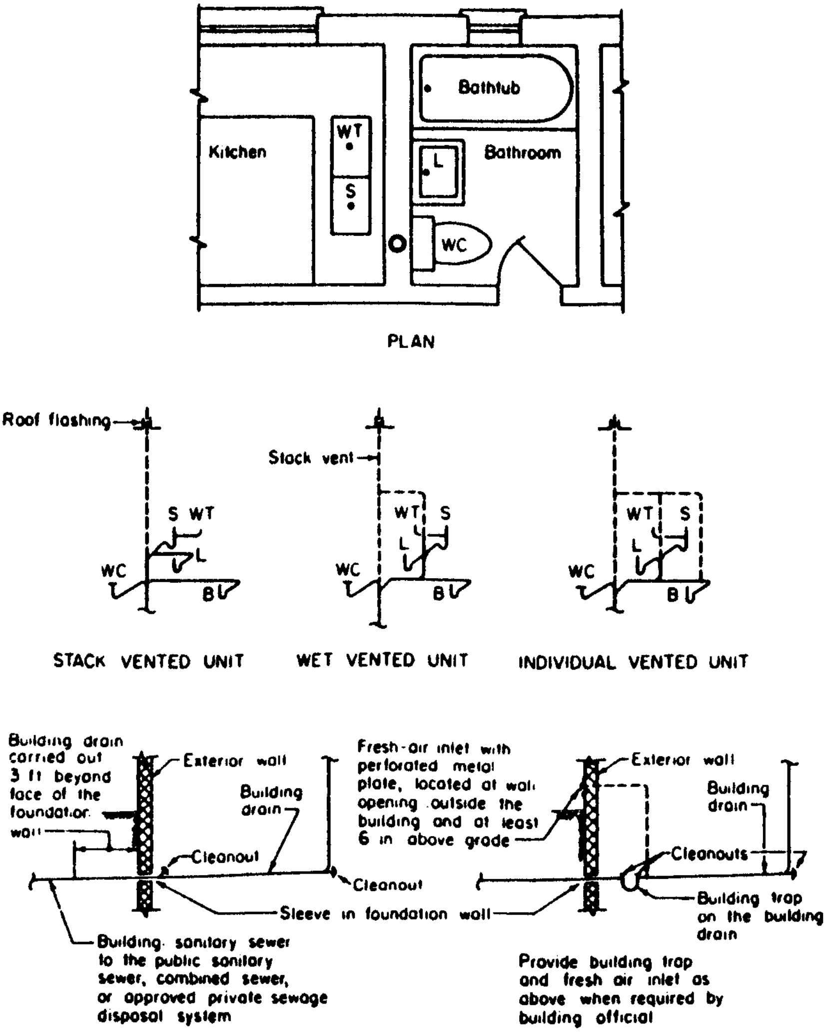

FIG. 17.18 Typical sewage drainage system for a one-family dwelling.

- The wet vent and its extension to the vent stack is at least 2 in (5 cm) in diameter.
- Each water closet below the top story is protected by an individual vent.
- The length of each fixture drain does not exceed the maximum distance permitted between a fixture trap and its vent connection.
- The vent stack is sized in accordance with Table 17.2.

Water closets below the top story of a building need not be protected by individual vents provided a 2-in (5-cm) wet-vented waste pipe connects directly to the upper half of the horizontal portion of the water-closet drain at an angle no greater than 45° from the direction of flow, as shown in Fig. 17.20.

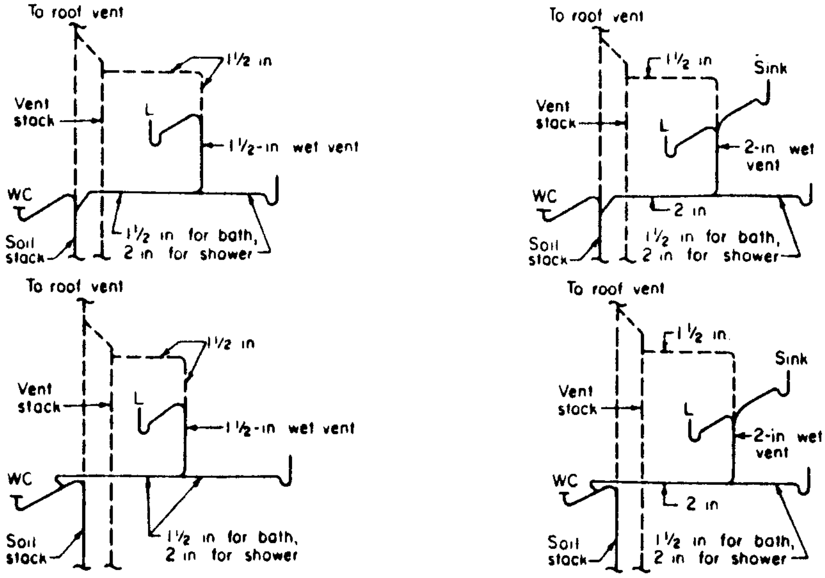

FIG. 17.19 Wet-vented single bathroom and kitchen fixture group on a stack or at top floor of a stack serving multistory bathroom groups.

TABLE 17.2 Size of Vent Stacks for Wet-Venting Bathroom Groups

	Diameter of vent stack	
Number of wet-vented fixtures	in	cm
1–2 bathtubs or showers	2	5.0
3–5 bathtubs or showers	2½	6.35
6–9 bathtubs or showers	3	7.5
10–16 bathtubs or showers	4	10.0

Stack Venting

This special method of venting is intended as an economical means of providing adequate protection of fixture trap seals for fixtures which are grouped adjacent to and at the top of a drainage stack, where only minor pneumatic effects may be anticipated in the drainage stack. In this case, the fixtures are individually connected to the drainage stack which serves as a vent connection to prevent excessive self-siphonage of water seals during fixture discharge.

Where a fixture discharges into a soil or waste stack above all other drainage branches, the drainage stack and its vent extension may serve as an individual vent to protect the fixture trap provided that the fixture drain connects to the drainage stack above the level of the dip of the trap, except for the fixture drains of floor-outlet-type water closets and urinals and of floor-outlet-type trap standards for service and slop sinks, and that the connection to the drainage stack is

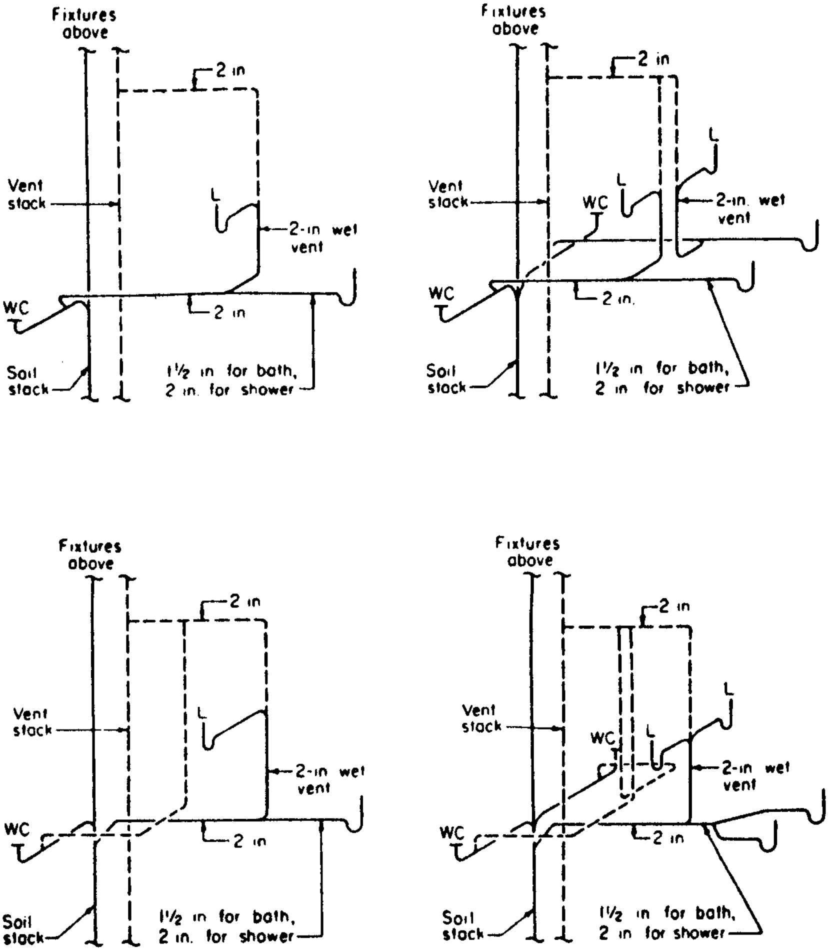

FIG. 17.20 Wet-vented multistory bathroom fixture groups below top-floor group.

not more distant than the maximum permitted between a fixture trap and its vent connection.

Where the highest two fixture drain connections to a soil or waste stack are for two horizontal fixture drains serving fixtures on the same floor level, the drainage stack and its vent extension may serve as an individual vent to protect the water seals of both fixture traps provided that the soil or waste stack is at least one pipe size larger than the highest fixture drain and not smaller than the lower fixture drain and that both fixture drains do not exceed in length the maximum permitted between a fixture trap and its vent connection.

In a 1-story building or on the top floor of a building, a group of fixtures on the same floor level consisting of one bathroom group and a kitchen sink or combination fixture may be deemed to be adequately protected by the drainage stack and its vent extension provided that each fixture drain connects independently to the soil stack, that the water-closet and the bathtub or shower-stall drains enter the stack at the same level, and that all fixture drains do not exceed in length the maximum permitted between a fixture trap and its vent connection. In an area where the public sewer may become overloaded sufficiently to cause frequent backwater conditions in the building sewer, a relief vent or an individually vented fixture drain should be connected to the soil stack below the fixture-drain connections serving a stack-vented water closet, bathtub, or shower stall, as illustrated in Fig. 17.17.

Circuit and Loop Venting

This special method of venting is intended as an economical means of providing adequate protection of fixture trap seals of floor-outlet-type fixtures which connect in battery arrangement to a horizontal branch soil or waste pipe wherein only minor pneumatic effects may be anticipated and the self-siphonage characteristics of the types of fixtures in this arrangement pose no problem. A single vent pipe connected to the most upstream section of the horizontal branch drain serves to relieve whatever pneumatic effects may occur therein.

With this method, a uniformly sized horizontal branch soil or waste pipe to which two or more, but not exceeding eight, floor-outlet-type water closets, shower stalls, or floor drains are connected in battery arrangement may be deemed adequately vented by means of a circuit or loop vent connected to the horizontal branch drain at a point between the two fixture drain connections most upstream on the drain. Lavatories and similar fixtures may be connected to the circuit- or loop-vented branch soil or waste pipe provided individual or common vents are installed to protect the traps of such fixtures (see Figs. 17.21 and 17.22).

Combination Waste and Vent System

This special method of venting is intended as an economical means of providing adequate protection of fixture trap seals for extensive floor- and shower-drain installations, floor sinks and drains in large markets, laboratory and work tables in school buildings, and similar installations where individual venting of fixture drains to protect trap seals is either impractical or causes undue hardship. With this method, the waste piping is purposely oversized so as to permit it to serve as both a waste and a vent pipe to avoid excessive pneumatic effects at fixture drains.

Combination waste and vent piping systems, limited for use as a means of venting the traps of floor drains and laboratory sinks, should be permitted in conjunction with horizontal branch waste piping of an independent acid-waste system or an independent flammable-oil-waste system or where deemed acceptable for other systems. Combination waste and vent piping should be two sizes larger than otherwise required for drainage only. Horizontal branch waste and vent piping should be provided with vent-pipe connections so as to permit air circulation through such horizontal branch drains.

SOVENT SYSTEM

A Sovent plumbing system, illustrated in Fig. 17.23, is a single-stack system used for both drainage and venting.* Because of its combined function, it may provide

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* *Copper Brass Bronze Product Handbook*, Copper Development Association, Inc., Greenwich, CT 06836.

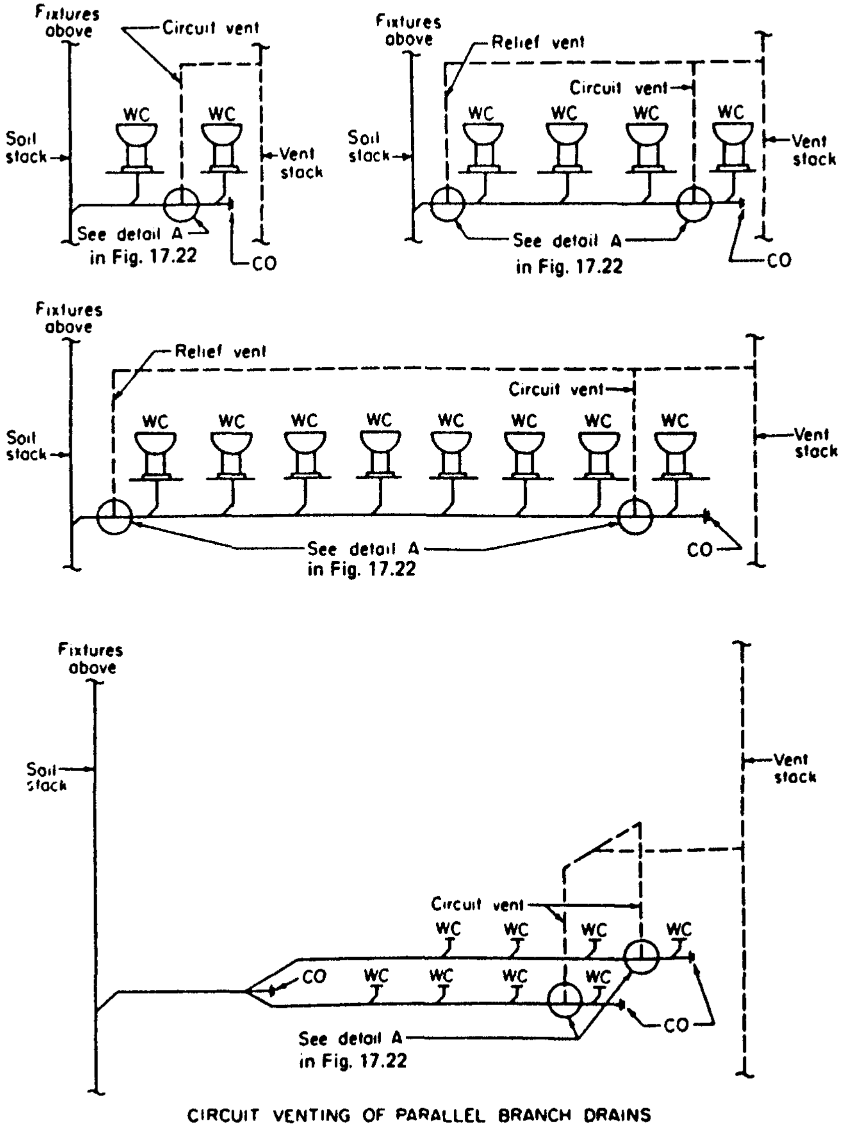

FIG. 17.21 Venting for batteries of fixtures: circuit venting.

for economy of installation, since less material is required than for a comparable two-pipe system, as can be seen from a comparison of Figs. 17.23 and 17.24. A conventional two-pipe system consists of (*a*) a drainage stack, i.e., a vertical drainage pipe which collects waste water and solids from fixture drains and horizontal branches from the different floors of a building, and (*b*) a vent stack installed primarily for the purpose of providing circulation of air to and from any part of the drainage system. Venting is provided by a *stack vent*, i.e., a stack carried up through the roof.

Although the Sovent system is based on familiar plumbing engineering principles that apply to all drainage systems, it is relatively new (introduced in the

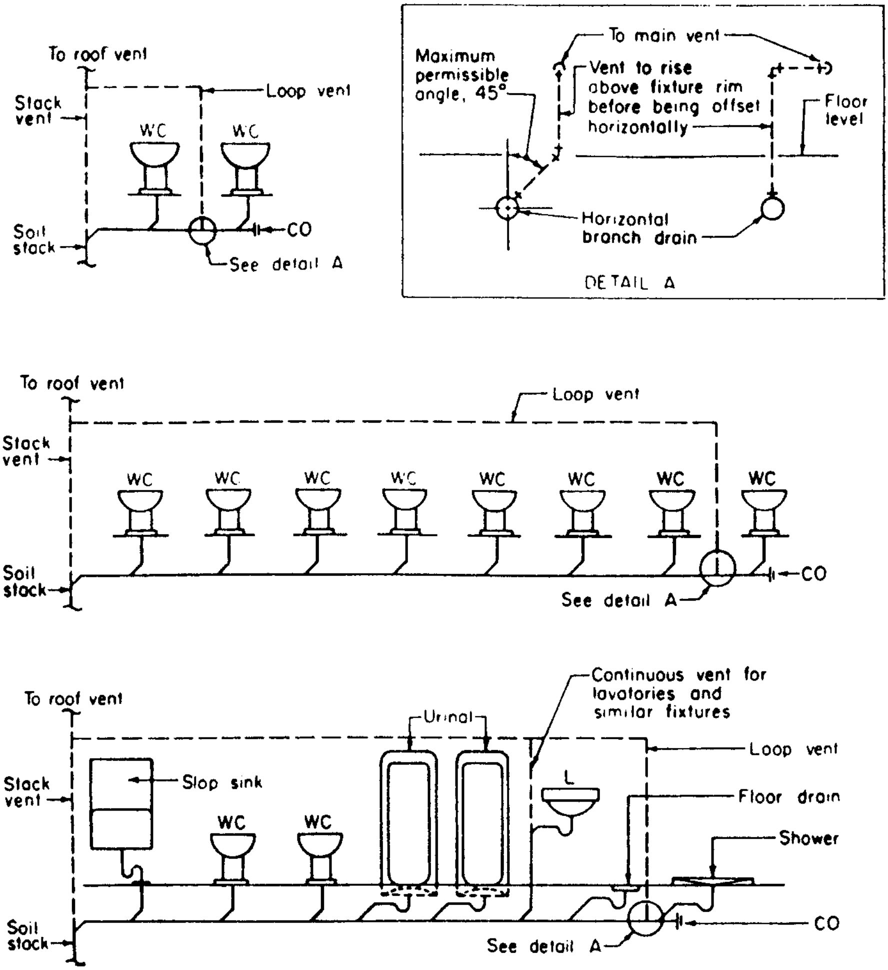

FIG. 17.22 Venting for batteries of fixtures: loop venting.

U.S.A. in 1968), so that it is not acceptable under some local codes. Therefore, code officials and the authority having jurisdiction should be consulted before such a system is designed.

The features of the system are illustrated in Fig. 17.25. The system is comprised of four major components:

- A *DWV (drain, waste, and vent) stack.*
- A *Sovent aerator fitting at each floor level* which (*a*) limits the velocity of both liquid and air in the stack, (*b*) prevents the cross section of the stack from filling with a plug of water, and (*c*) mixes the waste flowing in the branches efficiently with the air in the stacks.
- *DWV horizontal branches.*
- *Sovent deaerator fitting* at the base of the stack and at the upstream end of each horizontal offset, as illustrated in Fig. 17.25. This fitting separates the airflow in

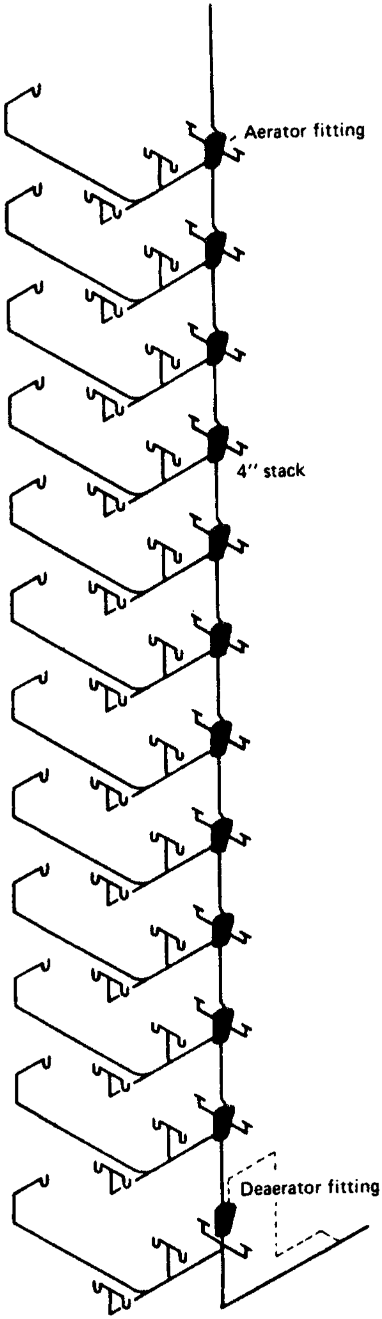

FIG. 17.23 A Sovent system. *(Courtesy of the Copper Development Association.)*

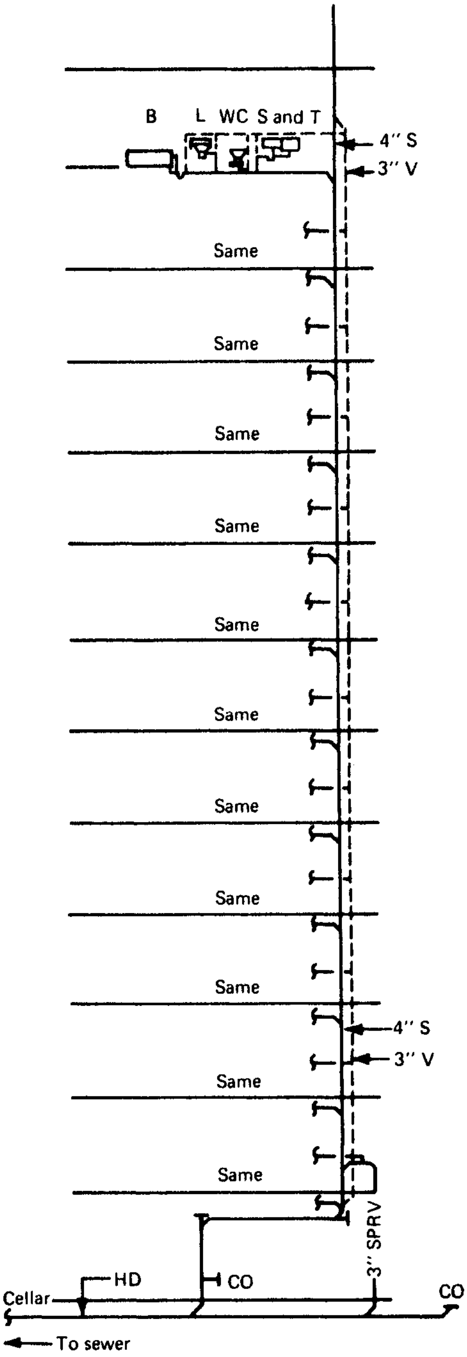

FIG. 17.24 A conventional two-pipe system.

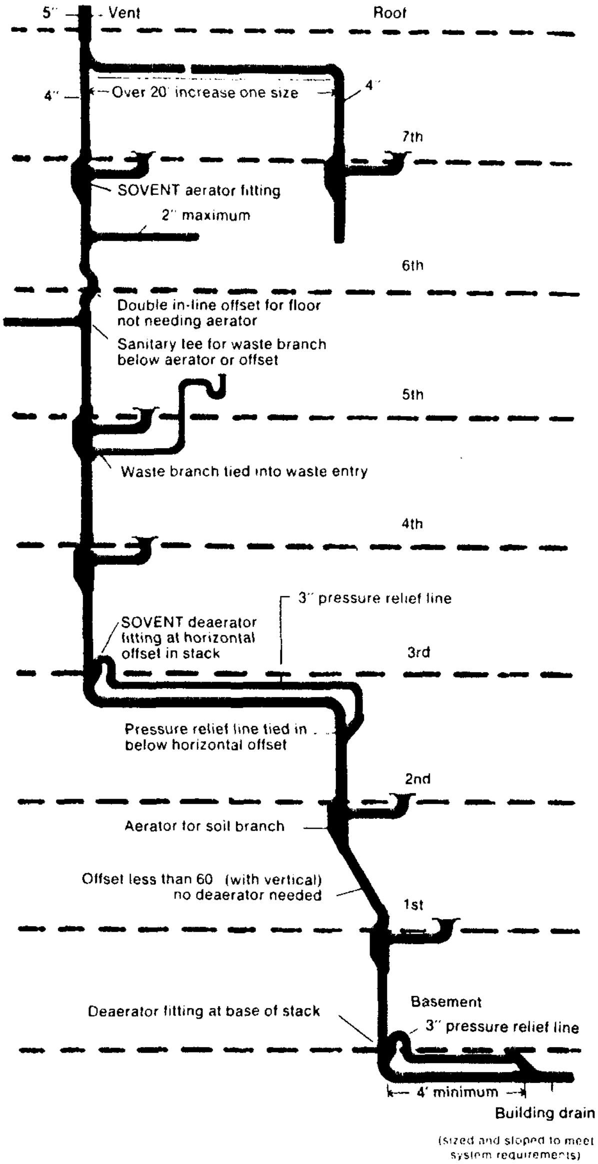

FIG. 17.25 Detail illustrating major features of the Sovent system. *(Courtesy of the Copper Development Association.)*

the stack from the liquid so as to ensure smooth entry into the building drain and to relieve the positive pressure at the bottom of the stack. For this reason, the single stack is self-venting, with balanced positive and negative pressures at or near the zero line through the system.

In designing and installing a Sovent system, it is necessary to ensure that (*a*) basic fundamentals of hydraulic and pneumatic drainage flow are adhered to, (*b*) piping and connections are direct and simple, (*c*) the horizontal lines have a slope of ¼ in/ft (2 cm/m), (*d*) thermal expansion and contraction are provided for, (*e*) cleanouts are located according to local code requirements, and (*f*) fixtures are selected and installed with the same care as for traditional systems.

FLOW OF AIR IN VENT PIPING

This section deals with the principles of fluid mechanics and pneumatics that are relevant to the flow of air, including suds, in vent piping. These principles concern physical and mechanical properties of air and suds and their application in engineering design of attendant vent piping systems.

The physical and mechanical properties of air and suds include their densities, viscosity, conditions of flow, and frictional resistance.

Energy principles include static and kinetic energy, friction between water and air, friction between air and pipe surfaces, pressurized flow in vent piping and from outlets, and gravity circulation of air by induced head or natural draft.

These properties and principles have specific application with regard to the flow of air and suds in vent stacks, individual vents, branch vents, and vent headers.

Physical Properties of Air

In any consideration of the flow of air in vent piping, several of the physical properties of air are of special interest. Those most pertinent to this subject are density, viscosity, and compressibility.

The density of air, i.e., its weight per unit of volume, varies with change in temperature and moisture content. One cubic foot of dry air at atmospheric pressure and 68.4°F weighs 0.075 lb/ft^3 (1.2 kg/m^3). This is the density of what is termed *standard air*, or air at normal pressure and temperature conditions. Moisture content or humidity of the air for such conditions is an insignificant factor and may be disregarded in calculations of airflow in vent piping. The weight per cubic foot of dry air corresponding to various temperatures is given in Table 17.3.

When a fluid flows, its natural characteristics of adhesion and cohesion result in the development of internal resistance to flow. This resistance is called the *viscosity* of the fluid. It is a measurable property which varies greatly from one fluid to another, and in gases, viscosity increases with rise in temperature. Air may be considered to be a gas at the normal temperature range existing in drainage and vent piping. The absolute viscosity and kinematic viscosity of air corresponding to various temperatures is given in Table 17.4.

Air is perfectly elastic, compressing when pressure is imposed and returning to original volume when pressure is removed. In the sanitary drainage system, only a very small amount of pressure rise may be permitted owing to the limited seal depth of fixture traps connected to the system. The attendant system of vent piping must be designed to permit admission and emission of air in all pipes so that the seals of fixture traps are subjected to an air-pressure differential of not more than 1 in (2.5 cm) of water column above or below atmospheric pressure. For this limited amount of pressure change, the corresponding volumetric

TABLE 17.3 Density of Dry Air

At 14.7 psia

Temperature		Density	
°F	°C	lb/ft³	kg/m³
-20	×28.9	0.09050	1.45162
-10	×23.4	0.08848	1.41922
0	-17.8	0.08656	1.38842
10	-12.2	0.08472	1.35891
20	-6.7	0.08299	1.33116
30	-1.1	0.08125	1.30325
40	4.4	0.07963	1.27727
50	10.0	0.07807	1.25224
60	15.6	0.07656	1.22802
70	21.1	0.07512	1.20492
80	26.7	0.07373	1.18263
90	32.2	0.07238	1.16098
100	37.8	0.07109	1.14028
200	93.3	0.06031	0.96737
300	149.0	0.05237	0.84001
400	204.5	0.04628	0.74233
500	260	0.04146	0.66502

Note: One pound of air at 70°F and 14.7 psia occupies 1/0.07512 or 13.31 ft³ of space.

TABLE 17.4 Viscosity of Air

Temperature		Absolute viscosity		Kinematic viscosity, ft²/s
°F	°C	cP	pdl · s/ft²	
32	0	0.0175	0.00001176	0.000147
50	10	0.0178	0.00001195	0.000153
60	15.6	0.0180	0.00001208	0.000156
70	21.1	0.0182	0.00001222	0.000163
80	26.7	0.0185	0.00001242	0.000168
100	37.8	0.0191	0.00001282	0.000180
120	48.9	0.0197	0.00001322	0.000212
140	60.0	0.0203	0.00001362	0.000211
160	71.1	0.0209	0.00001402	0.000210
180	82.2	0.0215	0.00001442	0.000209

Note: One centipoise equals 0.000672 pdl · s/ft². Kinematic viscosity (in square feet per second) is equal to absolute viscosity (in poundal seconds per square foot) divided by density (in pounds per cubic foot).

change may be determined from gas equations to be just $\frac{1}{400}$ less or more than at atmospheric pressure. Such small amounts of change in air volume in drainage piping indicate that vent piping must be designed to permit air to flow freely and without any compression other than the small amount permissible for overcoming friction-head losses in airflow.

In certain parts of the vent-piping system, pressure relief may occur in the form of flowing *suds* or *foam*, consisting of millions of small bubbles of air encased in films of liquid resulting from the discharge of detergents with waste water. Hence, in this discussion of the physical properties of air, it is pertinent to consider some of the important physical properties of suds. For example, manufacturers' reports show that the density of suds varies from a minimum of 0.2 to 12 lb/ft^3 for newly formed suds made with many different types of detergents. For old or regenerated suds, it appears reasonable to consider their density to be approximately 1.4 lb/ft^3 for the design of suds relief piping. In addition, values of the absolute viscosity may be taken as being 0.5516 centipoise (cP), and kinematic viscosity may be taken as being 0.000264 ft^2/s.

Equivalent Static Head of Water, Air, and Suds

At any point below the surface of a body of water at rest and exposed to the atmosphere, pressure is produced by the weight of water lying above the point. The pressure is equal and effective in all directions and is directly proportional to the depth of the point below the surface. Thus the pressure may be expressed in terms of still-water depth below the free surface, or *static head* of water above the point. This is often referred to as *hydrostatic head*. It is the measure of potential energy due to elevation of the water above a reference point.

Since the pressure is due to the weight of water, static head may be converted from feet of head to pounds per square inch of pressure. This may be done by determining the weight of a column of water equal in height to the head and 1 in^2 in cross-sectional area, as expressed in the following equation:

$$p = \frac{w}{144} h \qquad (17.1)$$

where p = pressure, psi
w = density or weight of fluid, lb/ft^3
h = static head of fluid, ft

Air and suds are fluids, and they produce pressure or head at submerged points in accordance with the weight of overlying fluid, just as is the case with water. However, since the densities of water, air, and suds are different, the amount of pressure produced by a 1-ft head or column of each of these fluids is not the same. For equal pressure, the preceding formula may be rearranged to express equivalent static heads for water, air, and suds as follows:

$$144\,p = w_w h_w = w_a h_a = w_s h_s \qquad (17.2)$$

where p = pressure, psi
w_w = density of water, lb/ft^3
w_a = density of air, lb/ft^3

w_s = density of suds, lb/ft^3
h_w = static head or column of water, ft
h_a = static head or column of air, ft
h_s = static head or column of suds, ft

Conditions of Flow

In vent piping, the condition of airflow may be streamline when the velocity is relatively low, such as prevails generally during gravity circulation of air through the drainage and vent piping system. However, the condition of airflow becomes turbulent at the relatively high velocities which occur when vent piping must serve to relieve air pressure resulting from the flow of liquids in the sanitary drainage system.

The critical velocity at which airflow changes from streamline to turbulent conditions may be determined from the following equation:

$$V_c = \frac{R_c}{D}\,\frac{\mu}{w} = \frac{2000}{D}\,\frac{\mu}{w} = \frac{2000\nu}{D} \tag{17.3}$$

where V_c = true critical velocity, ft/s
R_c = Reynolds number, 2000, corresponding to the lower critical velocity
μ = absolute viscosity of the fluid, pdl · s/ft^2
ν = kinematic viscosity of the fluid, ft^2/s
D = diameter of the pipe, ft
w = density of the fluid, lb/ft^3

In the preceding equation, applying a value of 0.000163 ft^2/s as the kinematic viscosity of air at 70°F, the critical velocities of airflow in vent pipes of 1¼-, 1½-, 2-, 2½-, and 3-in (3.13-, 3.75-, 5.0-, 6.25-, and 7.5-cm) diameters are, respectively, 3.10, 2.58, 1.94, 1.55, and 1.29 ft/s (0.95, 0.79, 0.59, 0.47, and 0.39 m/s). They correspond in turn to quantity flow rates of 11.9, 14.2, 19.0, 23.7, and 28.4 gpm (0.75, 0.90, 1.29, 1.50, and 1.79 L/s) of airflow.

For suds flow in vent pipes, a value of 0.000264 ft^2/s as the kinematic viscosity of suds may be applied to determine the critical velocities in vent pipes of 1¼-, 1½-, 2-, 2½-, and 3-in (3.13-, 3.75-, 5.0-, 6.75-, and 7.5-cm) diameters to be, respectively, 5.02, 4.18, 3.14, 2.51, and 2.09 ft/s (1.53, 1.27, 0.96, 0.77, and 0.64 m/s). They correspond in turn to quantity flow rates of 19.3, 23.0, 30.8, 38.4, and 46.0 gpm (1.22, 1.45, 1.94, 2.42, and 2.90 L/s) of suds flow.

Pneumatic Effects in and Venting Design Criterion for Sanitary Drainage Systems

When water flows in contact with air in a partially filled vertical or horizontal drain, there is friction between the water and air. This results in air being dragged along by the water, causing air to flow in the same direction in the drain. Wherever the cross-sectional area occupied by water increases sharply, such as at sudden changes in drain direction and at branch fittings through which additional flow enters the drain, the area available for airflow in the drain becomes correspondingly reduced or constricted. The effect of constricting the area available for airflow in the drain is that of a temporary stoppage or block to airflow at such points.

As air is dragged into a zone of a drain where a temporary stoppage to airflow exists, the air accumulates in the restricted volume of the drain and becomes pressurized. Highest pressure occurs at the point of airflow constriction, and pressure diminishes upstream therefrom. Consequently, when fixtures on upper floors discharge into a drainage system and water flows down a drainage stack conveying air into the lower section of the system, pneumatic effects considerably above atmospheric pressure may occur in the lower section of the sanitary drainage system. Fixture and branch drains connected to lower sections may be subjected to excessive back pressure sufficient to blow the water seals of fixture traps out of fixture waste outlets and into rooms.

All the air dragged along in drainage pipes by the flowing water is drawn from the upper section of the sanitary drainage system. The upper section of the system must supply air as rapidly as it is being dragged down in the system or the volume of air in the upper section will become exhausted and pneumatic effects considerably below atmospheric pressure may occur in that part of the sanitary drainage system. Fixture and branch drains connected to upper sections may be subjected to excessive aspiration sufficient to suck the water seals of fixture traps into the fixture drains.

When water seals of fixture traps are lost owing to back-pressure or aspiration effects in the sanitary drainage system, hazardous gases and objectionable odors from the system can enter rooms in which fixtures are located. Protection against such occurrence should be provided for the health, safety, and welfare of building occupants. Such protection may be afforded by the installation of an adequate system of vent piping to relieve excessive pneumatic effects in the sanitary drainage system.

The design criterion for a system of vent piping attendant upon the sanitary drainage system must be related to the strength or resistance of all trap seals connected to the drainage system. Fixture trap seals are the weakest of all the trap seals on the system, for they are permitted to have a minimum seal depth of 2 in (5 cm). In view of this limiting factor, it is recommended that the venting design criterion for sanitary drainage systems be as follows: to provide an attendant system of vent piping designed to permit adequate circulation of air in all pipes and the admission and emission of air so that the seals of fixture traps are subjected to an air-pressure differential of not more than 1 in (2.5 cm) of water column. This design criterion provides what is deemed a reasonable factor of safety.

Quantity Rate of Flow from Outlets

The velocity at which air flows through an outlet to the atmosphere is due to the total energy available in the vent pipe at the outlet during flow. This total energy is the sum of the potential and kinetic energies of the moving air. Potential energy, in this instance, is the pressure or head exerted by the flowing air against the inside wall of the vent pipe and is termed *flow pressure.*

In practice, the amount of kinetic energy, or velocity head, in the vent pipe during flow usually is relatively small and may be assumed to be an insignificant factor by comparison with the flow pressure. Hence the maximum rate of air discharged from an outlet of a vent pipe may be determined with reasonable accuracy based just on the flow pressure in the vent pipe and the diameter of the outlet.

The maximum rate at which air may discharge from an outlet into the atmosphere in practice may be expressed as follows:

$$q_d = c_d q_i = c_d(2.448 d_o^2 V_i) = c_d(2.448 d_o^2 \sqrt{2gh_m}) = c_d(19.65 d_o^2 \sqrt{h_m}) \qquad (17.4)$$

where q_d = quantity rate of air discharge from outlet in practice, gpm
q_i = ideal rate of discharge from outlet, gpm
c_d = coefficient of discharge for outlet
d_o = diameter of outlet, in
V_i = ideal velocity, ft/s
g = gravitational acceleration, 32 ft/s^2
h_m = head measured in vent pipe during flow, ft of air column

When the value of the coefficient of discharge c_d is assumed to be 0.67, a reasonable value for ordinary pipe outlets, the equation for the maximum rate of airflow which may be obtained from an outlet in practice has the following simplified form:

$$q_d = c_d(19.65) d_o^2 \sqrt{h_m} = 0.67(19.65) d_o^2 \sqrt{h_m} = 13.17 d_o^2 \sqrt{h_m} \qquad (17.5)$$

In vent piping, the design criterion calls for limiting the air-pressure differential above or below atmospheric pressure to no more than 1 in (25 mm) of water column. In terms of feet of air column, this may be established based on the density of dry air at 70°F (21.1°C) as follows:

$$h_a w_a = h_w w_w$$

$$h_a = \frac{h_w w_w}{w_a} = \frac{1 \text{ in} \times 62.408}{12 \text{ in} \times 0.07512}$$

$$= 69.23 \text{ ft (21.1 m) of air column or head}$$

[the equivalent of 1 in (2.5 cm) of water column or head]

This conversion factor may be applied to establish a simplified equation for the quantity rate of air discharge into the atmosphere from outlets of various nominal sizes in a vent pipe wherein the pressure is 1 in (2.5 cm) of water column as follows:

$$q_d = 13.17 d_o^2 \sqrt{h_m} = 13.17 d_o^2 \sqrt{69.32} = 13.17 \times 8.32 d_o^2 = 109.57 d_o^2 \qquad (17.6)$$

Suds discharge rates may be established in a similar manner. The feet of suds column or head equivalent to 1 in (2.5 cm) of water column may be calculated on the basis of the assumption of 1.4 lb/ft^3 (22.5 kg/m^3) as the density of old or regenerated suds as follows:

$$h_s w_s = h_w w_w$$

$$h_s = \frac{h_w w_w}{w_s} = \frac{1 \text{ in} \times 62.408}{12 \text{ in} \times 1.4}$$

$$= 3.71 \text{ ft (1.13 m) of suds column or}$$

head [the equivalent of 1 in (2.5 cm) of water column or head]

Applying this conversion factor, an equation may be established for the quantity rate of suds discharge into the atmosphere from outlets of various nominal sizes in a vent pipe wherein the pressure is 1 in (2.5 cm) of water column as follows:

$$q_d = 13.17d_o^2\sqrt{h_m} = 13.17d_o^2\sqrt{3.71} = 13.17 \times 1.925d_o^2 = 25.3d_o^2 \qquad (17.7)$$

Comparison of the equations for suds and air discharge rates indicates that the suds discharge rate is just $^{25.3}\!/_{109.547}$, or 23.1 percent of the air discharge rate for the same flow pressure. Table 17.5 shows the quantity rates at which both air and suds may discharge into the atmosphere from various sizes of vent outlets under a flow pressure equivalent to a 1-in (2.5-cm) water column or head.

TABLE 17.5 Outlet Discharge Rates for Air and Suds

Flow pressure = 1 in (2.5 cm) water head

Outlet diameter d_o		Air discharge q_d		Suds discharge q_d	
in	cm	gpm	L/s	gpm	L/s
1¼	3.13	171.2	10.8	39.5	2.49
1½	3.75	246.5	15.6	56.9	3.59
2	5.0	438.3	27.7	101	6.37
2½	6.25	684.8	43.2	158	9.97
3	7.5	986.1	62.2	228	14.4
4	10.0	1753	110.6	405	25.6
5	12.5	2739	172.8	633	39.9

Pressure Loss Due to Friction in Piping

When air flows through vent piping to relieve air pressure resulting from the flow of liquids in sanitary drainage piping, a continuous loss of pressure occurs along the piping in the direction of flow. This pressure loss is due to friction generated between the moving air and the inner surface of the vent piping in view of the fact that turbulent flow conditions prevail at the maximum rates of flow which vent pipes are designed to convey.

The amount of pressure or head loss due to friction in this case is dependent on such factors as physical properties of air, such as its density and temperature; roughness of the interior surfaces of the pipe; length of the pipe; diameter of the pipe; and the velocity at which air flows through the pipe.

Darcy's formula for pipe friction loss may be applied to calculate the head loss due to friction developed by airflow in vent piping. It is as follows:

$$h_f = \frac{fLV^2}{D2g} \qquad (17.8)$$

where h_f = head loss due to friction, ft of air column

f = coefficient of friction corresponding to the roughness of the pipe surface and diameter of the pipe

L = length of piping, ft

D = diameter of piping, ft

V = velocity of flow, ft/s

g = gravitational acceleration, 32.2 ft/s^2

Quantity Rate of Flow through Piping

When water flows through a channel, the quantity rate of flow past any given point is related to the cross-sectional area of flow and the velocity of flow at that point. This relationship is expressed in a rational equation, commonly termed the *basic flow formula*, which is as follows:

$$Q = AV \tag{17.9}$$

where Q = quantity rate of flow, ft^3/s
A = cross-sectional area of flow, ft^2
V = velocity of flow, ft/s

In a pressurized water-supply system, the piping is filled with water and is of circular cross section. The quantity, in this case, is the volume contained in a cylinder of the same cross-sectional area and of length equal to the velocity. Thus the quantity rate of flow is in direct proportion to the velocity of flow and to the cross-sectional area of flow or square of the pipe diameter.

For plumbing calculations, the basic flow formula is inconvenient because the types of plumbing piping available are of circular cross section. Pipe sizes are ordinarily stated in terms of inches of diameter, and quantity rates of flow are customarily referred to in terms of gallons per minute of flow.

To adapt the basic flow formula so that convenient and direct plumbing calculations may be made, appropriate factors must be applied to convert the terms to those commonly used in the plumbing industry. When this is done, the result is an adapted flow formula which is as follows:

$$q = 2.448d^2V \tag{17.10}$$

where q = quantity rate of flow, gpm
d = diameter of the pipe, in
V = velocity of flow, ft/s

Permissible Length of Vent Piping

For a more convenient expression of pipe friction loss in, and permissible length of, vent piping, the Darcy pipe friction formula [Eq. (17.8)] and the adapted flow formula [Eq. (17.10)] may be combined and their terms converted to those more generally used in practice, as in the following:

$$h_f = \frac{fLV^2}{D2g} \qquad q = 2.448d^2V$$

$$V = \frac{q}{2.448d^2}$$

Hence

$$h_f = \frac{fLq^2}{(d/12)(2.448)^2d^4(64.4)} = \frac{fLq^2}{(32.16)d^5} = \frac{(0.03109)fLq^2}{d^5} \tag{17.11}$$

where h_f = head loss due to friction, ft of fluid column
p_f = pressure loss due to friction, psi
w = density of fluid flowing, lb/ft^3
f = coefficient of friction corresponding to roughness of pipe surface and diameter of pipe
L = length of piping, ft
D = diameter of piping, ft
V = velocity of flow, ft/s
g = gravitational acceleration, 32.2 ft/s^2

and

$$L = \frac{h_f d^5}{(0.03109)fq^2} \tag{17.12}$$

where h_f = head loss due to friction, ft of fluid column
f = coefficient of friction corresponding to the roughness of the pipe surface and diameter of the pipe
L = length of piping, ft
D = diameter of piping, ft
d = diameter of piping, in
q = quantity rate of flow, gpm
g = gravitational acceleration, 32.2 ft/s^2
V = velocity of flow, ft/s

The maximum permissible length of vent piping may be expressed in accordance with the design criterion for vent piping, which requires that the seals of fixture traps be subjected to an air-pressure differential of not more than 1 in (2.5 cm) of water column above or below atmospheric pressure. Since the permissible head loss due to friction in this case is 1 in (2.5 cm) of water column, the equivalent head for air or suds may be applied in the preceding equation to determine the permissible length of vent piping for airflow or for suds flow.

For airflow, an equivalent head of 69.23 ft (21.1 m) of air column, based on the densities of water and air at 70°F (21.1°C), may be applied. This results in the following formula for the maximum permissible length of vent piping for airflow:

$$L = \frac{(69.23)d^5}{(0.03109)fq^2} = \frac{2226d^5}{fq^2} \tag{17.13}$$

Similarly, for suds flow, an equivalent head of 3.71 ft (1.13 m) of suds column, based on the densities of water at 70°F (21.1°C) and that given for old or regenerated suds, may be applied. This results in the following formula for the maximum permissible length of vent piping for suds flow:

$$L = \frac{(3.71)d^5}{(0.03109)fq^2} = \frac{119.3d^5}{fq^2} \tag{17.14}$$

From these two equations it can be seen that the permissible length of vent piping for suds flow is just 119.3/2226, or 5.36 percent as much as is permissible for airflow, and conversely, the permissible length for airflow is 2226/119.3, or 18.7 times as much as for suds flow.

Equivalent Length of Fittings in Vent Piping

The maximum permissible length of piping L expressed in the preceding equation should be understood to mean the developed length of straight piping free of any fittings. Where fittings are included in the run of piping, consideration must be given to the fact that they impose much more frictional resistance than straight pipe of the same developed length and size. Hence the length L should be recognized as including the developed length of the piping plus an equivalent length to be allowed in lieu of the additional resistance due to fittings.

Since the types of fittings commonly used in water supply systems are also used in vent piping, the recommended equivalent lengths to be allowed for fittings in vent piping are contained in Table 17.6. The lengths stated therein may be applied as reasonably appropriate for other types of fittings used in the same capacity.

Value of Coefficient of Friction *f*

In using the preceding formulas, proper selection should be made regarding the value of f, the coefficient of friction corresponding to the roughness of the pipe surface, diameter of the pipe, and pipe surface condition after a reasonable period of service. One such recommendation is shown in Table 17.7. The values shown in this table reportedly were computed assuming the absolute roughness of the vent-stack surface to be double that given for galvanized-steel pipe so as to take into account the expected effect of corrosion. In addition, each value of f represents the average of two values obtained from the assumption of two sizes of vent stacks for a particular size of drainage stack, in one case the vent stack and drainage stack being of the same size and in the other case the diameter of the vent stack being one-half that of the drainage stack.

TABLE 17.6a Equivalent Length for Fittings and Valves—U.S. Customary Units
Standard pipe

	Equivalent feet of pipe for various sizes							
Fitting or valve	½ in	¾ in	1 in	1¼ in	1½ in	2 in	2½ in	3 in
45° elbow	1.2	1.5	1.8	2.4	3.0	4.0	5.0	6.0
90° elbow	2.0	2.5	3.0	4.0	5.0	7.0	8.0	10.0
T, run	0.6	0.8	0.9	1.2	1.5	2.0	2.5	3.0
T, branch	3.0	4.0	5.0	6.0	7.0	10.0	12.0	15.0
Gate valve	0.4	0.5	0.6	0.8	1.0	1.3	1.6	2.0
Balancing valve	0.8	1.1	1.5	1.9	2.2	3.0	3.7	4.5
Plug-type cock	0.8	1.1	1.5	1.9	2.2	3.0	3.7	4.5
Check valve, swing	5.6	8.4	11.2	14.0	16.8	22.4	28.0	33.6
Globe valve	15.0	20.0	25.0	35.0	45.0	55.0	65.0	80.0
Angle valve	8.0	12.0	15.0	18.0	22.0	28.0	34.0	40.0

TABLE 17.6*b* Equivalent Length for Fittings and Valves—SI Units
Standard pipe

	Equivalent meters of pipe for various sizes							
Fitting or valve	1.27 cm	1.9 cm	2.54 cm	3.18 cm	3.81 cm	5.08 cm	6.35 cm	7.62 cm
45° elbow	0.36	0.45	0.54	0.73	0.91	1.21	1.52	1.82
90° elbow	0.60	0.76	0.91	1.21	1.52	2.13	2.43	3.04
T, run	0.18	0.24	0.27	0.36	0.45	0.60	0.76	0.91
T, branch	0.91	1.21	1.51	1.82	2.13	3.04	3.65	4.57
Gate valve	0.12	0.15	0.18	0.24	0.30	0.39	0.48	0.60
Balancing valve	0.24	0.33	0.45	0.57	0.67	0.91	1.12	1.37
Plug-type cock	0.24	0.33	0.45	0.57	0.67	0.91	1.12	1.37
Check valve, swing	1.70	2.56	3.41	4.26	5.12	6.82	8.53	10.24
Globe valve	4.57	6.09	7.62	10.66	13.71	16.76	19.81	24.38
Angle valve	2.43	3.65	4.57	5.48	6.70	8.53	10.36	12.19

TABLE 17.6*c* Equivalent Length for Fittings and Valves—U.S. Customary Units
Copper water tube

	Equivalent feet of tube for various sizes							
Fitting or valve	½ in	¾ in	1 in	1¼ in	1½ in	2 in	2½ in	3 in
45° elbow (wrought)	0.5	0.5	1.0	1.0	2.0	2.0	3.0	4.0
90° elbow (wrought)	0.5	1.0	1.0	2.0	2.0	2.0	2.0	3.0
T, run (wrought)	0.5	0.5	0.5	0.5	1.0	1.0	2.0	
T, branch (wrought)	1.0	2.0	3.0	4.0	5.0	7.0	9.0	
45° elbow (cast)	0.5	1.0	2.0	2.0	3.0	5.0	8.0	11.0
90° elbow (cast)	1.0	2.0	4.0	5.0	8.0	11.0	14.0	18.0
T, run (cast)	0.5	0.5	0.5	1.0	1.0	2.0	2.0	2.0
T, branch (cast)	2.0	3.0	5.0	7.0	9.0	12.0	16.0	20.0
Compression stop	13.0	21.0	30.0					
Globe valve				53.0	66.0	90.0		
Gate valve			1.0	1.0	2.0	2.0	2.0	2.0

Source: Courtesy of Copper Development Association.

Quantity Rate of Flow in Vent Stacks

In an earlier section, capacity flow of water in drainage stacks was described as having the form of a uniformly thick sheet of water in contact with the pipe wall and enclosing a core of air in the center of the stack. At capacity, the cross-sectional area occupied by water may be from $\frac{6}{24}$ to $\frac{7}{24}$ that of the drainage stack. In flowing down the pipe wall, terminal velocity is attained in a relatively short distance of fall, generally within 1 story of height for stacks up to 5 in (12.5

TABLE 17.6*d* Equivalent Length for Fittings and Valves—SI Units

Copper water tube

	Equivalent meters of tube for various sizes							
Fitting or valve	1.27 cm	1.9 cm	2.54 cm	3.18 cm	3.81 cm	5.08 cm	6.35 cm	7.62 cm
45° elbow (wrought)	0.15	0.15	0.30	0.30	0.60	0.60	0.91	1.21
90° elbow (wrought)	0.15	0.30	0.30	0.60	0.60	0.60	0.60	0.91
T, run (wrought)	0.15	0.15	0.15	0.15	0.30	0.30	0.60	
T, branch (wrought)	0.30	0.60	0.91	1.12	1.52	2.13	2.74	
45° elbow (cast)	0.15	0.30	0.60	0.91	1.12	1.52	2.43	3.35
90° elbow (cast)	0.30	0.60	1.21	1.52	2.43	3.35	4.26	5.48
T, run (cast)	0.15	0.15	0.15	0.30	0.30	0.60	0.60	0.60
T, branch (cast)	0.60	0.91	1.52	2.13	2.74	3.65	4.87	6.09
Compression stop	3.96	6.40	9.14					
Globe valve				16.15	20.11	27.43		
Gate valve			0.30	0.30	0.60	0.60	0.60	0.60

Source: Courtesy of Copper Development Association.

TABLE 17.7 Values of *f* for Use in Vent-Stack Calculations

Diameter of drainage stack		
in	cm	Pipe friction coefficient *f*
3	7.5	0.0367
4	10.0	0.0330
5	12.5	0.0307
6	15.0	0.0286
8	20.0	0.0260
10	25.0	0.0242
12	30.0	0.0230
15	37.5	0.0214

cm) in size and within 2 stories for other sizes up to 12 in (30 cm). Velocity remains constant thereafter owing to equalization of frictional resistance and gravitational force.

Part of the frictional resistance is developed by the sheet of water in descending in contact with the core of air in the center of the stack. As a result, the water drags the air core down the stack. The average velocity at which it is dragged down by water at capacity flow has been found to be approximately equal to that of the water flowing at terminal velocity. Hence, in the design of vent stacks, it is recommended that the velocities of both air and water flowing in drainage stacks at capacity be assumed to be equal.

In the horizontal drain at the base of the drainage stack, a hydraulic jump occurs in flow. Since this jump may completely fill the horizontal drain within a short distance of the base fitting when the stack is flowing at capacity, it is reasonable for design purposes to assume that the hydraulic jump constitutes a block to airflow in the horizontal drain and that all the air dragged down the drainage stack by the water must be relieved by flowing up the vent stack to its vent terminal in the atmosphere.

Consequently, the quantity rate of airflow which vent stacks should be designed to convey is related to the rate at which air is dragged down drainage stacks at capacity flow. When capacity flow is based on drainage stacks flowing $\frac{6}{24}$ full at terminal velocity, the air core occupies $\frac{18}{24}$ of the cross-sectional area of the stack, and the quantity rate of airflow dragged down the drainage stack by the water at the same velocity is equal to $\frac{18}{6}$, or 3 times the quantity rate of water flow. Similarly, for drainage stacks flowing $\frac{7}{24}$ full, the quantity rate of airflow is equal to $\frac{17}{7}$, or 2.43 times the quantity rate of water flow. Computations have been made to determine the respective rates of airflow required to be conveyed by vent stacks for various sizes of drainage stacks. They are presented in Table 17.8.

TABLE 17.8 Computed Airflow Capacity Required by Attendant Vent Stacks

Diameter of drainage stack		Airflow rate for fraction of drainage-stack area occupied by water at terminal velocity			
		$r_s = \frac{6}{24}$		$r_s = \frac{7}{24}$	
in	cm	gpm	L/s	gpm	L/s
1¼	3.13	15.0	0.95	15.8	1.06
1½	3.75	24.3	1.53	24.8	1.56
2	5.0	52.5	3.31	54.8	3.46
2½	6.25	95.4	6.02	99.8	6.30
3	7.5	156.0	9.84	164.0	10.3
4	10.0	333.0	21.0	348.0	22.0
5	12.5	606.0	38.2	633.0	39.9
6	15.0	1008.0	63.6	1065.0	67.2
8	20.0	2127.0	134.2	2220.0	140.0

Quantity Rate of Flow in Individual Vents

Considerable variation occurs in the quantity rate at which air may be required to be conveyed through an individual vent for pressure relief in the fixture drain. This is directly related to the amount of air relief required in the drainage piping at the branch fitting into which the fixture drain discharges and the principal function which the individual vent is to perform in any given installation.

For example, in one installation, the principal function of an individual vent may be simply to permit air to enter the fixture drain at a rate sufficient to disrupt siphonic action and thereby prevent excessive trap seal loss during discharge of the fixture. In this case, the rate of airflow into the fixture drain reaches a maximum when the drain flows approximately half full, air and water occupying equal space and moving at equal velocity. For this condition, the velocity of airflow may be considered to be approximately the same as would exist for uniform flow conditions in the horizontal section of the fixture drain at half-full flow, and consequently, the quantity rates of water and airflow may be assumed to be equal. Computed airflow rates for horizontal sanitary drains flowing half full are shown in Table 17.9.

TABLE 17.9 Computed Airflow Rates Required for Venting Horizontal Sanitary Drains Flowing Half Full

Diameter of drain		Slope of drain		Air and water flow rates	
in	cm	in/ft	cm/m	gpm	L/s
1¼	3.13	½	4.16	5.5	0.35
1½	3.75	½	4.16	8.3	0.52
2	5.0	¼	2.08	9.7	0.61
2½	6.25	¼	2.08	17.6	1.11
3	7.5	¼	2.08	28.6	1.80
4	10.0	¼	2.08	57.0	3.60
5	12.5	¼	2.08	96.5	6.09

In another installation, the principal function of an individual vent may be to serve as a wet vent or as a loop or circuit vent to convey air at the quantity rate of flow as may be required to enter the branch drain to prevent excessive pressure reduction therein when the branch drain flows half full. The rate of airflow required in this case is considerably higher than exists where the individual vent simply serves to disrupt siphonic action in a single fixture drain.

In still another installation, an individual vent may be required to serve in the same capacity as either a vent stack or a special relief vent. This is a much different and more demanding function, for the individual vent may be required to convey air at the same quantity rate as it is conveyed down a drainage stack or as may be required to relieve air pressure in a drain subject to pressurization in the lower section of the drainage system. Regulations do not prohibit the connection of fixture drains to zones of drainage piping wherein relatively high air or suds relief requirements may exist. Therefore, one may conclude that the airflow rates which should be satisfied by individual vents are those which correspond to the conditions prevailing for any given installation or piping arrangement in which they are to function.

Quantity Rate of Flow in Branch Vents and Vent Headers

The total rate at which air should be conveyed by a branch vent is the sum of all the airflows required to be conveyed by individual vent pipes connected thereto and served by the branch vent. Since the airflow rates in individual vent pipes vary with conditions under which they are required to function, a corresponding variation occurs in the total rate of airflow to be conveyed by a branch vent. This may be determined more properly by analysis of given installations and by summing up the appropriate airflows required for each individual vent function to determine the flow rate required in a branch vent.

Similarly, the quantity rate of airflow in a vent header which serves to convey air to the tops of a number of soil, waste, and attendant vent stacks is the sum of the respective airflow rates required for such stacks. Since the rate of airflow in such stacks is directly related to the rate of liquid flow therein, the rate of airflow in a vent header varies in accordance with the total drainage load of all the stacks served by the header.

Gravity Circulation of Air by Induced Head or Draft

The force causing gravity circulation of air in a sanitary drainage and vent system is the difference in head existing between air outdoors and that in the system. This difference in head is induced by the difference in temperatures and corresponding densities of the air outdoors and the air inside the system and by the height of air column in the system. The cooler air is more dense and produces greater head, or draft pressure, at any opening where the cool and warm air are in contact. Consequently, the cool air tends to move and displace warm air, setting up gravity circulation.

The amount of head induced or natural draft pressure produced in sanitary drainage systems for setting up gravity circulation of air may be determined for specific stack heights and air-temperature conditions outdoors and inside the system by applying the following formula:

$$\text{NDP} = \frac{(2.31)(12)(w_{to} - w_{ti})H_s}{144} = 0.1925(w_{to} - w_{ti})H_s \qquad (17.15)$$

where NDP = natural draft pressure or induced head, in of water column
w_{to} = density of air corresponding to temperature outdoors, lb/ft^3
w_{ti} = density of air corresponding to temperature inside stack, lb/ft^3
H_s = height of stack, ft

For any given conditions of air temperature and stack height, gravity circulation of air will proceed at a rate such as will dissipate as friction losses in the system all the natural draft pressure or induced head.

SIZING

This section deals with the application of principles of fluid mechanics and pneumatics in sizing vent piping so as to achieve adequacy of performance in extended service. The specific criteria used in each sizing application are presented in detailed discussion for each section of the attendant vent piping system. The criteria define the limits for adequacy of performance.

Vent Stacks

For any given quantity rate of airflow required to be conveyed by a vent stack, the maximum permissible total length of vent piping of a given diameter may be readily computed by means of Eq. (17.13). The total length determined in this manner should be understood to be the sum of the total developed length of the vent stack, measured from its base connection to its terminal in the atmosphere above the roof of the building, plus the total equivalent pipe length allowable for the pipe fittings in that run of vent piping. In general, the equivalent length of pipe fittings in multistory buildings has been found to work out to be approximately 50 percent of the developed length of vent stacks. Hence it may be assumed that the maximum permissible developed length is two-thirds of the computed total vent-stack length.

It may be noted also that the maximum airflow capacity of a given diameter of vent stack of zero length is that which may be computed as the quantity rate of discharge into the atmosphere from outlets of a vent pipe wherein the pressure is 1 in (2.5 cm) of water column. This may be calculated by means of Eq. (17.7).

To relieve suds pressure at the base of drainage stacks, it may be appropriate to connect the base of the vent stack to a point in the horizontal drain directly adjacent to the base fitting of the drainage stack and to size the lowest 2-story section of the vent stack in accordance with the size computed by means of Eq. (17.7) for suds discharge rate from outlets to the atmosphere. The computed size for suds relief purposes may be found to be at least three-fourths of the drainage stack size.

Table 17.10 may be used for sizing vent stacks in accordance with drainage-stack capacity loads. Permissible lengths of vent piping shown therein are sufficiently less than those which may be computed by formulas (in which additional allowance need be made for the equivalent length of pipe fittings) that the stated lengths may be applied directly as permissible developed length of pipe. It should be understood that this table applies exclusively to airflow loads of vent stacks attendant upon drainage stacks and is not intended for application to suds flow conditions.

Vent Extensions and Terminals of Stacks

The size of vent extensions and terminals of soil, waste, and vent stacks is directly related to their capacities for permitting air to enter the tops of stacks with-

TABLE 17.10 Size of Vent Stacks and Branch Vents

Size of soil or waste stack		Fixture units connected	Diameter of vent required, in (cm)								
			1¼ (3.13)	1½ (3.75)	2 (5.0)	2½ (6.25)	3 (7.5)	4 (10.0)	5 (12.5)	6 (15.0)	8 (20.0)
in	cm		Maximum developed length of vent, ft								
1¼	3.13	2	30								
1½	3.75	8	np	150							
2	5.0	24	np	50	150						
2½	6.25	42	np	np	100	300					
3	7.5	72	np	np	np	80	400				
4	10.0	500	np	np	np	np	180	700			
5	12.5	1100	np	np	np	np	np	200	700		
6	15.0	1900	np	np	np	np	np	np	200	700	
8	20.0	3600	np	np	np	np	np	np	np	250	800
10	25.0	5600	np	np	np	np	np	np	np	np	250

out causing excessive air-pressure reduction in the upper section of the sanitary drainage system. In no case should the size of the vent extension and terminal of a drainage stack be reduced to less than that required for its attendant vent stack, for air must be permitted to enter the top of the drainage stack at the same quantity rate of flow as it is dragged down the stack by water at capacity load.

To achieve maximum effective circulation of air up through the sanitary drainage system during periods of relatively small load, it is recommended that the vent extension and terminal of the drainage stack which connects to the most upstream end of the sanitary building drain be of the same size as the drainage stack. If vent extensions and terminals are not to restrict gravity circulation of air in the system, the sum of the cross-sectional areas of all terminals should be equal to the cross-sectional area of a fresh-air inlet through which air is supplied into the sanitary building drain of the system or, where there is no house trap and fresh-air inlet on the sanitary building drain, equal to the cross-sectional area of the sanitary building drain at its point of entry into the building.

Where vent extensions and terminals are subject to frost-closure conditions during frigid weather, provision should be made in sizing to ensure against the occurrence of excessive reduction of available flow area due to formation of ice within the vent extension or at the terminal. A recommendation in this regard is to provide vent extensions and terminals of at least 3-in (7.6-cm) size for all smaller stacks and to make such necessary changes in size by installation of a long increaser below the roof line within the building.

Vent Headers, Their Vent Extensions and Terminals

Vent headers should be of adequate size to convey air at the quantity rates of flow required at the tops of each of the drainage stacks served thereby without causing excessive air-pressure reduction in the upper section of the sanitary drainage system. When the system is operating at capacity, the quantity rate of air required to be supplied through the vent header to drainage stacks is directly related to the total drainage load of all stacks served by the vent header rather than being just the sum of the individual airflow requirements for each of the stacks at their respective capacities. Thus the various sections of a vent header should be sized as for a vent stack serving a drainage stack of capacity sufficient for the total drainage load, the length of the vent stack being the same as that of the longest vent stack connected to the vent header.

Vent extensions and vent terminals through which air is supplied to vent headers from the atmosphere above the building roof should be sized in the same manner as for any other section of a vent header. In this case, the vent extension and terminal convey the greatest quantity of airflow of all sections of the vent header and, hence, should be the largest in size.

Individual Vents

Proper sizes for individual vents connected to fixture drains should be determined in accordance with the principal function performed by such vents in any given installation and the corresponding quantity rate of airflow required to be conveyed. This may be established by analysis of the arrangement of drainage and vent piping for any particular system.

Where individual vents are connected to fixture drains which discharge into drainage stacks or into branch drains of stacks above the level of the base connection of an attendant vent stack of adequate size, the principal function of the individual vent can be assumed to be that of providing sufficient airflow to the fixture drain so as to disrupt siphonic action and thereby avoid excessive trap seal loss during discharge of the fixture. The quantity rate at which air is required may be determined from Table 17.9, based on the size of the fixture drain. A corresponding size may be computed by means of Eq. (17.13) and by reference to Table 17.5, based on the length of vent pipe measured from the fixture drain to the branch fitting in the vent stack or to its individual vent terminal in the atmosphere.

Where individual vents are connected to fixture drains which discharge directly into drainage stacks below the level of the base connection of an attendant vent stack or which discharge directly into the horizontal drain adjacent to the base fitting of a drainage stack, the principal function of such individual vents is that of a vent stack. In such a case, the size of the individual vent should be at least as large as is required for an attendant vent stack.

Individual vents connected to fixture drains which discharge directly into the sanitary building drain or horizontal branch thereof are subject to pneumatic effects prevailing in such lower piping of the system. Since these effects may vary from one extreme to another depending on the distance at which the fixture drain connection is made from points at which airflow is constricted in the building drain, the size and load on the drain, and the presence of other building drain connections which may be available for relief of pressure therein, the quantity rate of airflow to be conveyed by an individual vent in this instance may be determined only by analysis of the given installation.

Where individual vents are connected to fixture drains which discharge into zones of the drainage system wherein suds-pressure conditions may occur, the size of such vents should be determined for suds flow rather than airflow unless a special suds-pressure relief vent is connected to the suds-pressure zone. Appropriate sizes for suds flow may be computed by means of Eq. (17.14) and by reference to Table 17.5 for the quantity rates of flow corresponding to conditions in the particular piping arrangement.

The minimum size recommended for an individual vent is 1¼ in (3.2 cm). This is based on the fact that the most critical factor with regard to the capacity of a vent pipe is its diameter. Any decrease in diameter has a seriously adverse effect on the capacity of a vent pipe. Allowance must be made for a slight amount of fouling at the vent connection to the fixture drain. Consequently, the minimum recommended individual vent size is the same as the minimum permissible fixture drain size, 1¼ in (3.2 cm).

Branch-Vent Drops to Lower Floors

Rational analysis may be applied for the sizing of branch-vent drops to lower-floor fixtures. If each fixture drain of such fixtures is assumed to be installed vertically and to extend downward a sufficient distance such that flow reaches terminal velocity in the vertical drop, the fixture drain may be considered to have the same performance characteristics and airflow requirements as a drainage stack.

Also, if each individual vent is assumed to be connected at the top of the vertical drain, the vent may be considered to perform the same airflow function as a vent extension at the top of a vent stack, namely, that of supplying air into the drainage stack at the same rate as it is dragged down by the liquid flowing down the vertical drainage stack.

In drainage stacks of 1¼-in (3.2-cm) through 4-in (10-cm) diameter, terminal velocity is achieved in a drop of less than one normal story height. Ordinary airflow requirements for vertical fixture drains of that size range and conveying capacity flow are the same as for drainage stack-vent extensions.

Consequently, a branch-vent drop serving a number of individual vents may be considered to perform the same function as that of a vent header or combined vent serving as the single vent pipe extending above the roof for a number of vent extensions of soil and waste stacks and their attendant vent stacks. It follows logically, then, that the sizing of branch-vent drops should be comparable with the sizing of vent headers or combined vents in certain respects.

In the sizing of vent headers, using the standard tables developed for sizing vent stacks, the column headed "Size of soil or waste stack" is disregarded. The size is based on the sum of the fixture units of load of all drainage stacks vented through each section of the header. The developed length applied is that of the vent stack having the greatest developed length to the atmosphere above the roof.

In essence, this amounts to considering the vent header as a vent stack which serves an imaginary drainage stack having a load equal to that of the total number of fixture units of all the connected stacks. The vent header corresponds to an imaginary vent stack with a developed length equal to that of the actual vent stack having the greatest developed length of all connected to the vent header.

The logic of this basis for sizing vent headers is established on the fact that the total amount of flow in drainage piping is related to the number of fixture units of load connected to the drainage piping, rather than to the number and size of drainage stacks into which the various fixtures discharge. If a single stack were to be used in lieu of a number of drainage stacks, and to convey the same total load, the single stack almost always would have to be larger in size than any of the drainage stacks.

In any event, a single drainage stack could theoretically be used in lieu of a number of drainage stacks. However, in that case, long horizontal fixture drainage branches would be required, resulting in excessive loss of headroom due to slope in long branch drains. These branches would also be subject to excessive incidence of stoppages.

The developed length of vent stack for a single drainage stack with numerous long horizontal offsets would be comparable in length with that of the most extreme run or traverse of the drainage stack. Hence the basis cited for sizing vent headers may be deemed reasonable and rational.

The same basis may be applied to sizing branch-vent drops. But, in this case, the vent-stack connection for the branch-vent drop may be considered to be the equivalent of the vent terminal of a vent header or combined vent. Atmospheric pressure may be considered to prevail in vent stacks as a normal condition during service, except for relatively short periods when peak flow occurs in drainage stacks.

During peak flow periods, positive or above-atmospheric pressure conditions occur in the lower sections of drainage stacks and their attendant vent stacks. This positive-pressure condition in the vent stack simply assists flow in branch-vent drops, since their principal function is to supply air to the various fixture drains served when flow occurs therein.

Consequently, the rational basis for sizing branch-vent drops to lower-floor fixtures is the same as for sizing vent headers or combined vents, except that the maximum developed length which should be applied for branch-vent drops is that measured from the vent-stack branch connection to the farthest fixture drain connection served (Fig. 17.26).

Using Table 17.2 for sizing vent stacks, note the vent-pipe sizes suitable for the developed length applicable. Also note the number of fixture units of load suitable for each vent-pipe size for the developed length applicable. Then, for that developed length, select appropriate vent-pipe sizes for each section of the branch-vent drop corresponding to the load in fixture units. This corresponds to sizing branch-vent drops on a uniform-pressure-loss basis for their maximum developed lengths.

Branch Vents

Branch vents which serve to connect more than one individual vent to a vent stack or to a vent terminal in the atmosphere should be sized in accordance with the principal function performed thereby in any given installation and the corresponding quantity rate of airflow required to be conveyed. Just as for individual vents, proper sizes may be established by analysis of the arrangement of drainage and vent piping for any particular system.

Where several individual vents connect to a horizontal branch vent extending from a branch fitting in a vent stack and their respective fixture drains connect to a horizontal branch drain extending from a branch fitting in a drainage stack, a pressure relief circuit exists between the drainage-stack branch fitting and the vent-stack branch fitting. Each of the fixture drains and their individual vents form branch or parallel circuits for pressure relief and airflow between the drainage stack and vent stack. The proportion of the total airflow conveyed by each individual circuit is the same as would be the case in parallel circuits in a water-supply system.

In all other respects, the size of branch vents may be computed in the same manner as for individual vents, i.e., based on their principal function and the quantity rates of airflow or suds flow to be conveyed. A convenient basis for sizing branch vents is given in Table 17.10. The size in this case is based on the

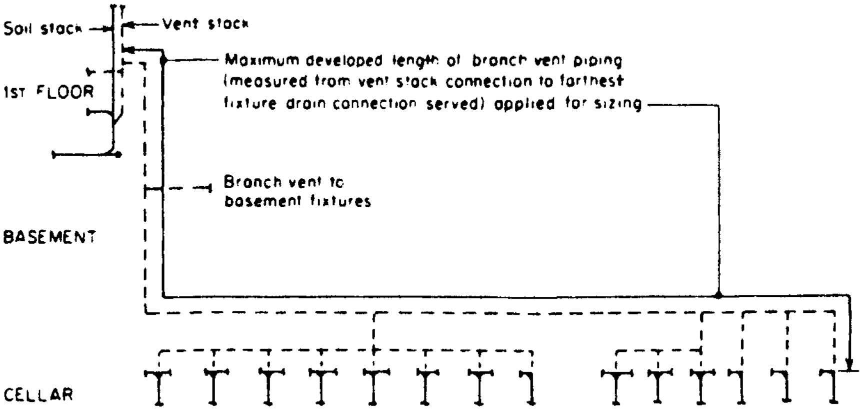

FIG. 17.26 Developed length applicable to sizing branch vent drops to lower-floor fixtures.

number of fixture units connected to the branch vent and the developed length of the branch vent measured from its vent stack or stack-vent connection to the farthest fixture-drain connection served by the branch vent.

Circuit and Loop Vents

A circuit or loop vent is little more than an enlarged individual vent connected to the fixture drain of the most upstream fixture discharging into a horizontal branch drain and provided to permit air to flow into the horizontal branch drain at a sufficient rate so as to prevent excessive aspiration effects from occurring therein. This is the principal function of a circuit or loop vent in most ordinary installations.

However, where a circuit or loop vent serves a horizontal branch drain which connects to a pressure zone of the sanitary drainage system, such as may occur adjacent to the base of a drainage stack or in the building drain, the principal function of the vent may be to prevent excessive back pressure effects from existing in the horizontal branch drain. Thus the quantity rate of airflow required to be conveyed by a circuit or loop vent must be determined in accordance with its principal function and corresponding airflow requirements, just as for individual or branch vents. For any given installation, the sizes of circuit or loop vents may be computed in accordance with their airflow and suds flow requirements in the same manner as was discussed for individual vents.

In general, codes require that the size of circuit or loop vents be at least one-half the diameter of the horizontal soil or waste branch to which they connect. This may be adequate for most ordinary installations requiring airflow to be conveyed to prevent excessive aspiration effects in the horizontal branch drain.

Relief and Yoke Vents for Soil and Waste Stacks

The function of a relief or yoke vent, provided in special locations in drainage stacks of extended height, is to permit air pressure to be relieved from the drainage stack directly to the vent stack by flow through a short relief or yoke vent of the same size as the vent stack. Wherever flow interference may occur in such drainage stacks, the relief or yoke vent functions as an additional elevated vent-stack base connection above the point of flow interference.

Sizing in this case is related to the sizing of vent stacks and their base connections. Hence the proper size for relief and yoke vents is the same as that of the vent stack required for the drainage stack.

Suds-Pressure Relief Vents

Suds-pressure relief vents, provided at special zones in the drainage system where suds pressure may develop, must be adequate in size to permit suds to flow out of the zone at a sufficient rate so that the pressure rise in the zone does not exceed the design criterion. Such special vents are necessary to prevent suds backup conditions at fixtures which discharge into such zones and are equipped with traps protected by vents which are inadequate to perform the function of relieving suds pressure.

An ordinary fixture trap with 1 in (2.5 cm) of residual trap seal depth in service has a maximum resistance of 2 in (5 cm) of water column when subjected to back pressure of suds. This resistance is equal to a column of suds 7.42 ft (2.26 m) in height, at which level suds backup through the fixture trap seal may occur.

A suds-pressure relief vent need not be of extensive length, for it is only necessary to relieve suds pressure from the pressure zone to a nonpressure zone downstream from and at a lower elevation in the sanitary drainage and vent system. Hence the principal factor involved in this case is the diameter of a relatively short vent required to relieve the quantity rate of suds flow in the pressure zone. A simple guide in this case is the quantity rate of airflow conveyed down a drainage stack into the suds-pressure zone, which may be determined from rates shown in Table 17.8, and the outlet discharge rates for suds at a flow pressure of 1 in (2.5 cm) water head, which may be determined from the capacities for various sizes of vent outlets in Table 17.5. The maximum permissible length of suds-pressure relief vents can be further computed by means of Eq. (17.14).

From these tables and by computations, it can be seen that the size of the suds relief vent in most cases is approximately three-fourths that of the drainage stack and its horizontal drain at the base of the stack. Thus this may be taken as a recommended guide in sizing such special relief vents.

Vents for Building Sewage Sumps and Receiving Tanks

Building sewage sumps and receiving tanks, other than pneumatic ejectors, operate at atmospheric pressure and receive sewage from sanitary subbuilding drains under gravity flow conditions. The only airflow required in a vent pipe from such an airtight receptacle is that which is displaced by sewage in entering the receptacle and that which is required to enter the receptacle as the sewage is ejected by the sewage pump. Thus the quantity rate of airflow required to be conveyed by the vent for a building sewage sump or receiving tank is the maximum rate at which sewage either may enter the tank or be pumped therefrom, whichever is the greater rate.

Based on the quantity rate of airflow required to be conveyed and the developed length of vent piping for a given installation, a proper size may be computed for such vents by means of Eq. (11.13) and by reference to Table 17.5.

CHAPTER 18

DRAINAGE AND VENT SYSTEM COMPONENTS

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INTRODUCTION

This chapter is introduced with a guide to component selection and a description of the various types of pipes, fittings, and joining methods used in drainage, waste, and vent systems. Then a detailed description is given of the components, including cleanouts, drains, interceptors, traps, and valves, which permits selection of the most appropriate components for a given installation.

GUIDE TO COMPONENT SELECTION

The *applicable plumbing code* is of primary importance in selecting a piping material for any component of a drainage and vent system. Materials that are permitted under the code are specified along with any restrictions on their use. The code also may stipulate accepted standards that govern the manufacture of the components, their tolerances, and their installation. The piping materials discussed in this chapter are all accepted for use in various national, regional, and most local codes, although some may not be acceptable for use in specific local codes.

When renovating a drainage system or when special circumstances require a unique design, it may be necessary to ask the authorities for a deviation from the accepted list of materials in order to match existing piping or to obtain special design characteristics. In reviewing such requests, the authorities usually require enough information to determine if the intent of the applicable code provisions is adhered to in terms of safety and suitability of the materials for the purpose intended.

The following characteristics of pipe and fittings are important in considering their suitability for installation in a drainage system:

- *Total installed cost.* This includes the cost of the pipe and fittings, assembly of the joints, handling, allowance for physical damage, and the cost of the support system for the piping.
- *Corrosion resistance of the pipe and fittings.* This is a measure of the ability of the pipe and fittings to resist both the internal corrosive effects of the effluent likely to flow through them and the effects of soils on their exteriors. Corrosion can be reduced or eliminated by the application of a suitable coating, lining, and cathodic protection.
- *Physical strength of the pipe and fittings.* This is a measure of the ability of the pipe and fittings to resist physical damage that may occur either during installation or after being placed in service.
- *Fire resistance of the pipe and fittings.* This is a measure of the ability of the pipe and fittings (*a*) to remain intact and not fail during a fire and (*b*) to retain the ability to carry water during a fire. Where fire resistance is important, pipe, joints, and supports should be selected taking this consideration into account.

METALLIC PIPE AND PIPING MATERIALS IN DRAINAGE SYSTEMS[1]

Cast-Iron (CI) Soil Pipe

Cast-iron soil pipe, known technically as *gray cast-iron pipe*, is a pipe fabricated of an iron alloy containing carbon and silicon.[2,3] It is manufactured in three classifications: *service* (*standard*) *weight, extraheavy weight,* and *hubless*. This pipe usually is lined internally with cement or coal-tar enamel and is coated externally with a variety of materials to reduce corrosion by soils. Two types of pipe ends are manufactured: hub and spigot or hubless. *Hub-and-spigot pipe* is available in diameters from 3 to 15 in (8 to 40 cm). *Hubless pipe* is available in diameters 1½ to 10 in (4 to 25 cm). The hub-and-spigot ends can be joined by either caulking or an elastomeric compression gasket. Hubless ends can be joined only by an external compression coupling.

Cast iron is well suited for use in any part of a drainage and vent system. Its advantages include the ability to withstand moderate external pressure (such as that resulting from burial in soil), good fire resistance, low flow resistance, and good corrosion resistance in most soils. Some piping of this type has been in use for over 100 years. Disadvantages include brittleness (it is subject to breakage when roughly handled), low corrosion resistance in aggressive soils and to highly septic effluent, heavy weight, and high initial cost.

Cast-iron soil pipe should conform to ASTM Standards A-74 (*Hub and Spigot Pipe and Fittings*) and CISPI 301 (*Hubless Pipe and Fittings*).

Acid-Resistant Cast-Iron Pipe (AR)

Acid-resistant cast-iron pipe, commonly called *high-silicon iron pipe*, is a gray cast-iron alloy containing between 14.25 and 15 percent silicon and small amounts of manganese, sulfur, and carbon. It is manufactured in the same dimensions as cast-iron pipe, but only in the extraheavy weight. It is available with two types of pipe ends: hub and spigot or hubless. The hub-and-spigot ends can be joined by caulking. Hubless pipe is joined by compression couplings. Acid-resistant cast-iron pipe is used for drainage of corrosive liquids and in exposed or underground applications where it may be subject to physical damage.

Acid-resistant cast-iron pipe should conform to ASTM Standards A-518 and A-861.

Ductile-Iron (DI) Pipe

Ductile-iron pipe is fabricated of a cast-iron alloy in which graphite replaces the carbon that is present in cast-iron soil pipe.[2] It is available for use either as a gravity sewer pipe or as a pressure pipe in sizes ranging from 3 to 54 in (8 to 135 cm). Eight pressure ratings are available: Class 50 [25 psi (172 kPa)] to Class 56 [350 psi (2410 kPa)], as well as gravity sewer pipe. A cement or bituminous pipe lining can be provided to resist internal corrosion. This type of pipe can be assembled with mechanical joints, gasketed joints, or flanged joints.

The advantages of this type of pipe are the same as those for cast-iron pipe. It has the additional advantage of a higher pressure rating and higher external load-bearing capacity. It is not as brittle as cast-iron pipe, permitting rougher handling. Its initial cost is higher than that of cast-iron pipe, though.

Ductile-iron gravity sewer pipe should conform to ASTM Standard A-746.

Steel (ST) Pipe

Steel pipe is manufactured in a large number of alloys. It is produced either by extrusion (seamless) or by welding (which results in a seam). It is available either plain (black) or galvanized (zinc-plated on the inside, outside, or both). Its wall thickness is expressed as a *schedule*, with thicknesses ranging from Schedule 10 (lightest) to Schedule 160 (heaviest). The relationship between schedule and wall thickness depends on the pipe diameter.

Steel pipe can be obtained with threaded ends (for screwed fittings), plain ends, and beveled ends (for welding). Steel pipe is used for vent systems, for gravity drainage systems where human waste is not discharged, for indirect waste lines, and for pressure piping. Advantages of steel pipe include its availability in long lengths, its availability in varying pipe thickness to meet almost any design pressure, and high internal and external strength. It has good flow characteristics, good fire resistance, and a low initial cost. A disadvantage is its low corrosion resistance, which results in the need for internal and external corrosion protection—galvanization being the most commonly used method of such protection.

Steel pipe alloys most commonly used for drainage and vent systems should conform to ASTM Standards A-120 or to A-53, which differ only in the percentage of components in the alloy.

Copper Tube, Type DWV

Copper tube used in drainage systems is classified as *type DWV* (drainage, waste, and vent). It is a seamless tube made from almost pure copper (99.9 percent) and is available only in drawn, or soft, form with plain ends. Joints for this pipe can be either soldered or brazed. Soldering provides adequate strength; it is also less costly than brazing. Therefore, soldering is the preferred method of joining (see "Joints and Connections," Chap. 11). The pipe is available in diameters from 2 to 6 in (5 to 15 cm). It is primarily used in residential buildings for waste lines and in larger buildings for local branch lines where human waste is not discharged. Its advantages include light weight, ease of assembly, and a smooth interior. Its disadvantages include corrosive attack by ordinary sewage, poor fire resistance, and the need for dielectric connections to eliminate galvanic corrosion where this material is connected to iron piping.

Type DWV copper tube for drainage systems should conform to ASTM Standard B-306.

Brass Pipe

Brass pipe is manufactured from an alloy containing 85 percent copper and 15 percent zinc. For drainage systems, tubing having plain ends is used. Joints can be either screwed or soldered (see "Joints and Connections," Chap. 11). Brass pipe is generally used in local branch drainage lines (where this alloy resists specific corrosive drainage effluent) and in alterations to match existing work. The advantages and disadvantages of brass pipe are the same as those for copper tubing, except that brass can be used as a drain pipe under pressure.

Brass pipe should conform to ASTM Standard B-43.

Lead Pipe

Lead pipe is made from 99.7 percent pig lead; various alloys also are available for special applications. This pipe is joined by wiped joints, burned joints, or flanged mechanical joints. Lead pipe is used for connections to floor-mounted water closets, for radioactive wastes, and for special laboratory corrosive wastes. It is rarely used in modern drainage systems.

Lead pipe should conform to U.S. Government Standard WW-P-325a.

PLASTIC PIPE

Plastic pipe is fabricated in a great variety of compositions, many of which are suitable for drainage and vent systems. The applicable code is usually the most important factor in determining the use and selection of plastic pipe for such purposes.

Plastic pipe is manufactured in two general types: thermoset (TS) and thermoplastic (TP). *Thermoset piping* (for example, epoxy and phenolic) is not affected by heat and will remain permanently rigid. It is more resistant to solvents than thermoplastics. *Thermoplastic piping* softens when subject to heat and rehardens upon removal of the heat. This process of heating and subsequent rehardening affects the strength of the pipe. Therefore, the selection of plastic pipe must be closely coordinated with the pipe hangers and pipe support system.

The advantages of plastic pipe in drainage and vent systems include excellent resistance to a very wide range of sanitary and chemical effluents, resistance to aggressive soils, availability in long lengths, low resistance to fluid flow, and low initial cost. Disadvantages include poor structural stability (requiring additional support), susceptibility of some types of plastics to physical changes resulting from exposure to sunlight, low resistance to solvents, poor fire resistance, lowered pressure ratings at elevated temperatures, and the production of toxic gases which are released upon combustion of some types of plastic pipe. Additional information on plastic pipe and fittings may be obtained from Refs. 4 and 5.

Polyvinyl Chloride (PVC) Pipe

Polyvinyl chloride pipe (type TS) is available in Schedules 40 and 80 and in diameters up to 20 in (50 cm). Drainage fittings are made in diameters up to 8 in (20 cm). Schedule 80 pipe can be joined either by threading or solvent welding, but Schedule 40 pipe can only be joined by solvent welding because it cannot be threaded. This pipe will not burn and is self-extinguishing. However, when subject to conditions of a fire, a toxic gas is developed. PVC is the plastic having the highest mechanical strength and is the plastic most widely used for plastic pipe, but it has very poor resistance to solvents.

PVC sewer pipe should conform to ASTM Standard D-2729.

Polypropylene (PP) Pipe

Polypropylene pipe (type TP) is available in Schedules 40 or 80 and in diameters up to 8 in (20 cm). Joining by heat fusion is recommended. This material is one of the more widely used plastics for drainage piping systems. It is capable of withstanding a wide range of both corrosive and sanitary waste. It is the most resistant to solvents of all the common plastic pipe materials and is only slightly less rigid than PVC.

It should conform to ASTM Standard D-2146.

Polyethylene (PE) Pipe

Polyethylene pipe (type TP) used in drainage systems is of the rigid type. It is available in Schedule 80 in diameters up to 6 in (15 cm). It is joined by heat fusion. It has the least mechanical strength of all the common plastic pipe materials and is only moderately resistant to solvents. Its greatest use is for foundation drainage piping.

It should conform to ASTM Standards D-2239, D-2447, and D-2104.

Acrylonitrile Butadiene Styrene (ABS) Pipe

Acrylonitrile butadiene styrene (type TP) is available in Schedules 40 and 80 and in diameters up to 12 in (35 cm). Drainage fittings are available only in diameters up to 6 in (15 cm). Joints are made by either solvent welding or threaded connections. Only Schedule 80 can be threaded. Acrylonitrile butadiene styrene (ABS) is slightly more rigid than PVC and is the least resistant to solvents of all the popular plastic materials.

ABS pipe should conform to ASTM Standards D-2661 and D-2751.

SPECIALIZED PIPE MATERIALS

Glass pipe is fabricated from a low-expansion borosilicate glass having a low alkali content. This pipe is primarily used for the drainage of various corrosive liquids. It is very brittle and should be used only where some measure of protection is provided against damage.

Vitrified clay pipe is made from selected clay and shale that is mixed with water and then baked until it fuses, or vitrifies, to form a homogeneous mass. It is very brittle and only suitable for use in underground gravity drainage systems. It is resistant to a wide variety of effluent and aggressive soils.[6]

FITTINGS IN DRAINAGE SYSTEMS

A *fitting* is a device used to connect one or more pipes and/or to change the direction of a straight run of pipe. Four types of fittings are illustrated in Fig. 18.1. Codes require that any change in direction of piping in a drainage system be made with fittings. The bends in fittings used in drainage systems should have a radius of curvature large enough to prevent solids from accumulating and to provide good hydraulic flow characteristics. Fittings that satisfy these characteristics are known as *drainage-pattern fittings* or *sanitary-type fittings*; they are required by code to be used in drainage systems. Vent piping does not require drainage-pattern fittings. Threaded drainage fittings should be of the recessed type, so that the interior of the assembled pipe is smooth and unbroken.

Bends (Sweeps). A *bend*, illustrated in Fig. 18.1*a*, is a fitting used to change the direction of a pipe. Fittings are available with changes at various angles. A *¼ bend* is a 90° fitting; it is available as either a short or long sweep (i.e., short or long radius of curvature). A *⅛ bend* is a 45° fitting, and a *1/16 bend* is a 22½° fitting. A bend of radius *R* is shown in Fig. 18.1*b*.

Wye. A *wye*, illustrated in Fig. 18.1*c*, is a fitting used to connect a branch pipe into a straight run of piping at a 45° angle. Wyes are available with end connections that are of the same size or with various combinations of reduced pipe sizes in any direction.

Tee. A *tee*, illustrated in Fig. 18.1*d*, is a fitting used to connect a branch pipe into a straight run of piping at a right angle. Where flow characteristics are important, such as in the drainage system, codes require that a *sanitary tee* be used. Where flow is not a consideration, such as in a vent system, *standard tees* are permitted. They are available with end connections of all similar sizes or in various combinations of reduced pipe sizes in any direction.

Elbow. An *elbow*, illustrated in Fig. 18.1*e*, is a fitting having a 90° change of direction with a very short radius. It is only suitable for use in vent systems. El-

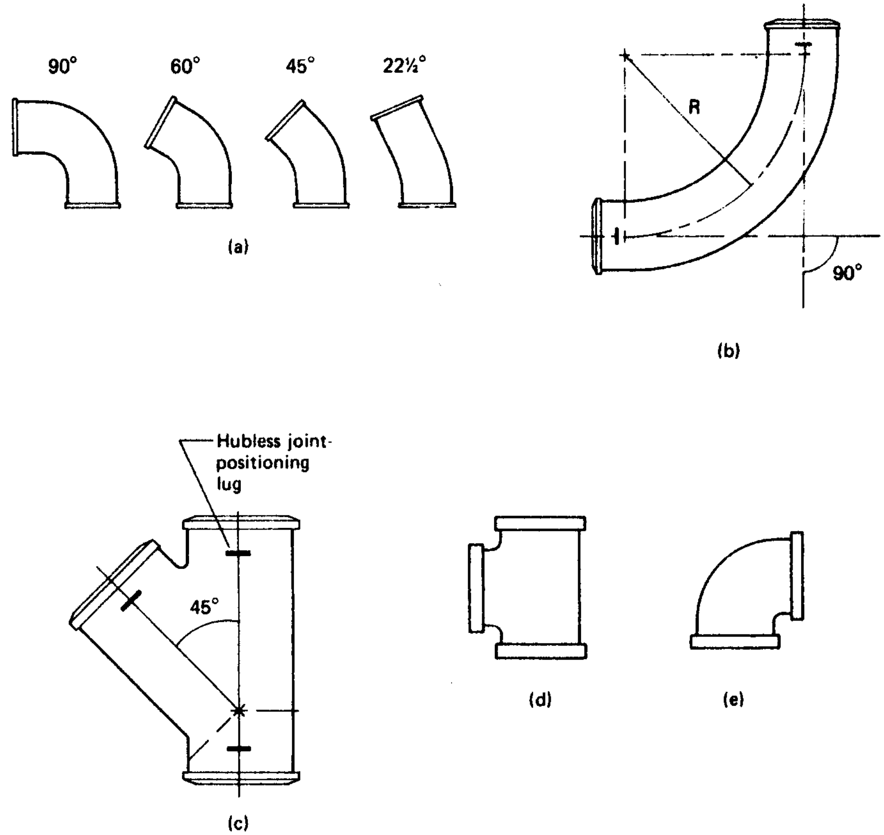

FIG. 18.1 Typical sanitary fittings. (*a*) 90°, 60°, 45°, and 22½° bends; (*b*) 90° sweep; (*c*) 45° sanitary tee; (*d*) standard tee; (*e*) elbow.

bows are available with end connections of all similar sizes or in various combinations of reduced pipe sizes.

Fitting Materials

Cast-iron fittings can be used with either cast-iron or steel pipe. They are available with screwed, hub-and-spigot, hubless, and flanged ends. These fittings should conform to the following standards: ANSI B16.12 (threaded), ASTM A-74 (hub and spigot), and CISPI 301 (hubless).

Malleable-iron fittings can be used with steel or cast-iron pipe. They are available with screwed ends only. These fittings should conform to ANSI Standard B16.3.

Cast-copper-alloy fittings can be used with drainage, waste, and vent pipe. They are available with solder ends only. These fittings should conform to ANSI Standard B16.23.

Wrought-copper and copper-alloy fittings can be used with type DWV copper pipe. They are available with solder ends only. These fittings should conform to ANSI Standard B16.29 (*Solder Joint DWV Drainage Fittings*).

Plastic fittings must be made of the same material as the individual plastic pipe to which they are connected. The various materials should conform to the ANSI Standards D2665 (PVC), D2661 (ABS), and D2609 (PE).

Acid-resistant fittings are fabricated of the same material as the pipe and conform to the same standards.

Unions, illustrated in Fig. 18.2, are fittings used to connect the ends of two fixed pipes, neither of which can be turned. A union consists of three interconnected pieces, i.e., two ends that are internally threaded, and a center piece that draws the two ends together when rotated. These fittings should conform to ANSI Standards B16.39 (steel or malleable iron) and B16.41 (brass or bronze).

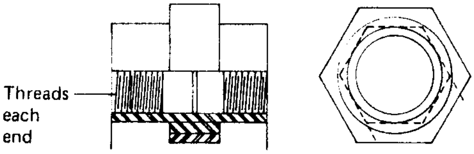

FIG. 18.2 A typical union.

Dielectric fittings, illustrated in Fig. 18.3, are adapters used to connect any pipe containing copper with any pipe containing iron. Such a fitting is used to prevent the galvanic action between dissimilar metals from causing corrosion failure. The fitting itself is constructed so that insulation prevents the two connecting pipes from coming into direct contact with each other.

JOINTS IN DRAINAGE SYSTEMS

A *joint* is a connection between one pipe and (*a*) another pipe, (*b*) a fitting, or (*c*) a piece of equipment. A joint must be able to withstand the greatest pressure capable of being exerted on it. Most plumbing codes refer to standards that govern the methods and materials used in forming joints. Selection of the joining method is determined by the type of pipe used, the type of fitting, the maximum pressure expected in the system, and the possible need for disassembly.

Caulked Joints

A *caulked joint*, illustrated in Fig. 18.4, is used only for cast-iron pipe having hub-and-spigot ends. After the spigot end of one pipe is placed inside the hub end of the other, a rope of oakum or hemp is packed into the annular space around spigot end until it reaches 1 in (2.5 cm) below the top of the hub. (For acid-resistant cast-iron pipe, hydrous magnesium aluminum silicate reinforced with fiberglass is used as a packing material instead of oakum.) Then, a ring 1 in (2.5 cm) thick of molten lead is poured into the annular space on top of the rope. Finally, the lead is pounded farther into the joint with a caulking iron until it is ⅛ in

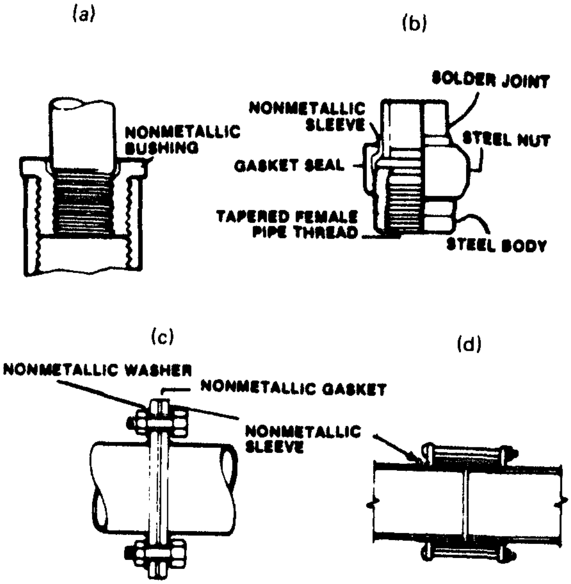

FIG. 18.3 Typical dielectric fittings. (*a*) Bushing; (*b*) union; (*c*) flanged; (*d*) compression coupling.

(0.3 cm) below the rim of the hub. In use, the hemp or oakum swells when it absorbs water and further increases the joint's ability to resist leakage.

A caulked joint is a rigid, non-pressure-type joint that is suitable for installations both above ground and underground. Because caulked joints are labor-intensive, they have been replaced by compression-coupling joints and gasketed joints for most cast-iron joint applications where permitted by code.

Compression Couplings

A *compression coupling* (sometimes called a *sealing sleeve*) is used to connect sections of hubless pipe (i.e., pipe with no hub), acid-resistant cast-iron pipe, and

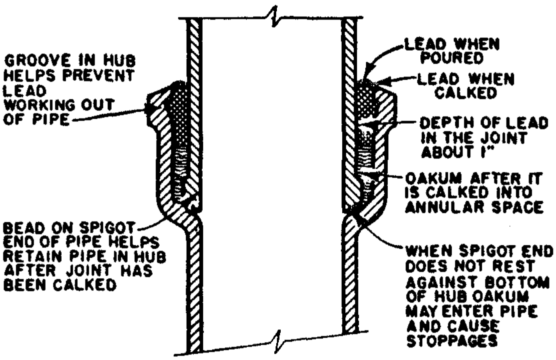

FIG. 18.4 A caulked joint.

glass pipe. Such a coupling, shown in Fig. 18.5, consists of an inner elastomeric gasket and an outer metallic sleeve with an integral bolt used for tightening and compressing the seal. Such joints rely on the pressure between the sleeve and the pipe exterior to provide a seal and to resist forces tending to pull the joint apart. The two pipes to be joined are placed end-to-end, separated by a gasket, as illustrated. The entire sleeve assembly is then placed over both the ends, and the bolt is securely tightened to a torque value specified by the manufacturer. The same sleeve assembly may be used to join cast-iron pipe.

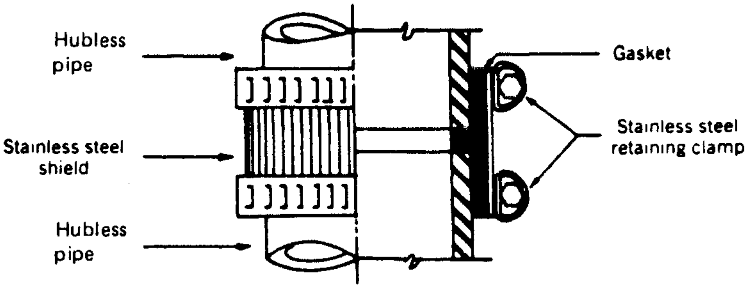

FIG. 18.5 A compression-coupling joint.

A compression coupling is a rigid, non-pressure-type joint that is preferred for above-ground installations because it is easy to assemble and has considerable mechanical strength. Underground, the metallic sleeve often fails after years of service as a result of corrosion by surrounding soil or fill. Standards governing the fabrication of this type of joint are ASTM Standard C-564 and Cast Iron Soil Pipe Institute Standard 310.

Screwed Joints

A *screwed joint*, illustrated in Fig. 18.6*a*, uses threads on two pipe ends (or on a pipe and a fitting) to draw the two pieces together and form a leakproof seal. Such a joint can be used with any plain-end pipe that has the necessary wall strength and thickness to have threads cut into it. A screwed joint requires that threads be cut on the outside of a pipe (*male threads*) and inside a fitting (*female threads*). The threads used for pipe, illustrated in Fig. 18.6*b*, are known as *American tapered pipe threads* (APT). They may be either internal (APTI) or external (APTE). Before assembly, the threads are cleaned of burrs and chips resulting from the cutting process. Pipe-joint compound or Teflon tape is applied on the male thread to ensure a tight seal. Then the male thread is placed inside the female thread and the joint is tightened. This type of joint is inexpensive and easy to fabricate. It is generally limited to pipe 3 in (7.5 cm) or smaller in diameter because of the great effort required to turn a pipe of larger size in making a joint.

Applicable plumbing codes usually specify the type of pipe that can be threaded. The standard governing the fabrication of this type of joint is ANSI Standard B2.1.

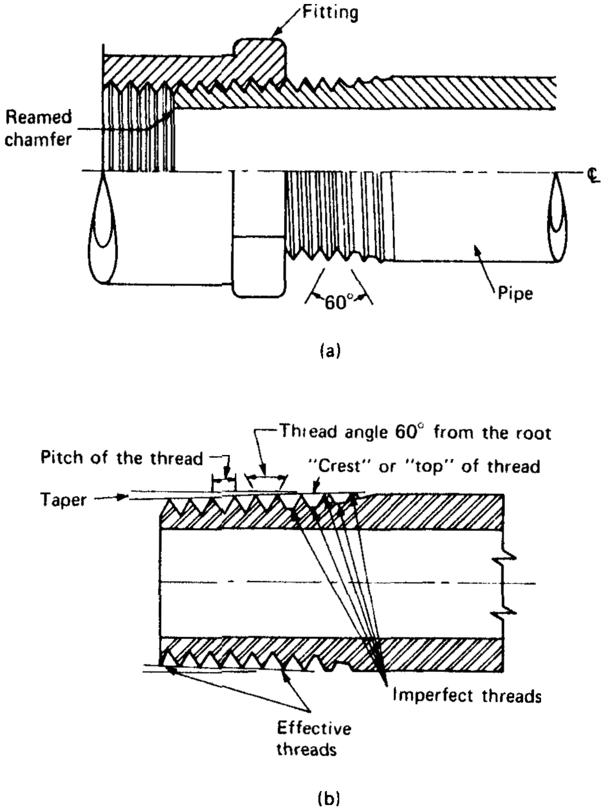

FIG. 18.6 Screwed joint. (*a*) Whole joint; (*b*) detail of American National Tapered Pipe Thread.

Soldered Joints

A *soldered joint* (also known as a *sweat joint*), illustrated in Fig. 18.7, is a gastight metal pipe joint made with solder (also see "Making Soldered Joints," Chap. 11). Soldered joints are used to join plain-end copper pipe or copper-alloy pipe with solder-end fittings. The solder used in drainage and vent systems is an alloy (usually tin and lead or tin and antimony) that melts at a temperature of 800°F (427°C) or lower. The joint is made by placing flux on the clean male end of the pipe and then inserting it fully into a clean socket (female) end of a fitting. The excess flux is wiped off. Then the assembly is heated to a temperature high enough to melt the solder. Next, the solder is applied completely around the perimeter. Capillary action draws the solder throughout the entire joint. When the solder cools, it adheres to the walls of both pipe and fitting, creating a leakproof, rigid, pressure-type joint that is suitable for any type of installation for which the piping itself is acceptable. This type of joint is generally limited to pipes having diameters no larger than 4 in (10 cm) because of the difficulty of applying heat evenly to larger joints.

The solder should conform to ASTM Standard B-32.

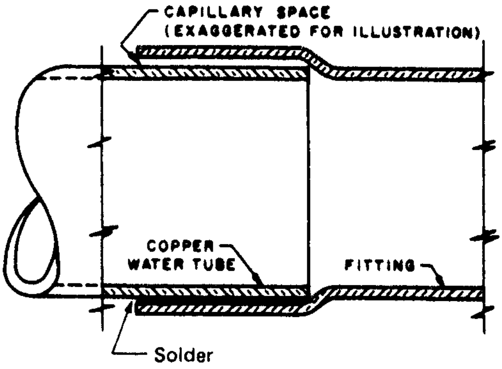

FIG. 18.7 A soldered joint.

Gasketed Joints

A *gasket* is a ring or circular sleeve of elastomeric material used to provide a tight seal. A *gasketed joint*, illustrated in Fig. 18.8, uses a gasket under compression to join cast-iron soil pipe and ductile-iron sewer and pressure pipe. The end of each pipe must be of a type suitable for the individual joint. Although the shape of the gasket differs according to the application, the method of fabrication of such joints is similar. First, the gasket is inserted into the bell end of the fitting. Then an approved lubricant is spread on the male end of the pipe before it is inserted into the fitting. The barrel of the pipe compresses the gasket, forming a leakproof joint.

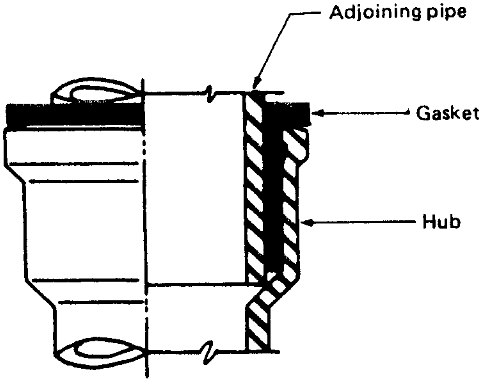

FIG. 18.8 A gasketed joint.

A gasketed joint has some degree of flexibility, allowing some deflection of the pipe during installation. Gasketed joints are well suited for both above-ground and underground installations. Gasketed joints have replaced caulked joints and compression-coupling joints for underground piping because they are easy to fabricate and the inert nature of the gasket eliminates the possibility of corrosive attack on the outer metallic sleeve of the compression coupling.

Standards governing the fabrication of gasketed joints are ASTM C-564 (metallic pipe), ASTM D-3212 (plastic pipe), and CISPI HSN (cast-iron soil pipe).

Solvent-Weld Joints

A *solvent-weld joint*, illustrated in Fig. 18.9, is made by spreading a cement on the surfaces to be joined. The cement reacts chemically with the pipes and fittings it comes in contact with, dissolving the material it contacts. The cement is spread on the male section, which is then inserted in the female portion of the joint and rotated to distribute the solvent evenly. When dry, the two components are fused into a homogeneous mass, producing a leakproof joint. This is a rigid, pressure-type joint that is suitable for any type of installation for which the piping itself is acceptable. Solvent-weld joints can only be used with specific matching types of plastic pipe and fittings with plain and socket ends.

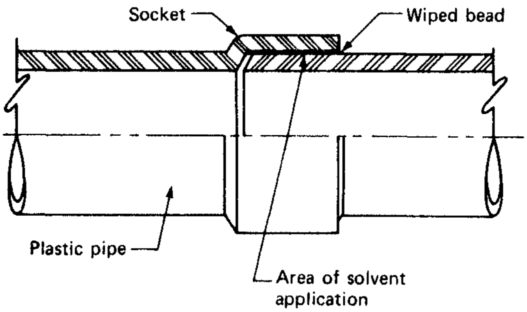

FIG. 18.9 A solvent-weld joint.

The following ASTM standards govern the use of solvent cement, depending on the type of pipe for which the cement will be used: ASTM D-2235 (ABS), ASTM D-2541 (PP), and ASTM D-2846 or F-93 (PVC).

Heat-Fusion Joints

In a *heat-fusion joint*, illustrated in Fig. 18.10, heat is used to melt the end of a plastic pipe and the socket of a fitting into a homogeneous mass. Such a joint can only be used with plain-end plastic pipe and socket fittings manufactured specifically for this purpose. The joint is made as follows: First, multiple loops of electrically conducting wire are placed around the outside of the end of the pipe. Then the pipe and wire are placed in the socket of a fitting. Next, the pigtails are connected to a carefully controlled source of electricity provided by the pipe manufacturer for this purpose. When the electric current is turned on, the wires inside the joint are heated, causing the end of the pipe and that part of the fitting with which it is in contact to melt and fuse together. After the electricity is turned off, the plastic hardens, creating a watertight joint that is suitable for all aboveground and underground installations. Then the leads are cut off, leaving

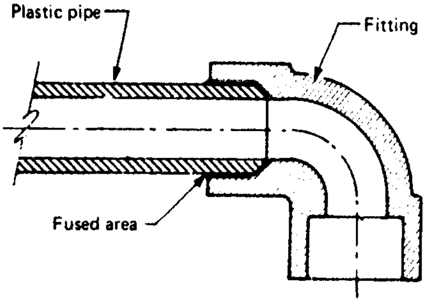

FIG. 18.10 A heat-fusion joint.

the embedded wires as part of the joint. The manufacturer's instructions must be followed carefully throughout each phase of the process.

Mechanical Joints

A *mechanical joint*, such as that shown in Fig. 18.11, uses nuts and bolts attached to the ends of two pipes to draw them together. Many kinds of proprietary joints are available, but all are similar in principle. The correct type of joint must be selected for the specific type of pipe. Mechanical joints are used on ductile-iron pressure pipe or on sanitary drainage pipe. The joint is made by first placing a gasket (and a metal retaining ring, if required by the joint type) on the male end of the pipe, inserting the pipe into the joint, and then attaching the bolts (*a*) to both pipes or (*b*) to one pipe and the retainer ring. As the bolts are tightened, the pipes are brought together, thereby compressing the gasket and forming a leakproof joint. Mechanical joints have some flexibility, allowing the pipes to be installed with an angle of deflection of up to about 5°. Such joints are highly resistant to being pulled apart.

Grooved Joints

Grooved joints, such as that shown in Fig. 18.12, are only used to connect steel and ductile-iron pipe. They are of two types: roll (shoulder) grooved and cut grooved. Each requires a different pipe-end preparation in making a joint. *Roll grooves* are used to form joints when the pipe wall is not thick enough to have a groove cut in it. The coupling assembly for both types is the same. It consists of an inner elastomeric gasket and an outer split-metallic sleeve with an integral bolt used for tightening. The outer sleeve has extensions at each end that fit into grooves cut in (or formed around) the pipe near the ends to be joined. The coupling assembly is placed over both the ends and the extensions are mated with the grooves in the pipe. The bolt is tightened to the torque requirements established by the manufacturer to form a pressure-type watertight joint that is well suited for pump discharge lines. This joint has some flexibility, allowing the pipes to be installed with an angle of deflection of up to about 5°.

Standards governing the fabrication of grooved joints are AWWA Standard C606 (couplings), ASTM Standard D-735 (gaskets), and ASTM Standard D-183 (bolts).

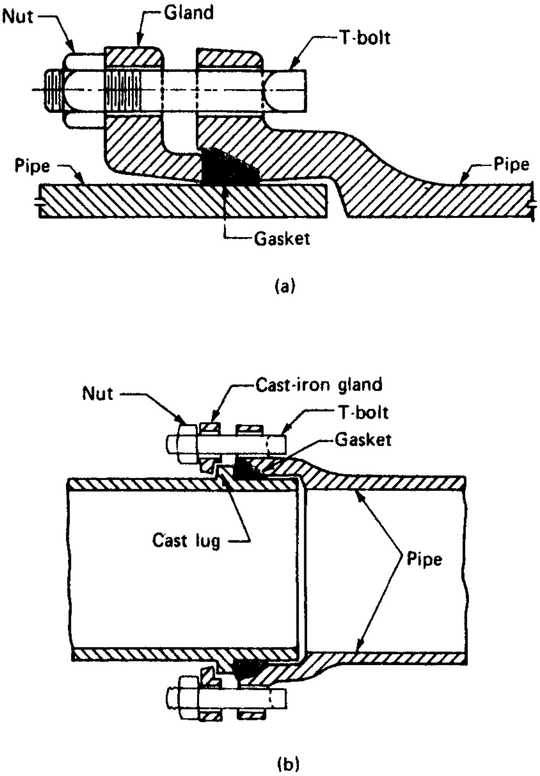

FIG. 18.11 A typical mechanical joint. (*a*) Standard mechanical joint; (*b*) modified mechanical joint.

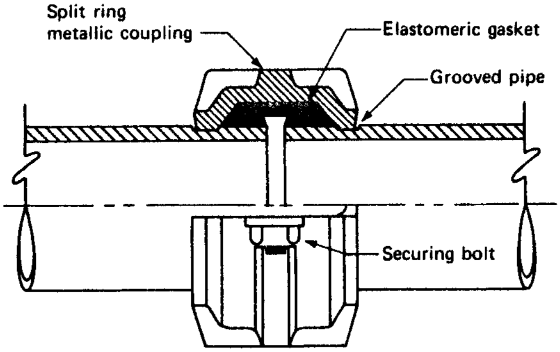

FIG. 18.12 A typical grooved joint.

Wiped Joints

A *wiped joint*, illustrated in Fig. 18.13, uses molten lead to join one lead pipe to another lead or brass pipe in a drainage system. The joint is formed by fitting the end of one pipe into the flared end of the other. Molten lead is then poured onto the joint and spread evenly or wiped with a hand-held pad, providing a minimum dimension of about ¾ in (1.9 cm) and a maximum thickness of about ⅜ in (1 cm). This is a rigid, non-pressure-type joint that can only be used to connect one lead pipe to either a lead or a brass pipe or to a suitable adapter when used for other kinds of pipe. Lead pipe is rarely used in modern drainage systems.

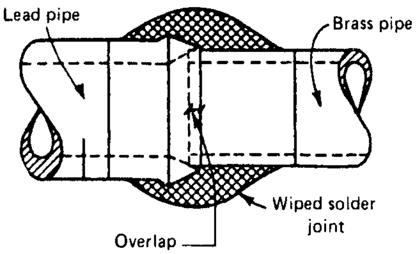

FIG. 18.13 A wiped joint.

Burned Joints

A *burned joint* is a joint formed by fitting the end of one lead pipe into the flared end of another lead pipe in drainage systems. Heat is then applied evenly around the perimeter, melting the overlapping edges and fusing them together. This is a rigid, non-pressure-type joint.

Adapters

Adapters are used to join two different pipe materials or piping with dissimilar joint ends. Most plumbing codes require the use of approved adapters.

CLEANOUTS

A *cleanout*, illustrated in Fig. 18.14*a*, is a gastight, watertight pipe fitting with a removable plug that is used in a drainage system. The plug fits into a threaded *ferrule*, which is a metal sleeve with internal (female) threads that is inserted into a fitting. This provides an opening into the pipe, allowing easy access for inspecting or cleaning the interior. The removable plug must have a raised nut or a recess where a wrench can be applied. A brass plug should be used for iron ferrules to make removal easier. Another type of plug uses a neoprene gasket to make removal easier and to provide a gastight seal. If installed in a floor, a cleanout must be strong enough to support the floor traffic in the location where it is installed.

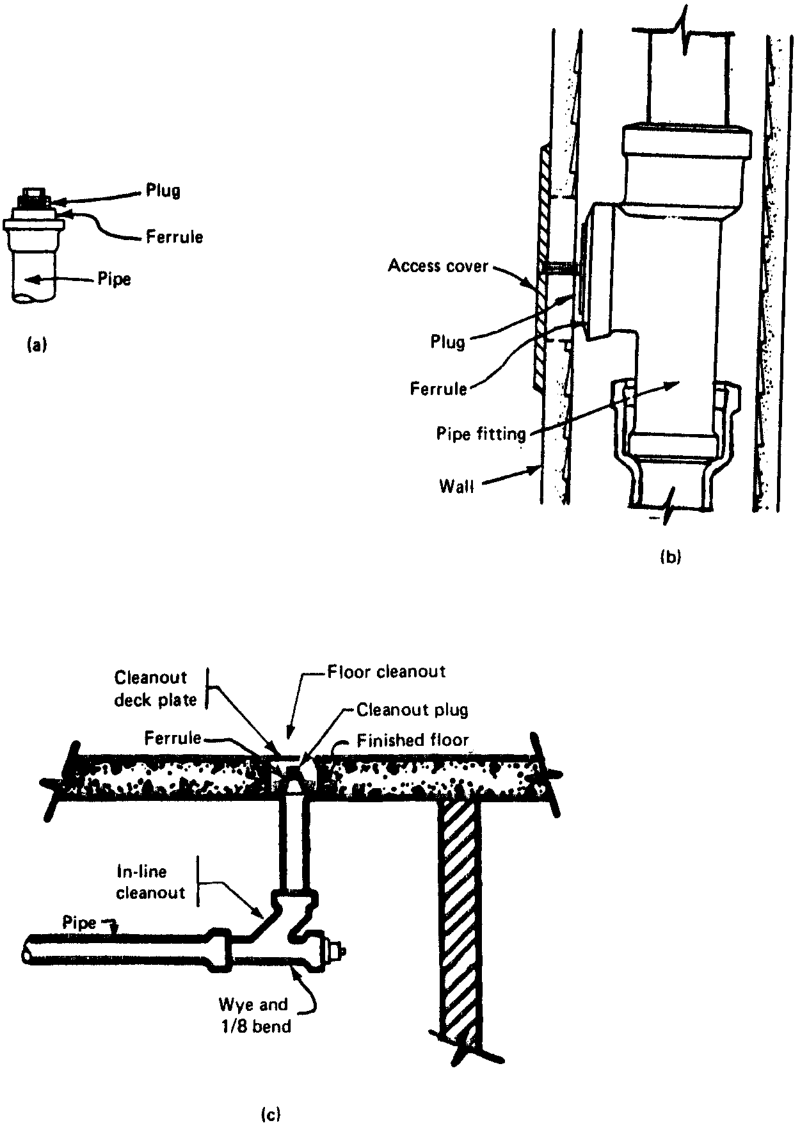

FIG. 18.14 Typical cleanouts. (*a*) Cleanout components; (*b*) wall cleanout; (*c*) floor and in-line cleanouts.

An *in-line-type cleanout* is a cleanout that is installed in exposed, accessible piping. It is the most economical type of cleanout, generally requiring only a wye-type fitting and a ferrule.

A *wall cleanout* is a cleanout that is used where a drainage line is concealed behind a partition. The cleanout may be reached through an access cover, as illustrated in Fig. 18.14*b*.

A *floor cleanout* is a cleanout used to provide access to piping where installation otherwise prevents access. It is installed in the slab or floor above the pipe where access is possible, as illustrated in Fig. 18.14c.

Code Requirements. The following code requirements apply to cleanouts:

- Cleanouts within buildings must be spaced at a distance no greater than 50 to 75 ft (15.2 to 22.9 m) depending on the local code.
- Cleanouts must be provided at every change of direction greater than 45° for both horizontal and vertical pipes.
- Cleanouts must be provided at the base of each vertical drainage stack.
- Sufficient clearance for inserting a cleaning rod must be provided.
- Cleanouts must be installed such that they open in the direction of flow.
- Cleanout sizes must be the full size of a pipe having a diameter of up to 4 in (10 cm) and half size for all pipe 5 in (12.5 cm), with a minimum 4-in (10-cm) connection.

On concealed piping, a fixture with an integral trap or a fixture trap is acceptable as a cleanout provided no other piping is disturbed when the fixture or trap is removed to provide access to the pipe interior.

DRAINS

Drains may be divided into two general categories: floor drains and roof drains. Although they may be similar in appearance, each satisfies different requirements. A *floor drain* is located indoors and is generally subject to traffic. It provides a receptacle for spills, washdown, and effluent to be collected and routed directly into the sanitary drainage system. Typical floor drains are shown in Fig. 18.15.

A *roof drain* is used to remove storm water falling onto a roof (or other area which is open to the weather) and route the water directly into the storm-water drainage system. A typical roof drain is illustrated in Fig. 18.16. Roof drainage systems are discussed in Chap. 19.

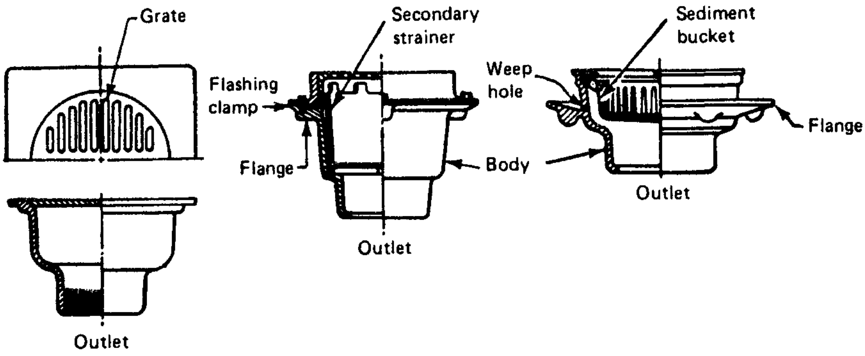

FIG. 18.15 Typical floor drains. *(Courtesy of Jay R. Smith Co.)*

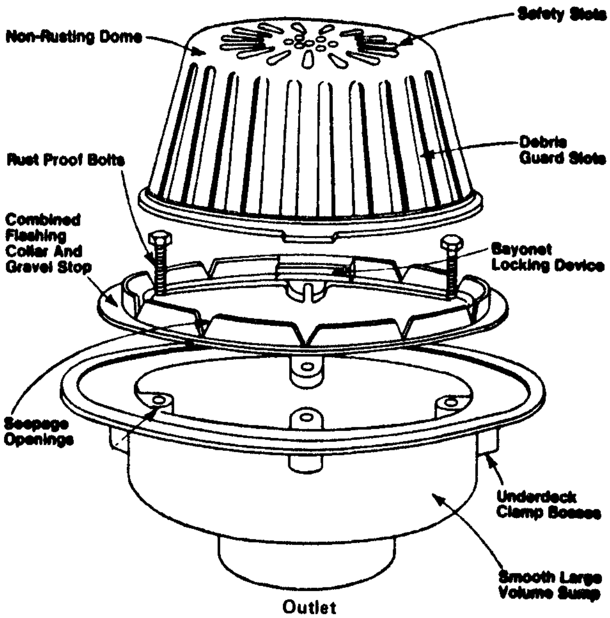

FIG. 18.16 A typical roof drain. *(Courtesy of Jay R. Smith Co.)*

Drain Components

The *body* of a drain is the main receptacle that receives the effluent. It contains all the components required for the anticipated design conditions. The body is usually fabricated of cast iron, which is suitable for most purposes. Plastic and stainless steel may be used in corrosive environments or for corrosive effluent. Extensions are available to increase the depth of the body of the drain to allow proper positioning of the top in relation to the finished floor or roof. The *outlet* of the drain connects to the piping system. The outlets that are commonly available are *inside caulk* (also used for no-hub piping), *outside caulk*, and *male screwed end*. A *flange* on the body of a drain is used where the body is cast into a floor slab to anchor the drain to the slab. A secondary purpose of the flange is to trap any liquid that may seep around the perimeter of the body of the drain at the grate enclosure. Weep holes must be drilled in the body of the drain to allow the trapped liquid to enter the drain for disposal. This flange is integrally cast into the body of the drain and must be included as part of the specifications for the drain. Extrawide flanges are available for special floor finishes, where necessary.

A coating is usually applied on a cast-iron drain to protect it against corrosion either while being stored or after it is cast into a slab. The coating differs with each manufacturer.

A *flashing ring* or *clamp* is a device used to secure flashing directly to the body of the drain. It provides a waterproof seal to permit any liquid that finds its way to this level to be routed into the body of the drain for disposal. The flashing ring is attached to (and on top of) the flange, with the flashing between them.

A *closure plug* is a plug that is screwed into the body of the drain to seal it temporarily for testing purposes or to close it in areas where the drain is not used for long periods of time. An O-ring may be used to ensure a gastight seal.

An *underdeck clamp* permits the body of the drain to be secured firmly to the slab. This is to avoid the possibility of the drain's shifting position either as a result of normal expansion and contraction or in response to loads resulting from rain or snow. The shifting may cause the flashing or insulation to fail, resulting in leaks.

An *expansion joint* may be installed on the outlet of the drain. It is required where the roof may be subject to excessive expansion and contraction. Since the drain is anchored by the piping, if the roof moves, the flashing will separate from the flashing ring, allowing a leak to develop.

A *grate* (sometimes called a *strainer*) is a device located at the top of a drain permitting liquid effluent to enter the drain body while excluding larger solids and foreign matter. The grate may be either the bar-type (for light- and medium-duty use) or the tractor-type (for heavy-duty use). Grates are available in a wide variety of materials. Their selection is based on requirements for a shape and finish that match the aesthetics of the surrounding area and on requirements for a material that is strong enough to support the heaviest type of traffic it is expected to support. Grates are classified according to ANSI Standard A12.21-1 (floor drains) as follows: *light duty*, foot traffic only; *medium duty*, live wheel loads of up to 2000 lb (907 kg); *heavy duty*, live wheel loads of less than 5000 lb (2270 kg); *extraheavy duty*, live wheel loads of 5000 lb (2270 kg) or more.

Cast iron is the material most commonly used for grates. Grates fabricated of this material are suitable for light- to heavy-duty usage. Grates that are subject to shock loads should be fabricated of ductile iron. Brass, bronze, and nickel-alloy grates are available for use in finished areas. These materials also can be laminated as a top layer on cast- or ductile-iron grates to combine strength with good appearance. Grates may be hinged or removable and not secured to the drain body. They also can be secured to the drain body by standard or vandal-proof screws. One type of grate, called a *dome* (illustrated in Fig. 18.16), extends above the top of the body of the drain to allow for the continued entry of storm water when leaves or other debris accumulate at the drain in quantities that could block a flat grate. Domes are available in a wide variety of materials, including plastic, which is low in cost, high in strength, and high in corrosion resistance.

Sediment Trap. A *sediment trap* (or *bucket*) is a removable device inside the drain body used to trap and retain small solids that pass through the grate. The grate is removed to provide access to the sediment trap. Then the unwanted solids that have accumulated are disposed of. Stainless-steel or bronze-mesh screens can be inserted into the bucket to trap smaller material.

A *secondary strainer* may be installed below the grate in a drain that does not have a sediment bucket. The strainer has smaller openings than the grate, and it traps some debris that passes through the grate openings. Strainers are available in a variety of materials to meet corrosion requirements for the effluent.

Drain Sump. A *drain sump*, also called a *receiver*, is usually used with a roof drain where the drain is not cast into the slab. It is a preformed steel plate with a recessed center opening sized to accommodate the body of the drain. It is installed over an opening in the roof that is larger than the drain flange. It is used in roof systems where the weight of a drain must be spread over a large area and where it is necessary to compensate for an irregular roof surface. An underdeck clamp should be used to secure the drain to the drain sump.

Codes and Standards

Codes do not specify where a drain should be located. However, most codes regulate the minimum seal requirements for drain traps, the minimum open area of grates and strainers, and the mandatory inclusion of certain individual components (such as removable secondary strainers or sediment buckets) for some locations. A standard commonly cited in the selection of floor drains is ANSI Standard A112.21-1 (floor drains). The diameter of the roof-drain outlet pipe is also governed by code.

INTERCEPTORS

An *interceptor* is a device that separates, retains, and permits removal of specific harmful material suspended in the waste stream while permitting the remaining effluent to be discharged into the drainage system. Plumbing codes generally require that any liquid waste containing grease, flammable waste, sand, or other objectionable materials (or any substance that in the opinion of the local authority may be harmful to either the building drainage system, the public sewer, or the sewage treatment process) be prevented from being discharged into the public sewer system.[7]

The size and shape of interceptors depend on whether the waste is lighter or heavier than water, the amount of material to be retained, the rate and volume of total discharge into the interceptor, and the corrosion potential of the effluent (i.e., whether it is acid, caustic, or abrasive). In most cases, the interceptor either is installed on top of the slab or is supported from under the slab with the cover or grate extending up to the finished floor above. Some interceptors are very heavy, requiring special support when filled with water. If the grate or cover extends through the slab, additional strengthening of the slab may be required because of the size of the penetration.

The interceptor must be located so that it is easily accessible for cleaning and maintenance. For example, if a ladder is required to remove the intercepted material, such an installation is not permitted by many codes. Most interceptors require the removal of the trapped material by hand. They must be located in areas where access will not interfere with normal operations in the area where they are installed. It is advisable to locate interceptors as close as possible to the source of the substances being removed.

Grease Interceptors (Grease Traps)

Grease is commonly discharged into drainage systems from food-preparation areas, such as cafeterias and kitchens. Grease that is suspended in hot water will harden as it cools while flowing in a pipe; then it will accumulate and restrict or block flow.

A *grease interceptor* is a device for removing grease from waste water that flows through the interceptor. Internal baffles direct the effluent so that the grease floats to the top of the grease interceptor, where it is held for periodic removal. A typical grease interceptor is shown in Fig. 18.17. To be effective, the flow through such a grease interceptor must be slow enough to allow time for the

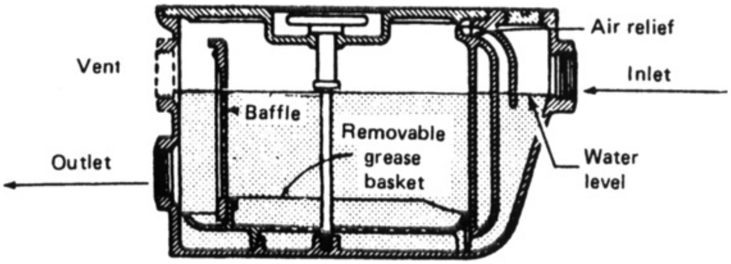

FIG. 18.17 A typical grease trap.

grease to float to the top. Therefore, grease interceptors are sized to limit the rate of flow. This requires the addition of a flow-control device at the inlet.[8]

There are several types of grease interceptors: *manual type*, where a cover must be taken off to remove the grease by hand; *semiautomatic type*, where the grease that accumulates may be discharged into a separate container through a special valved connection; and *automatic type*, where grease is removed continuously from the effluent. The automatic type is practical only where very large amounts of grease are discharged.

A grease interceptor can be placed either under the floor or above the floor depending on the space available. The semiautomatic removal of grease requires an above-the-floor installation, usually under a sink or in a storage room.

Oil Interceptor

An *oil interceptor*, illustrated in Fig. 18.18, is a device for removing oil and other flammable or volatile liquids from waste water. Oil interceptors operate on the principle of flotation. As the water mixed with oil flows through the interceptor, 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, either manually or continuously, by an overflow arrangement that sends the separated oil to a remote oil storage tank.

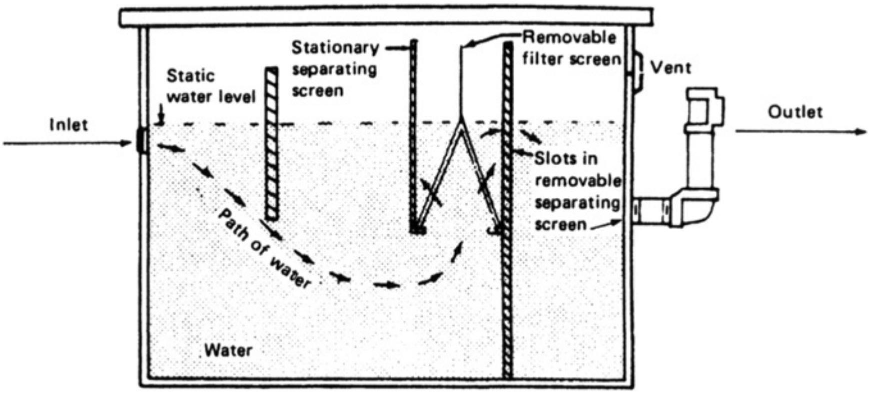

FIG. 18.18 A typical oil interceptor. *(Courtesy of Rockford Co.)*

Because there is the possibility that the vapor given off by the flammable liquid could ignite, it is important to provide a vent that terminates in the open air at an approved location above the highest part of the structure.

Sand Interceptor

A *sand interceptor* (commonly called a *sand trap*), such as that illustrated in Fig. 18.19, is used to remove solids or semisolids that are discharged into the drainage system. Such traps operate on the principle of settlement, permitting solids to accumulate at the bottom of the trap as the effluent flows through it. The outlet of the sand trap should be located so that the accumulated material is prevented from being discharged. The solids must be removed periodically from the trap by hand. Sufficient space must be available around the trap to permit such removal.

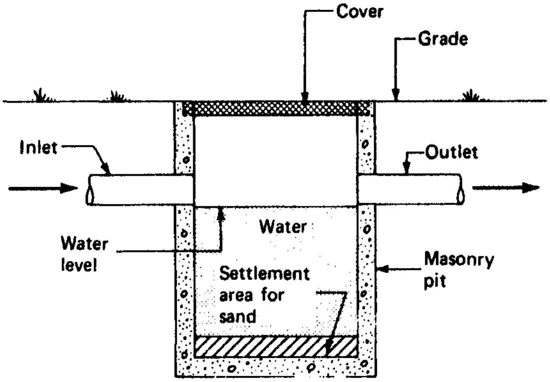

FIG. 18.19 A typical masonry sand interceptor.

Hair Interceptors

A *hair interceptor*, such as that illustrated in Fig. 18.20, is used to remove hair before it can enter the drainage system. It is usually a small in-line unit using a perforated basket strainer inserted inside a small housing. This housing is installed in lieu of a trap on a fixture. To remove the accumulated hair, the housing is opened and the strainer is removed and emptied. The housing may be fabricated of brass, cast iron, steel, plastic, or any material permitted by the local code. The strainer is usually made of stainless steel.

Acid Neutralizers

An *acid neutralizer*, such as that shown in Fig. 18.21, is installed whenever the possibility exists that acid may be discharged into the drainage system. (As a general rule, many authorities permit waste with a pH of 4 or above to enter the drainage system, where it will be further diluted with other effluent.) Acid will attack ordinary piping material, causing premature failure.

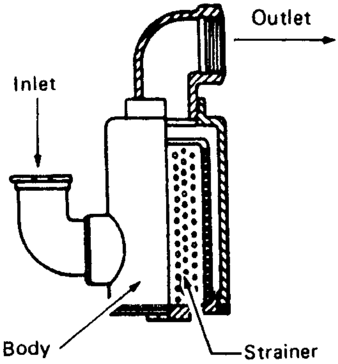

FIG. 18.20 A typical hair trap.

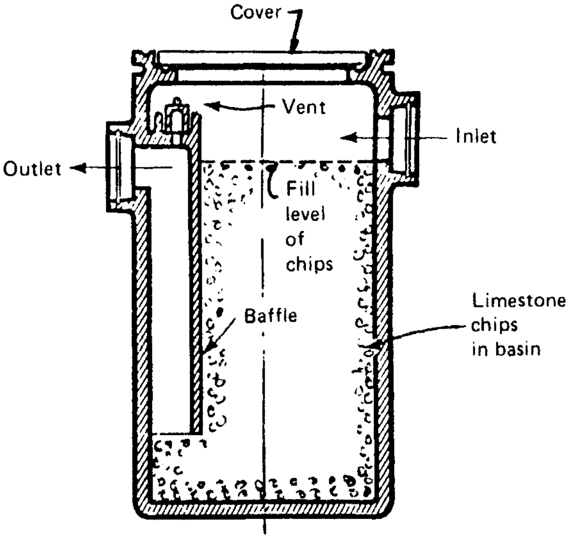

FIG. 18.21 A typical acid-neutralizing basin. *(Courtesy of Knightware, Inc.)*

An acid neutralizer consists of a tank containing limestone chips of between 1 and 3 in (2.5 to 7.6 cm) in size. A baffle arrangement within the tank is used to ensure that the effluent is in continuous contact with the limestone chips. Acid neutralization is accomplished by chemical reaction with the chips. There is no residue, since the chips are consumed. However, the chips must be replenished periodically, depending on the amount of acid that is treated. The size of acid neutralizers varies, ranging from small units that can be placed under an individual sink to tanks suitable for large facilities. Acid neutralizers must be located in areas where their covers can be readily removed to add new limestone chips. The larger tanks are heavy, so additional structural support may be necessary. Neutralizers can be installed either above the floor or below the slab, with the cover extending up to the finished floor above.

TRAPS

A *trap* is a device that maintains a water seal against the passage of sewer gas, vermin, air, and odors originating from inside the drainage system while permitting the unrestricted passage of liquid waste into the system. It consists of a U-shaped section of pipe of the necessary depth to retain sufficient liquid required by code. A *fixture trap*, illustrated in Fig. 18.22*a*, is required on every direct connection between a fixture and the sanitary drainage system. In general, traps must (*a*) be self-cleaning, (*b*) provide a liquid seal of at least 2 in (5 cm), with

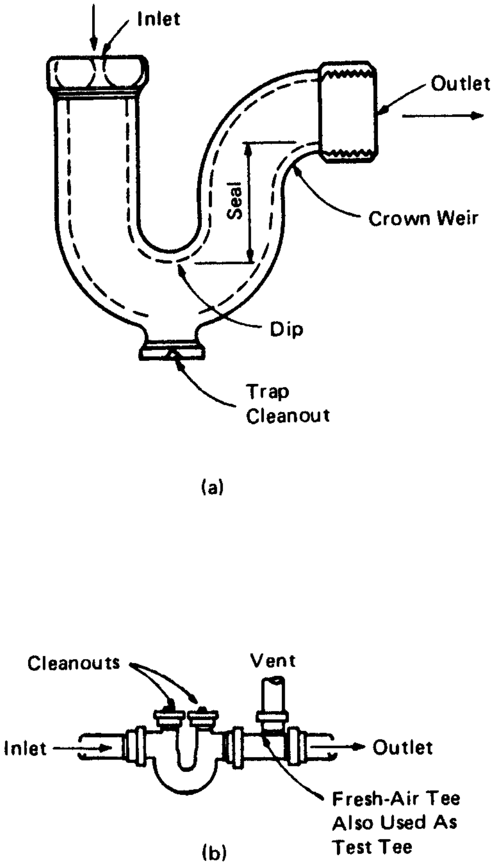

FIG. 18.22 Typical traps. (*a*) Fixture trap; (*b*) building trap.

larger seals where required, (*c*) conform to local code requirements in terms of minimum size, and (*d*) provide an accessible cleanout. All traps must be vented in some manner, except for specific conditions waived by local code requirements or authorities.

Some fixtures, such as water closets, have a trap integral with the fixture itself. Integral traps should have a uniform interior and provide a smooth waterway.

Traps that are prohibited by code include traps requiring moving parts to maintain the seal, full S-type traps, crown-vented traps, bell traps, and drum traps. Bell traps may be permitted by some codes for use in refrigerator safes and receptors set at floor level, where the bell is protected from damage, may easily be removed, and can serve as a convenient means of access to the pipe to which the trap connects. Drum traps may be permitted by some codes for use on special-use sinks, such as those found in laboratories.

See Chap. 5 for additional information regarding the installation of fixture traps and Table 5.3 for minimum trap sizes of various fixtures.

A *building trap* (*house trap*), illustrated in Fig. 18.22*b*, is located on the main building sewer before connection to the public.sewer. Its function is to prevent the entry of sewer gas from the public sewer into the building. Local codes may mandate the use of such traps, mandate their absence, or permit them as an option.

VALVES

Valves in drainage systems are used for the following purposes:

1. *To shut off a drainage line.* Valves used for this purpose are of the same types as those used in potable water supply systems. Such valves are described in Chap. 11. A gate valve is one such type. A valve of the rising-stem type is commonly used because the position of the stem provides a convenient visual indication as to whether the valve is open or closed. There are no code requirements regarding valves used for this purpose.

2. *To prevent the reversal of flow (i.e., backflow) of effluent in the drainage line.* Check valves are used to prevent backflow. One type of check valve, a swing check valve, is shown in Fig. 11.23. Another type, the backwater valve, is used in drainage lines where solids are normally expected, e.g., in sanitary drainage lines or in vertical lines leading down from floor drains. A backwater valve of the ball-float type is shown in Fig. 18.23. The housing contains a ball so positioned by gravity that it permits the full flow of effluent down the drain line. However, when the flow is reversed, the ball floats upward to a position in which it blocks through the line—thereby preventing backflow. This type of valve is subject to the following restrictions:

- It must be installed in the vertical position.
- It should be installed so that the working parts are easily accessible.
- It must be installed only on the drainage branch that is subject to backflow—not on the main drainage line.
- The capacity of the valve must be at least equal to the capacity of the pipe in which it is installed.

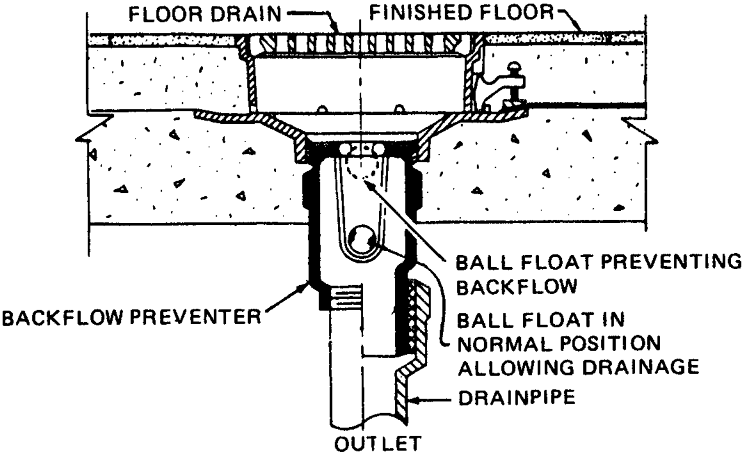

FIG. 18.23 A typical backwater valve of the ball-float type. *(Courtesy of Jay R. Smith Co.)*

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CHAPTER 19

STORM-WATER DRAINAGE SYSTEMS

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INTRODUCTION

This chapter describes the fundamentals of designing storm-water drainage systems for buildings, lawns, planted areas, and outdoor facilities adjacent to the building. *Storm water* is water that falls on a surface as a result of any type of precipitation. *Runoff* is the portion of storm water which is discharged from the surface. Not all storm water will run off. Some storm water fills depressions, evaporates, or soaks into the surface. This chapter discusses the basic concepts and parameters used in the design of storm-water drainage systems and shows (*a*) how to size roof-drain systems and (*b*) how to estimate storm-water runoff. The basic objectives of a storm-water drainage system are (*a*) to provide a conduit or channel through which runoff will be transmitted from a point of collection to a point of disposal, (*b*) to protect property and the public from the uncontrolled flow of runoff, and (*c*) to provide drains and inlets adequately sized to receive the volume of runoff which flows to the drains.

ROOF DRAINAGE SYSTEMS

A roof drainage system is composed of storm-water collection devices located in the roof (or at the roof line) and piping, connected to the collection devices, which transports the runoff out of the building or to the ground. (Drainage-system components are described in Chap. 18.) Storm-water collection devices utilized for draining roofs are roof drains, deck drains, gutters, scuppers, etc. A *roof drain* is a drain which is installed through the roof deck or slab; it generally has a dome-type strainer and receives storm water on all sides of the drain. A typical roof drain is illustrated in Fig. 18.16. A *deck drain* is a drain which is similar in all respects to a roof drain except that it generally has a flat strainer and is located in an area such as a patio, walk, etc. A *gutter* is a collection device which is attached along the entire lower side of a pitched roof and generally receives storm water on one side. A *scupper* is a boxlike collection device which is located on the exterior of a building and receives storm water on one side.

The piping in a roof drainage system can be attached to the outside wall of the building or installed within pipe chases located within the building. A *rainwater leader* is a pipe that is attached to the outside wall of a building. A *storm-water conductor* is a pipe that is located within a building.

Roof drainage systems transport water that may vary in temperature between the summer and winter months. An expansion device may be required in the piping system to control the expansion and/or contraction of the piping system (see Chap. 11). The location and spacing of the expansion device is dependent on the type of piping used in the roof drainage system and the length of the straight runs of pipe.

A *combined sewer* is a sewer which transports both storm-water drainage and sanitary drainage. *Sanitary drainage* is water and waste material originating at plumbing fixtures, floor drains, etc. If a building is constructed in an area where a combined sewer is used, the storm-water drainage piping and the sanitary drainage piping are generally connected together before being connected to the trunk sewer serving the site. In such an installation, a trap must be installed on the storm-water conductor or rainwater leader to prevent the passage of sewer gasses through the roof-drain piping and drain. The traps should be the same size as the horizontal piping to which they are connected. Consideration should be given to the installation of a separate storm drainage system within the building to which the individual drains, storm-water conductors, or rainwater leaders may be connected. Then one trap can be located on the main storm-water drainage pipe leaving the building before the storm-water drainage pipe and the sanitary drainage pipe are interconnected.

Roof drains should be equipped with strainers which extend at least 4 in (10 cm) above the roof surface adjacent to the drain. Deck drains should be used on sun decks, patios, parking decks, and similar areas. Roof-drain strainers should have a free inlet area not less than 1.5 times the area of the storm-water conductor or rainwater leader connected to the drain. The strainer of a deck drain should have a free inlet area not less than 2 times the area of the storm-water conductor or rainwater leader connected to the deck drain. Areas which are subject to walking traffic should be furnished with flat strainers that will not catch the heels of shoes, especially women's high heels. The recommendations just listed may change depending on the codes and regulations of the area in which the building is constructed. Commercially available drains meet most code and regulatory requirements. Roof drains should be flashed to the roof with lead, neoprene, flexible flashing material, or other material as dictated by the type of roofing material used.[1]

Spacing and location of the roof drains are dependent on a number of local conditions and building characteristics. Consideration should be given to such criteria as the local climatic conditions, type of roof, slope of the roof, location of pipe chases in which the storm-water conductors are installed, and available ceiling space in which to install piping.[2]

Two types of roof drainage systems are commonly used: the conventional flow system and the controlled-flow system.

Conventional Roof Drainage Systems

A *conventional roof drainage system* is composed of drains so designed and so sized as to handle the runoff as fast as it reaches the drain. The design of these systems is based on rainfall rates (expressed as inches per hour or centimeters per hour) stipulated by local codes and regulations. Such a system can be used on roofs that have (*a*) gutters and rainwater leaders or (*b*) roof drains and storm-water conductors. Local codes also may require that systems incorporating roof drains and storm-water conductors be provided with overflow drains. An *overflow drain* protects the roof against structural and roof damage resulting from blocked or partially blocked roof drains.

Controlled-Flow Roof Drainage Systems

A *controlled-flow roof drainage system* utilizes drains which allow the runoff to drain off the roof much more slowly than the rate at which the runoff reaches the drain. Excess runoff is allowed to accumulate on the roof and is drained off at a controlled rate after the storm has abated. A *flow-control device* is a device in a controlled-flow roof drainage system that controls the rate at which runoff is allowed to drain off the roof. A controlled-flow system should only be used on a roof drainage system (*a*) that incorporates storm-water conductors, (*b*) that utilizes a drain which has a flow-control device built into the drain, and (*c*) that has overflow drains. Control of the rate at which the runoff is removed from the roof should only be accomplished by flow-control devices designed and installed by the drain manufacturer.

The accumulation of excess runoff on the roof may cause structural loading and potential flashing problems unless adequate protection is incorporated into the design of (*a*) the roof drainage system, (*b*) the structural system, and (*c*) the flashing details. This protection can be accomplished by installing overflow drains or scuppers set at a height to perform the same function as the overflow drains. The maximum storage depth of excess runoff on the roof is 3 in (7.6 cm) for flat roofs and an average of 3 in (7.6 cm) for a sloped roof.[3] The overflow drains or scuppers and the storm-water conductors or rainwater leaders connected to these drains should be sized as if the drainage system were a conventional roof drainage system. The structural engineer for the project should be made aware of the fact that a controlled-flow roof drainage system is being considered which will cause water to accumulate in ponds on the roof. The architect also should be notified that water will accumulate in ponds on the roof during heavy rainfall so that the roof flashing can be installed to an elevation high enough to ensure its proper performance.

ROOF DRAINAGE DESIGN PROCEDURE

Conventional Roof Drainage Systems

The following procedure should be used in designing a roof drainage system:

Step 1. *Lay out the position of the roof drains, deck drains, scuppers, gutters, and rainwater leaders.* Consideration should be given to placing an overflow drain adjacent to each roof drain. Scuppers may be provided on flat roofs or on roofs with minimal slope for overflow protection. The amount of drainage provided by overflow drains or scuppers may be reduced on roofs that are flat or nearly flat. This is because under such circumstances, storm water can flow to another drain before enough water can accumulate to cause potentially damaging structural loads. These overflow drains may be required by some local jurisdictions. Therefore, the possibility of such requirements should be checked with the local plumbing officials. It is good practice to provide at least two drains in all individual roof areas.

Step 2. *Determine the tributary area to each roof drain, deck drain, scupper, gutter, or rainwater leader.* The *tributary area* to the roof drain, deck drain, scupper, gutter, or rainwater leader is the surface area of roof that drains toward a specific drain, gutter, or rainwater leader. This tributary area should include the effects of runoff from adjacent walls which drain onto the roof and into the drains, scuppers, gutter, or rainwater leader. Figure 19.1 indicates the wall area A that should be added to roof areas to determine the total tributary area for each drain.

Step 3. *Determine the routing and slope of the storm-water conductors.* First, determine the points from which, and to which, the conductors must be installed. Then determine the space available for installing the storm-water conductors. Finally, determine the routing and slope of the storm-water conductors.

Step 4. *Determine the rainfall rate to be used in the sizing of the roof drainage system.* The *rainfall rate* (also known as the *rainfall intensity*) is a term that relates the quantity of rainfall to a unit of time. Such rainfall rates are usually expressed in inches per hour or centimeters per hour. The rainfall rate can be determined from Table 19.1, which indicates rainfall rates which can be expected in various cities across the U.S.A. The rainfall rate used for designing roof drainage systems is related to the average frequency of occurrence and the time that it takes runoff to reach the collection device from the most remote portion of the tributary area. The *average frequency of occurrence* is an indication of the average number of years between storms that will produce rainfall rates equaling or exceeding a given amount. The average frequency of occurrence is sometimes called the *return period*. The amount of time that it takes the runoff to reach the collection device from the most remote portion of the tributary area is known as the *time of concentration*. The *duration* of a storm equals the time of concentration and is the period of time during which the heaviest rainfall occurs and, in theory, when the greatest amount of runoff occurs. The rainfall rate used for the design of roof drainage systems is based on a 10-year return period and 5-min duration. The 10-year, 5-min rainfall rate is recommended as a minimum for use in designing roof drainage systems. This recommendation is based on the time of concentration normally expected on roof drainage systems. Some national codes base the roof drainage system design on a storm of 1-h duration resulting in a lower rainfall rate. Conductors designed on this basis may not be able to handle the runoff as fast as the water reaches the drain. Consequently, positive and negative pressures can develop in various portions of the system that can cause adverse effects in the drainage system. These adverse effects often are exhibited in high-rise buildings, especially where drains from lower roof levels are connected to drainage piping serving roof drains on upper levels. The use of a lower rainfall rate in design may be considered if the code in the area in which the project is located stipulates such a reduced rainfall rate.

Step 5. *Determine the flow rate (volume per unit time) of equipment such as pumps, ejectors, air-conditioning equipment, and similar equipment which discharge into the roof drainage piping. Then convert these flow rates into equivalent roof area.* *Flow rate* is a term expressing a volume of water over a period of time such as cubic feet per second (cubic meters per hour), gallons per minute

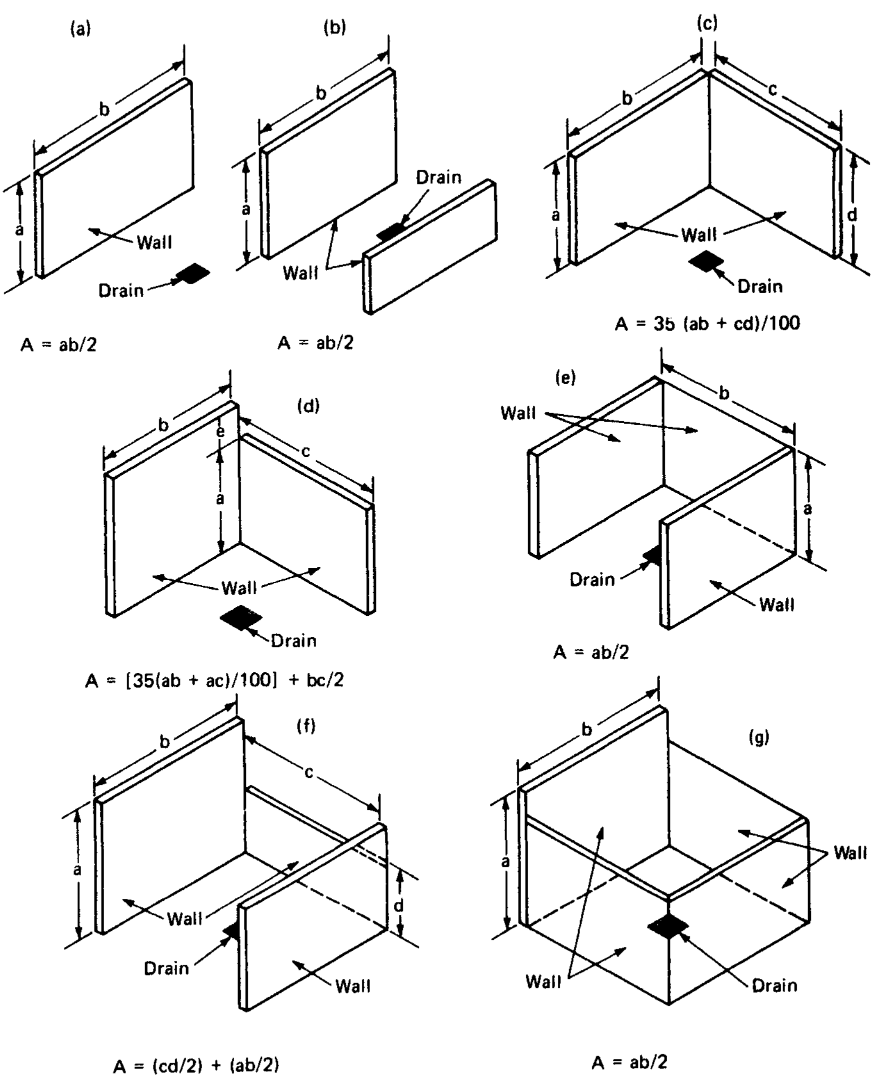

FIG. 19.1 Computation of wall area *A* for (*a*) a single wall surface, (*b*) two opposing walls of unequal height, (*c*) two adjoining walls of equal height, (*d*) two adjoining walls of unequal height, (*e*) three adjoining walls of equal height surrounding the drain, (*f*) three adjoining walls of unequal height surrounding the drain, and (*g*) four walls surrounding the drain. The four dimensions (*a, b, c, d,* and *e*) are the lengths of the wall surfaces which are tributary to the roof drains, scuppers, or gutters. *(Ref. 2.)*

(liters per second), etc. The following equations determine the roof area which will produce runoff at a flow rate equal to the flow rate of the equipment:

$$\text{Equivalent roof area} = \frac{96}{R} \times \text{flow rate of the equipment} \quad \text{ft}^2 \qquad (19.1)$$

$$\text{Equivalent roof area} = \frac{359}{R} \times \text{equipment flow rate} \quad \text{m}^2 \qquad (19.1a)$$

where *R* is the rainfall rate used in the design of the roof drainage system in

TABLE 19.1 Rainfall Rates for Various Cities in the U.S.A., in/h (cm/h)

Alabama:	
Birmingham	7.0 (18)
Mobile	8.4 (21)
Alaska:	
Fairbanks	3.7 (9.4)
Juneau	1.7 (4.3)
Arizona:	
Phoenix	4.3 (11)
Arkansas:	
Little Rock	6.7 (17)
California:	
Los Angeles	3.6 (9.1)
Sacramento	3.0 (7.6)
San Diego	3.3 (8.4)
San Francisco	3.0 (7.6)
Colorado:	
Denver	5.7 (14)
Grand Junction	3.0 (7.6)
Pueblo	5.0 (13)
Connecticut:	
Hartford	6.2 (16)
New Haven	6.6 (17)
District of Columbia:	
Washington	7.2 (18)
Florida:	
Jacksonville	7.4 (19)
Miami	7.5 (19)
Pensacola	9.4 (24)
Tampa	8.4 (21)
Georgia:	
Atlanta	7.7 (20)
Savannah	6.8 (17)
Hawaii:	
Honolulu	5.2 (13)
Idaho:	
Boise	2.7 (6.9)
Pocatello	3.7 (9.4)
Illinois:	
Cairo	6.6 (17)
Chicago	7.0 (18)
Springfield	6.6 (17)
Indiana:	
Ft. Wayne	6.3 (16)
Indianapolis	6.3 (16)
Iowa:	
Davenport	6.4 (16)
Des Moines	6.4 (16)
Dubuque	7.4 (19)
Sioux City	7.0 (18)
Kansas:	
Topeka	6.8 (17)
Wichita	6.9 (18)
Kentucky:	
Lexington	6.0 (15)
Louisville	7.0 (18)
Louisiana:	
New Orleans	8.2 (21)
Shreveport	7.5 (19)
Maine:	
Eastport	4.7 (12)
Portland	4.7 (12)
Maryland:	
Baltimore	7.8 (20)
Massachusetts:	
Boston	5.5 (14)
Nantucket	4.8 (12)
Michigan:	
Detroit	6.4 (16)
Grand Rapids	6.0 (15)
Sault Ste. Marie	5.2 (13)
Minnesota:	
Duluth	6.2 (16)
Minneapolis	6.6 (17)
St. Paul	6.3 (16)
Mississippi:	
Meridian	7.4 (19)
Vicksburg	7.5 (19)
Missouri:	
Kansas City	6.9 (18)
St. Louis	6.5 (17)
Springfield	7.0 (18)
Montana:	
Havre	4.3 (11)
Helena	3.8 (9.7)
Miles City	7.0 (18)
Nebraska:	
Lincoln	6.6 (17)
North Platte	6.0 (15)
Omaha	7.0 (18)

inches per hour (centimeters per hour). The flow rate of the equipment is expressed in gallons per minute (liters per second).

Step 6. *Calculate the total roof area drained by each segment of the roof drainage system.* This calculation should include all roof areas calculated in Step 2 and the equivalent roof area calculated in Step 5. Express the total area in square feet (square meters).

TABLE 19.1 Rainfall Rates for Various Cities in the U.S.A., in/h (cm/h)*(Continued)*

Nevada:		**Rhode Island:**	
Reno	3.2 (8.1)	Providence	4.8 (12)
Winnemucca	2.7 (69)	**South Carolina:**	
New Hampshire:		Charleston	7.0 (18)
Concord	6.2 (16)	Columbia	6.6 (17)
New Jersey:		Greenville	6.6 (17)
Atlantic City	6.2 (16)	**South Dakota:**	
Trenton	6.4 (16)	Huron	6.2 (16)
New Mexico:		Rapid City	5.5 (14)
Albuquerque	3.7 (9.4)	**Tennessee:**	
Santa Fe	4.4 (11)	Knoxville	6.2 (16)
New York:		Memphis	6.8 (17)
Albany	6.0 (15)	Nashville	7.2 (18)
Buffalo	5.5 (14)	**Texas:**	
Ithica	6.0 (15)	Dallas	7.2 (18)
New York	6.6 (17)	El Paso	4.2 (11)
Rochester	5.4 (14)	Houston	8.0 (20)
Syracuse	6.3 (16)	San Antonio	7.5 (19)
North Carolina:		**Utah:**	
Charlotte	7.0 (18)	Modena	3.8 (9.7)
Greensboro	6.6 (17)	Salt Lake City	3.4 (8.6)
Wilmington	7.0 (18)	**Vermont:**	
North Dakota:		Burlington	5.4 (14)
Bismarck	6.7 (17)	Northfield	6.3 (16)
Williston	6.5 (17)	**Virginia:**	
Ohio:		Lynchburg	6.0 (15)
Cincinnati	6.5 (17)	Norfolk	6.8 (17)
Cleveland	6.9 (18)	Richmond	7.2 (18)
Columbus	6.1 (15)	**Washington:**	
Oklahoma:		Seattle	2.2 (5.6)
Oklahoma City	6.7 (17)	Spokane	3.1 (7.9)
Oregon:		Tacoma	2.8 (7.1)
Baker	3.3 (8.4)	**West Virginia:**	
Portland	3.0 (7.6)	Elkins	6.2 (16)
Pennsylvania:		Parkersburg	6.7 (17)
Erie	6.5 (17)	**Wisconsin:**	
Philadelphia	6.5 (17)	LaCrosse	6.5 (17)
Pittsburgh	6.4 (16)	Madison	6.0 (13)
Puerto Rico:		Milwaukee	6.2 (16)
San Juan	5.7 (14)	**Wyoming:**	
		Cheyenne	5.6 (14)
		Sheridan	5.2 (13)

Source: Ref. 1.

Step 7. *Determine the size of the roof drains and storm-water conductors or the gutters and rainwater leaders.* Sizes can be determined using Tables 19.2*a* through 19.2*d* and 19.3.[2] These tables list the maximum roof area in square feet (square meters) which can be handled by storm-water drainage piping of different sizes and slopes for various rainfall rates. Table 19.2*a* is for vertical conductors. Tables 19.2*b* through *d* are for horizontal storm-water drainage piping of different sizes having slopes of ⅛, ¼, and ½ in/ft (1.0, 2.1, and 4.2 cm/m). The slopes of horizontal storm-water piping *inside* a building are expressed in terms of inches per feet (centimeters per meter).

TABLE 19.2a Maximum Tributary Areas Which Can Be Drained by Roof Drains, Vertical Rainwater Leaders, or Storm-Water Conductors for Various Rainfall Rates

Rainfall rate, in/h	Size of drain or leader, in					
	2	3	4	5	6	8
	Maximum tributary area, ft^2					
1	2,880	8,800	18,400	34,600	54,000	116,000
2	1,440	4,400	9,200	17,300	27,000	58,000
3	960	2,930	6,130	11,530	17,995	38,660
4	720	2,200	4,600	8,650	13,500	29,000
5	575	1,760	3,680	6,920	10,800	23,200
6	480	1,470	3,070	5,765	9,000	19,315

Rainfall rate, cm/h	Size of drain or leader, cm					
	5	8	10	13	15	20
	Maximum tributary area, m^2					
2.5	267.6	817.5	1,709.4	3,214.3	5,016.6	10,776.4
5.1	133.8	408.8	854.7	1,607.2	2,508.3	5,388.2
7.6	89.2	272.2	569.5	1,071.1	1,671.7	3,591.5
10.2	66.9	204.4	427.3	803.6	1,254.2	2,694.1
13	53.4	163.5	341.8	642.9	1,003.3	2,155.3
15	44.6	136.6	285.2	535.6	836.1	1,794.4

Source: Adapted from Ref. 2.

TABLE 19.2b Maximum Tributary Area Which Can Be Drained by Storm-Water Conductors or Rainwater Leaders Installed at a Slope of ⅛ in/ft (1 cm/m) for Various Rainfall Rates

Size of pipe, in	Rainfall rate, in/h				
	2	3	4	5	6
	Maximum tributary area, ft^2				
3	1,644	1,096	822	657	548
4	3,760	2,506	1,880	1,504	1,253
5	6,680	4,453	3,340	2,672	2,227
6	10,700	7,133	5,350	4,280	3,566
8	23,000	15,330	11,500	9,200	7,600
10	41,400	27,600	20,700	16,580	13,800
12	66,600	44,400	33,300	26,650	22,200
15	109,000	72,800	59,500	47,600	39,650

Size of pipe, cm	Rainfall rate, cm/h				
	5.1	7.6	10	13	15
	Maximum tributary area, m^2				
8	152.7	101.8	76.4	61	50.9
10	349.3	232.8	174.7	139.7	116.4
13	620.6	413.7	310.3	248.2	206.9
15	994	662.7	497	397.6	331.3
20	2,136.7	1,424.2	1,068.4	854.7	706
25	3,846.1	2,564	1,923	1,540.3	1,282
30	6,187.1	4,124.8	3,093.6	2,475.8	2,062.4
38	10,126.1	6,763.1	5,527.6	4,422	3,683.5

Source: Adapted from Ref. 2.

TABLE 19.2c Maximum Tributary Area Which Can Be Drained by Storm-Water Conductors or Rainwater Leaders Installed at a Slope of ¼ in/ft (2.1 cm/m) for Various Rainfall Rates

Size of pipe, in	Rainfall rate, in/h				
	2	3	4	5	6
	Maximum tributary area, ft^2				
3	2,320	1,546	1,160	928	773
4	5,300	3,533	2,650	2,120	1,766
5	9,440	6,293	4,720	3,776	3,146
6	15,100	10,066	7,550	6,040	5,033
8	32,600	21,733	16,300	13,040	10,866
10	58,400	38,950	29,200	23,350	19,450
12	94,000	62,600	47,000	37,600	31,350
15	168,000	112,000	84,000	67,250	56,000

Size of pipe, cm	Rainfall rate, cm/h				
	5.1	7.6	10	13	15
	Maximum tributary area, m^2				
8	215.5	143.6	107.8	86.2	71.8
10	492.4	328.2	246.2	197	164.1
13	877	584.1	438.5	350.8	292.3
15	1,402.8	935.1	701.4	561.1	467.6
20	3,028.5	2,019	1,514.3	1,211.4	1,009.5
25	5,425.4	3,618.5	2,712.7	3,169.2	1,806.9
30	8,732.6	5,815.5	4,366.3	3,493	2,912.4
38	15,607.2	10,404.8	7,803.6	6,247.5	5,202.4

Source: Adapted from Ref. 2.

The sizes of storm-water conductors and rainwater leaders cannot be decreased in the direction of flow. Therefore, if a 6-in (12.5-cm) horizontal storm-water conductor or rainwater leader is required, any vertical storm-water conductor or rainwater leader that is downstream of the horizontal portion of pipe also must be 6 in (12.5 cm) in diameter.

Controlled-Flow Roof Drainage Systems

The roof drainage design procedure for controlled-flow roof drainage systems is similar to that for conventional roof drainage systems, described earlier, except that the drains are designed to allow the runoff to drain off at a fixed rate. The piping system then is sized using the fixed flow rates and Table 19.3. This table indicates the capacity of the vertical and variously sloped horizontal storm-water conductors and rainwater leaders of different sizes. The *capacity* of a storm-water drainage pipe expresses the maximum flow rate that can travel through the pipe without causing pressure to build up in the pipe. As with the conventional roof drainage system, the sizes of the storm-water conductors and rainwater leaders must not be decreased in the direction of flow.

TABLE 19.2*d* Maximum Tributary Area Which Can Be Drained by Storm-Water Conductors or Rainwater Leaders Installed at a Slope of ½ in/ft (4.2 cm/m) for Various Rainfall Rates

Size of pipe, in	Rainfall rate, in/h				
	2	3	4	5	6
	Maximum tributary area, ft^2				
3	3,288	2,295	1,644	1,310	1,096
4	7,520	5,010	3,760	3,010	2,500
5	13,360	8,900	6,680	5,320	4,450
6	21,400	13,700	10,700	8,580	7,140
8	46,000	30,650	23,000	18,400	15,320
10	82,800	55,200	41,400	33,150	27,600
12	133,200	88,800	66,600	53,200	44,400
15	238,000	158,800	119,000	95,300	79,250

Size of pipe, cm	Rainfall rate, cm/h				
	5.1	7.6	10	13	15
	Maximum tributary area, m^2				
8	305.5	213.2	152.7	121.7	101.8
10	698.6	465.4	349.3	279.6	232.3
13	1,241.1	826.8	620.6	494.2	413.4
15	1,988.1	1,272.3	994	797.1	663.3
20	4,274.4	2,847.4	2,136.7	1,709.4	1,423.2
25	7,692.1	5,128.1	3,846.1	3,079.6	2,564
30	12,374.3	8,249.5	6,187.1	4,942.3	4,124.8
38	22,110.2	14,752.5	11,055.1	8,853.4	7,362.3

Source: Adapted from Ref. 2.

Gutter Systems

Gutter systems are designed in a manner similar to roof-drain systems. The vertical rainwater leaders are sized according to Table 19.2*a* or Table 19.3. Horizontal gutters are sized according to Table 19.4. Table 19.4 lists the capacity of semicircular gutters at various slopes and rainfall rates. The gutters can have shapes other than semicircular provided that the flow area is maintained equal to the flow area of a gutter with a semicircular shape given in Table 19.4.

STORM-WATER RUNOFF

Storm-water runoff is that part of the precipitation that is not lost by (*a*) infiltration into the soil, (*b*) ponding in surface depressions, or (*c*) evaporation from plant surfaces. The rate of storm-water runoff is difficult to evaluate. Precipitation rate, surface composition and slope, duration of the precipitation, and degree of saturation of the ground are a few of the highly variable elements which affect the quantity of storm-water runoff. The determination of the rate of storm-water

TABLE 19.3 Capacity of Vertical and Various Sloped Horizontal Storm-Water Conductors and Rainwater Leaders

Pipe diameter, in (cm)	Roof drains and vertical piping (L/s)	Horizontal piping slope, in/ft (cm/m)		
		⅛ (1.0)	¼ (2.1)	½ (4.2)
	Capacity, gpm (L/s)			
3 (7.6)	92 (5.8)	34 (2.1)	48 (3.0)	69 (4.3)
4 (10)	192 (12)	78 (4.9)	110 (6.9)	157 (9.9)
5 (13)	360 (23)	139 (8.8)	197 (12)	278 (18)
6 (15)	563 (35)	223 (14)	315 (20)	446 (28)
8 (20)	1208 (76)	479 (30)	679 (43)	958 (60)
10 (25)	—	863 (54)	1217 (77)	1725 (109)
12 (30)	—	1388 (87)	1958 (123)	2775 (175)
15 (38)	—	2479 (156)	3500 (220)	4958 (312)

Source: Adapted from Ref. 8.

runoff is therefore a process of estimation; precise determination is nearly impossible.

Infiltration is the movement of water through the surface of the soil and into the soil below the surface. Infiltration rates depend on the following factors: (*a*) *porosity of the soil* (the infiltration rates for loose, noncohesive, sandy-type soils with a high degree of porosity are higher than the rates for tight, cohesive, clay-type soils); (*b*) *quantity of water in the pores* (if the pores are saturated with water, the soil cannot absorb additional water); and (*c*) *filling of pores with surface soil* (hard-driving rain tends to move surface soil into the pores of subsurface soil and decreases the ability of the soil to absorb additional water; ground cover in the form of vegetation protects the surface soil against the effects of such movement). For these reasons, infiltration rates usually are determined from experimental data. For example, the infiltration rate in bare soils (under average summer conditions), after being subjected to 1 h of rainfall, is approximately 0.1 in/h (0.25 cm/h) for clay soils; it is as much as 1 in/h (2.5 cm/h) for sandy soil. Infiltration rates after 12 h of rainfall may be as little as ⅕ the rate at the start of the rainfall.[4] Grass ground cover increases the infiltration rate 3 to 7 percent.

Depression storage is the quantity of storm water that is lost as a result of minor surface depressions, the magnitude of which is largely a function of the land use. Water that is trapped in these depressions can only escape through infiltration or evaporation.[5] As the rainfall duration increases, the amount of water loss due to depression storage decreases. Similarly, as the surface slope increases, depression storage decreases. Increasing the slope of the ground surface from 1 to 2 percent results in a decrease in the quantity of depression storage by approximately 40 percent.

Calculation of the rate of storm-water runoff is important in determining the size of inlets, drains, sewers, etc. All portions of the storm drainage system must be designed to handle the peak flow anticipated under certain design conditions.

Estimating Storm-Water Runoff

The most widely used method for estimating peak storm-water runoff is called the *rational-formula method*. Although the assumptions made in this method may not

TABLE 19.4 Maximum Tributary Area (ft²) Which Can Be Drained by Various Sloped Gutters at Various Rainfall Rates

Diameter of gutter, in	Rainfall rate, in/h				
(slope = 0.0005)	2	3	4	5	6
3	340	226	170	136	113
4	720	480	360	288	240
5	1,250	834	625	500	416
6	1,920	1,280	960	768	640
7	2,760	1,840	1,380	1,100	918
8	3,980	2,655	1,990	1,590	1,325
10	7,200	4,800	3,600	2,880	2,400

Diameter of gutter, in	Rainfall rate, in/h				
(slope = 0.01)	2	3	4	5	6
3	480	320	240	192	160
4	1,020	681	510	408	340
5	1,760	1,172	880	704	587
6	2,720	1,815	1,360	1,085	905
7	3,900	2,600	1,950	1,560	1,300
8	5,600	3,740	2,800	2,240	1,870
10	10,200	6,800	5,100	4,080	3,400

Diameter of gutter, in	Rainfall rate, in/h				
(slope = 0.02)	2	3	4	5	6
3	680	454	340	272	226
4	1,440	960	720	576	480
5	2,500	1,668	1,250	1,000	834
6	3,840	2,560	1,920	1,536	1,280
7	5,520	3,680	2,760	2,205	1,840
8	7,960	5,310	3,980	3,180	2,655
10	14,400	9,600	7,200	5,750	4,800

Diameter of gutter, in	Rainfall rate, in/h				
(slope = 0.04)	2	3	4	5	6
3	960	640	480	384	320
4	2,040	1,360	1,020	816	680
5	3,540	2,360	1,770	1,415	1,180
6	5,540	3,695	2,770	2,220	1,850
7	7,800	5,200	3,900	3,120	2,600
8	11,200	7,460	5,600	4,480	3,730
10	20,000	13,330	10,000	8,000	6,660

Source: Adapted from Ref. 2.

be realistic, the results of the calculations are usually reasonably good. The rational-formula method assumes that if rain falls on a totally impervious surface at a constant rate long enough, the rate of runoff eventually equals the rate of rainfall on the surface. This formula assumes (*a*) that the rate of storm-water runoff from an area is a direct function of the average rainfall rate during the time that it takes the runoff to travel from the most remote point of the tributary area to the inlet or drain, (*b*) that the average frequency of occurrence of the peak runoff equals the average frequency of occurrence of the rainfall rate, and (*c*) that the quantity of storm water lost due to evaporation, infiltration, and surface depressions remains constant throughout the rainfall.[6] The *coefficient of runoff* is a coefficient which accounts for storm-water losses attributed to evaporation, infiltration, and surface depressions. The peak value of the flow rate Q of storm-water runoff is estimated using the following equations:

$$Q = CIA \qquad \text{ft}^3\text{/s} \tag{19.2}$$

$$Q = \frac{CIA}{100} \qquad \text{m}^3\text{/h} \tag{19.2a}$$

where C = coefficient of runoff
I = rainfall rate for a specified rainfall duration and average frequency of occurrence, in/h (cm/h)
A = tributary area to the inlet or drain, acres (m^2)

The coefficient of runoff C is the variable in Eq. (19.2) that is least susceptible to precise determination.[6] Since the amount of evaporation, infiltration, and surface-depression storage increases or decreases depending on a number of factors, the coefficient of runoff is determined empirically. Typical values for the coefficient of runoff are shown in Table 19.5.

A given site may have areas with different coefficients of runoff all draining to

TABLE 19.5 Typical Coefficients of Runoff *C* Used in the Design of Storm-Water Drainage Systems

Character of surface	Coefficient of runoff
Pavement:	
Asphaltic and concrete	0.70–0.95
Brick	0.70–0.85
Roofs	0.75–0.95
Lawns, sandy soil:	
Flat, 2 percent	0.05–0.10
Average, 2 to 7 percent	0.10–0.15
Steep, 7 percent	0.15–0.20
Lawns, heavy soil:	
Flat, 2 percent	0.13–0.17
Average, 2 to 7 percent	0.18–0.22
Steep, 7 percent	0.25–0.35

Note: The coefficients in these two tabulations are applicable for storms of 5- to 10-year frequencies. Less frequent, higher-intensity storms will require the use of higher coefficients because infiltration and other losses have a proportionally smaller effect on runoff. The coefficients are based on the assumption that the design storm does not occur when the ground surface is frozen.

Source: Adapted from Ref. 6.

a common point. It is desirable to use a single coefficient of runoff for the entire area. Such a dimensionless coefficient (termed a *weighted coefficient of runoff*) C_w can be calculated using

$$C_w = \frac{(A_1 \times C_1) + (A_2 \times C_2) + \cdots + (A_n \times C_n)}{A_1 + A_2 + \cdots + A_n} \tag{19.3}$$

where A_1, A_2, and A_n are the area in acres (m^2), and C_1, C_2, and C_n are the corresponding coefficients of runoff of the individual tributary areas to a common point. A weighted coefficient of runoff must be calculated for each segment of the storm-water drainage system.

In the design of a storm-water drainage system, runoff must be transported as fast as it is received, unless specific provisions are made for ponding of the excess runoff which the storm-water drainage system cannot handle. Determination of the rainfall rate to be used for design purposes involves an evaluation of the potential damage which could occur as a result of flooding. If the potential damage from flooding is high, the selection of an average frequency of occurrence of 50 or 100 years may be warranted. If the potential damage from flooding is rather slight, the selection of an average frequency of occurrence of 5, 10, or 25 years may be appropriate. In many cases, the local authority having jurisdiction will determine the average frequency of occurrence to be used in the design of storm-water drainage systems.

Exceedance Probability

The *exceedance probability* (i.e., the probability of a storm which equals or exceeds the rainfall rate used in the design of the storm-water drainage system occurring during any 1 year) can be expressed[7] by

$$P = \frac{1 \text{ year}}{T} \tag{19.4}$$

where P is the exceedance probability, and T is the average frequency of occurrence of the rainfall rate used in the design of the storm-water drainage system, in number of years. Thus, for a rainfall rate having a 25-year average frequency of occurrence, the exceedance probability is

$$P = \frac{1}{25} = 0.04$$

The probability of this rainfall rate being equaled or exceeded in this example is 4 percent. The exceedance probability expresses the probability over a specified period of time, usually 1 year. In the example, if rainfall occurs which equals or exceeds the rate given for a 25-year average frequency of occurrence, there is still a 4 percent chance of the rainfall rate being equaled or exceeded within a year following the occurrence of the storm which exceeded the design rainfall rate. It is entirely possible for a specific rainfall rate to be equaled or exceeded on succeeding days. With the average frequency of occurrence being greater (i.e., 100 years), the probability of this occurring is considerably reduced.

The rainfall rate is also related to the time that storm water takes to travel from the most remote portion of the tributary area to the inlet or drain. This time, known as the *time of concentration*, must take into account the time that it takes for runoff (*a*) to flow across the ground to the inlets (or drains) and (*b*) to be transported by the storm-water drainage piping. The time of concentration therefore is generally equal to the longest combination of the time to travel across the ground and the time to be transported in the storm-water drainage piping system. The time for the runoff to travel across the ground to the inlet can be estimated by using Fig. 19.2. An example is shown on this illustration for a tributary area that has its most remote point 400 ft (122 m) from the inlet. If the average slope of the tributary area is 1.0 percent (i.e., 1.0 ft in 100 ft), and if the coefficient of runoff of the tributary area is 0.70, Fig.

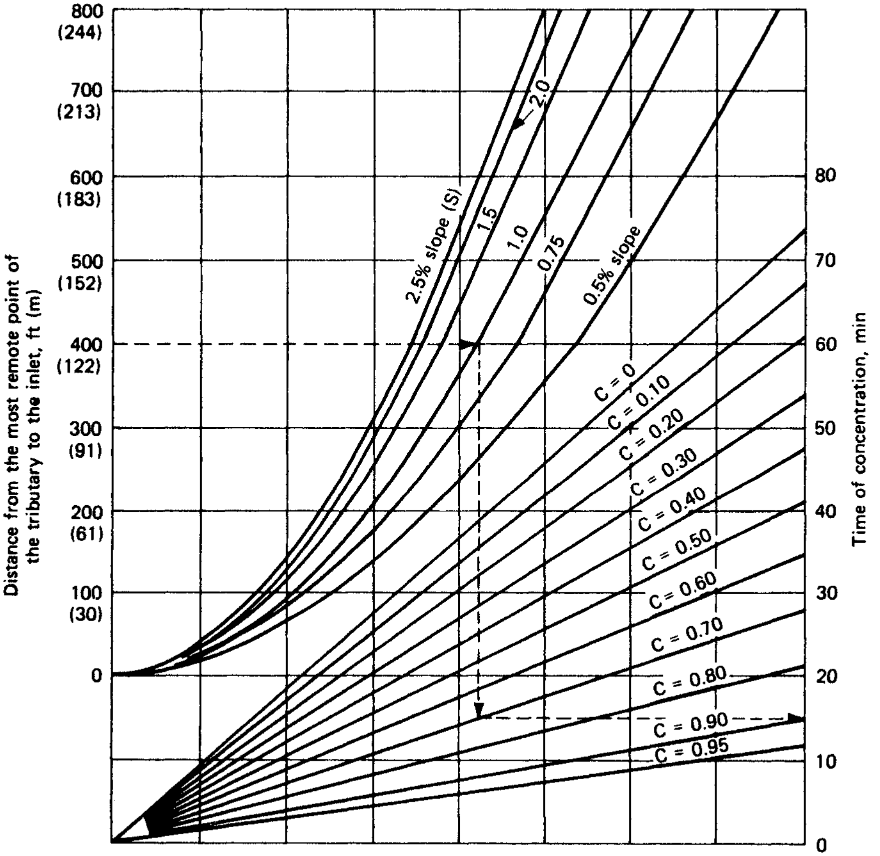

FIG. 19.2 Graph for determining the time of concentration for runoff traveling across the surface of the ground. (1) Determine the distance from the most remote point of the tributary area to the inlet. (2) Enter this distance at the appropriate point on the left vertical scale. (3) From this point draw a horizontal dashed line until it intersects the slope which has an average slope *S* equal to the slope of the tributary area. (4) From this point of intersection, draw a dashed line vertically downward until it intersects a curve having the appropriate coefficient of runoff *C*. (5) At this point of intersection, draw a dashed horizontal line to the right vertical scale, where the time of concentration will be indicated. *(Ref. 5.)*

19.2 indicates that the time for the runoff to travel across the ground to the inlet would be approximately 15 min. The time for the runoff to be transported through the storm-water drainage system can be determined by dividing the flow rate within each segment of the storm-water drainage system by the area which the storm-water runoff occupies within the open channel or the storm-water drainage piping.

The most extensive source of information for rainfall in the U.S.A. is the Weather Bureau of the U.S. Department of Commerce.[8,9] Reference 8 provides information on rainfall in the form of several maps of the U.S.A. with curves representing total quantity of rainfall (in inches) which can be expected during a specified period of time. These maps are developed for average frequencies of occurrence of 1, 2, 5, 10, 25, 50, and 100 years and times of concentration ranging from ½ to 24 h. Use of these curves involves selection of the average frequency of occurrence to be used in the design of the storm-water drainage system and determination of the time of concentration for the segment of the storm-water drainage system being designed. The proper map to be used in the design of the system is the map on which the average frequency of occurrence and the time of concentration for which the curves were developed match the average frequency of occurrence and time of concentration for the segment of the storm-water drainage system being designed. These curves represent *total* rainfall, which must be converted to a rainfall rate in inches per hour. This conversion is made by taking the total quantity of rainfall, represented by the curves on the map, and dividing this rainfall quantity by the number of hours which this amount of rainfall can be expected to occur. An example of such information is given in Fig. 19.3.

Reference 9 expresses rainfall data in the form of curves of rainfall rate versus time of concentration for storms of various average frequency of occur-

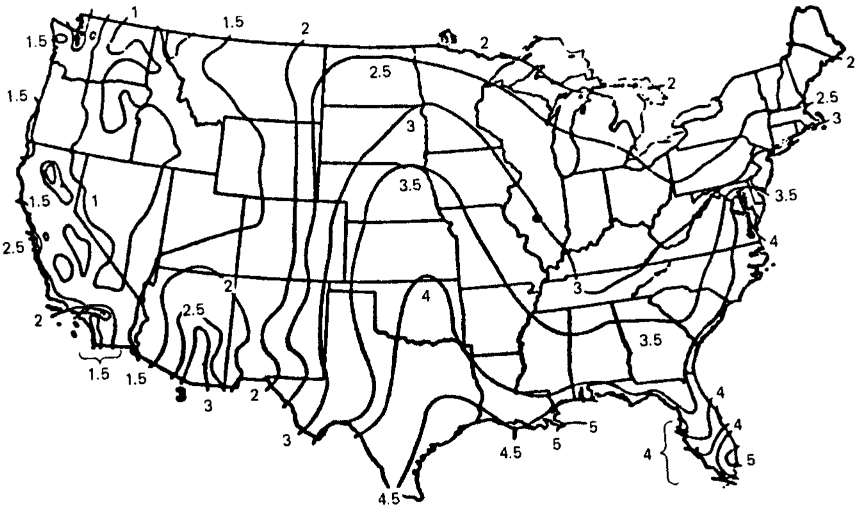

FIG. 19.3 Total amount of rainfall in inches that can be expected to occur over a 1-h period with an average frequency of occurrence of 100 years. *(Ref. 8.)*

rence. These curves have been developed for a number of cities in the U.S.A. Figure 19.4 represents an example of such a curve for Springfield, Illinois. If the time of concentration for a tributary area is 25 min and the average frequency of occurrence for the storm is 25 years, Fig. 19.4 indicates that the rainfall rate to be used for the runoff calculation is 4.1 in/h (10 cm/h).

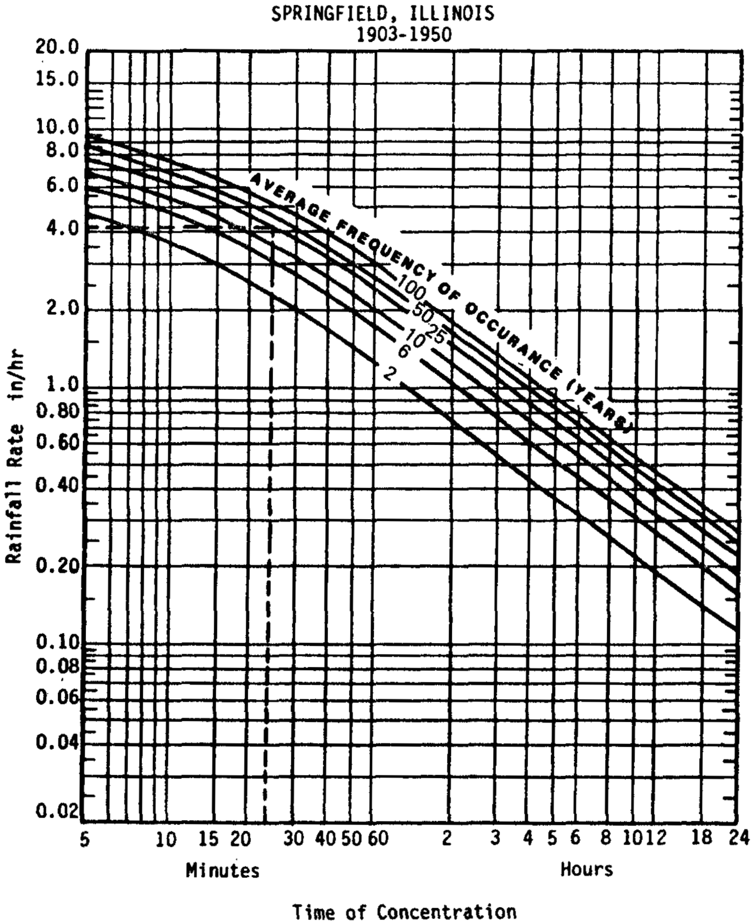

FIG. 19.4 Rainfall rate versus time of concentration for various average frequencies of occurrence. *(Ref. 8.)*

Area, the only variable in Eq. (19.2) that can be calculated, is determined through an analysis of the grading plan. The grading plan should be subdivided into tributary areas for inlets, drains, etc. The tributary area for each of the inlets, drains, etc., can then be calculated.

SURFACE RUNOFF CALCULATION PROCEDURE

The peak rate of runoff from the ground surface may be calculated as follows:

Step 1. Subdivide the site into tributary areas.

Step 2. Subdivide each tributary area into subareas of grass, pavement, and roof, and then calculate the area of each subarea: A_1, A_2, A_3.

Step 3. Calculate the total area of each tributary area: $A = A_1 + A_2 + A_3$.

Step 4. Determine the coefficient of runoff C for the subareas (grass, pavement, and roof) within each tributary area. These values are given in Table 19.5.

Step 5. Calculate the weighted coefficient of runoff C_w for each tributary area using Eq. (19.3).

Step 6. Calculate the time for the runoff to travel from the most remote portion of the tributary area to the inlet, drain, etc., using Fig. (19.2). (Since this calculation procedure only involves calculating the surface runoff from each tributary area, the time for the water to be transported through the storm-water drainage system is not considered here. It will be taken into account when the storm-water drainage piping is designed.) The time of concentration for each tributary area is the amount of time for the water to travel from the most remote point of the tributary area to the inlet or drain; it is obtained from Fig. 19.2.

Step 7. Using the value of the time of concentration obtained in Step 5, determine the rainfall rate I from Fig. 19.4.

Step 8. Calculate the peak rate of storm-water runoff Q by substituting the values of C_w, I, and A in Eq. (19.2).

EXAMPLE 19.1 Calculate the storm-water runoff into one inlet from a tributary area having a grass area A_1 of 0.5 acre (2000 m^2), a pavement area A_2 of 0.5 acre (2000 m^2), and a roof area A_3 of 0.2 acre (800 m^2) in Springfield, Illinois. The water must travel across 100 ft (30 m) of grass and 100 ft (30 m) of pavement between the most remote point of the tributary area and the inlet. The slope of the grass is 2 percent. The slope of the pavement is 1 percent. The runoff shall be based on a storm having an average frequency of occurrence of 25 years. Note that the roof area drains onto the grass area at the most remote point of the tributary area.

SOLUTION

Step 1. The tributary area has already been determined in this example.

Step 2. The tributary area is subdivided into three areas: $A_1 = 0.5$ acre (2020 m^2), $A_2 = 0.5$ acre (2020 m^2), and $A_3 = 0.2$ acre (810 m^2).

Step 3. The total tributary area $A = A_1 + A_2 + A_3 = 1.2$ acres (4850 m^2).

Step 4. From Table 19.5, the coefficient of runoff C for each area is approximately: *grass*, 0.15; *pavement*, 0.90; and *roof*, 1.00.

Step 5. From Eq. (19.3), the weighted coefficient of runoff is given by

$$C_w = \frac{(0.50 \times 0.15) + (0.50 \times 0.90) + (0.2 \times 1.00)}{1.2} = 0.60$$

Step 6. From Fig. 19.2, the time of concentration is

Distance, inlet to the most remote point, ft (m)			Travel time, min			
Grass	Pavement	Roof	Grass	Pavement	Roof	Total
100 (30)	100 (30)	—	15	3	5	23

Step 7. Using Fig. 19.4, the rainfall rate I is approximately 4.2 in/h (10.67 cm/h).

Step 8. From Eq. (19.2), the peak rate of storm-water runoff from the surface of this tributary area is

$$Q = 0.60 \times 4.2 \times 1.20 = 3.0 \text{ ft}^3/\text{s } (310 \text{ m}^3/\text{h})$$

SITE STORM-WATER DRAINS

The storm-water runoff from the ground surface (such as from a lawn and parking lot adjacent to a building) is collected by inlets which are located over storm sewers. They are of the following basic types: (*a*) curb-opening inlet, (*b*) open-throat inlet, and (*c*) grated inlet. Curbs may or may not be provided at the perimeter of pavement areas. While curbs are effective at keeping vehicular traffic on the pavement, they also help in directing storm-water runoff toward inlets. A *gutter* is that portion of pavement adjacent to the curb which carries storm-water runoff toward the inlets. *Curb-opening inlets* are located adjacent to gutters, usually with the curbs terminating at the corners of the inlet adjacent to the inlet opening. These inlets can be designed for use with or without a depression in the pavement directly in front of and adjacent to the inlet opening. The flow capacity of this type of inlet is governed by (*a*) the longitudinal slope of the surface, (*b*) the cross slope of the surface, and (*c*) the geometry of the depression around the inlet.

The *open-throat inlet* is similar to the curb-opening inlet, except that storm water may enter the inlet on more than one side.

A *grated inlet* is an inlet covered by a grate. Such grates are manufactured in many different patterns and materials. They may or may not be located in a depression in the pavement. Often, the back of the inlet is aligned with the face of the curb, which positions the grate in the gutter. The flow capacity of a grated inlet is governed by the same parameters as those affecting curb-opening inlets, but, in addition, it is affected by the design of the grate. Some grate manufacturers provide data that are useful in estimating the capacity of the inlet. A disadvantage of the grated inlet is that although the grate filters out large solid particles, preventing these particles from entering the storm-water drainage piping, it may become fouled. Then its capacity is considerably reduced.

The *grated inlet with a back opening* is a combination of the curb-opening inlet and the grated inlet. This type of grated inlet has the advantage of having an open throat in case the grate becomes fouled.

Inlet Location

An inlet should be located

1. So that the capacity of the inlet will not be exceeded during a design rain

2. Upstream from main pedestrian crossing locations
3. In grass areas to prevent the flow of water over the grass area onto paved areas, especially in the colder regions, where freezing of the water is possible
4. Adjacent to buildings so as to ensure positive drainage away from buildings
5. So that the gutter flow does not exceed its calculated capacity

Gutter Capacity

The capacity of a gutter is governed by the following two parameters: (*a*) the *maximum depth of water against the curb* (this should be approximately two-thirds the height of the curb) and (*b*) the *maximum width of storm water traveling in the gutter* (this should not be greater than 5 ft (1.5 m) in width or, in the case of driveways, half the width of the driving lane adjacent to the gutter).

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PART 3

NOISE CONTROL

CHAPTER 20

CONTROL OF PLUMBING NOISE IN BUILDINGS

John J. Van Houten

INTRODUCTION

Water flow through plumbing restrictions, discontinuities, valves, and pumps generates noise which penetrates the structure of a building. Often it is a cause of embarrassment and annoyance, especially when heard from waste piping or when generated by a neighbor's lengthy shower late at night. When experienced by the occupants, its annoyance potential may exceed that of other sources of noise which intrude at much higher levels. This chapter describes how noise is generated in a plumbing system and methods of controlling plumbing noise within buildings. The emphasis is on multifamily residential structures such as hotels, motels, apartments, and condominiums. However, the sources of noise, paths, and the control methods apply to any noise-sensitive building (commercial, theatrical, educational, medical, etc.).

MECHANISMS OF NOISE GENERATION IN PLUMBING SYSTEMS

Noise is generated in plumbing systems by the following mechanisms: *turbulence, cavitation, water splash, waste/water flow,* and *water hammer.* These noise-generation mechanisms are related to the sources of noise within buildings in Table 20.1.

Turbulence

The flow of liquids in pipes generally is classified as *laminar flow* or *turbulent flow.* In laminar flow, as illustrated in Fig. 20.1*a,* the liquid moves in such a way that individual fluid particles move along paths parallel to one another and to the general direction of motion. In turbulent flow, there is an irregular, random motion of the particles in directions transverse to the direction of the main flow, as illustrated in Fig. 20.1c. The major factors which influence whether the flow is

TABLE 20.1 Sources of Noise in the Plumbing System of a Building, Their Generation Mechanisms, and Their Potential for Annoyance

Plumbing system component/equipment	Generation mechanism	Potential annoyance
Piping runs:		
Couplings	Turbulence	Minimal
Elbows	Turbulence	Minimal
Tees	Turbulence	Minimal
Fixtures:		
Bar sink	Cavitation/turbulence/splash/waste flow	Minimal
Bathtub	Cavitation/turbulence/splash/waste flow	Very significant
Bidet	Cavitation/turbulence/waste flow	Nominal
Flushometer	Cavitation/turbulence	Significant
Hose pipe valves	Cavitation/turbulence	Nominal
Laundry tubs	Cavitation/turbulence/splash/waste flow	Nominal
Pressure regulator	Cavitation/turbulence	Nominal
Shower	Cavitation/turbulence/splash/waste flow	Very significant
Sink	Cavitation/turbulence/waste flow	Significant
Valves	Cavitation/turbulence	Significant
Water closet, tank stool	Cavitation/turbulence/splash/waste flow	Very significant
Urinal	Cavitation/turbulence/splash/waste flow	Nominal
Appliances:		
Dishwasher	Vibration/cavitation/spray/water hammer	Very significant
Drinking fountain	Cavitation/turbulence	Minimal
Washing machine	Vibration/cavitation/impact/motor/ water hammer	Very significant
Waste disposal	Vibration/waste flow	Very significant
Water heater	Cavitation/turbulence	Minimal
Supply and waste pumps:		
Booster	Rotational flow/cavitation/motor	Significant
Recirculation	Rotational flow/cavitation/motor	Nominal
Sewage	Rotational flow/cavitation/motor	Significant
Sump	Rotational flow/cavitation/motor	Significant

laminar or turbulent are (1) pipe diameter d, (2) density of the fluid ρ, (3) absolute viscosity μ, and (4) flow velocity v. These variables are related by a dimensionless quantity known as the Reynolds number, which is defined as

$$R = \frac{dv\rho}{\mu} \tag{20.1}$$

For Reynolds numbers less than about 2000, the flow is laminar. For Reynolds numbers greater than about 4000, the flow is usually turbulent. Between these two values lies a transition region in which the flow may be either laminar or turbulent, as illustrated in Fig. 20.1*b*.

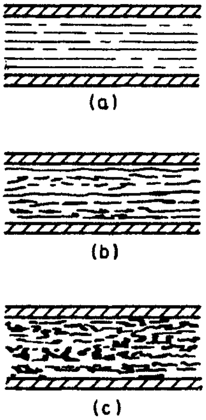


FIG. 20.1 Laminar and turbulent flow: (*a*) laminar flow in which the flow is undisturbed; (*b*) transition region in which the flow is becoming turbulent; and (*c*) turbulent flow.

Generally, noise generated by laminar flow is so low in intensity as to be of no concern, even under the most critical design conditions. In most practical plumbing systems, however, velocities are high enough to result in turbulent flow. For example, in domestic plumbing systems, typical velocities are on the order of 8 ft/s (2.5 m/s). For a standard copper pipe having an inside diameter of 0.63 in (1.6 cm) carrying water at 60°F (16°C) with a density of 62.4 lb/ft^3 (1000 kg/m^3) and an absolute viscosity of 7.66×10^{-4} lb/ft · s (1.14×10^{-3} kg/m · s), according to Eq. (20.1) the flow has a Reynolds number of

$$R = \frac{0.016 \times 2.5 \times 1000}{0.00114} = 35{,}000$$

Therefore, the flow is turbulent and is a basic mechanism of noise generation within the piping runs and fixtures of the plumbing system.

Cavitation

Most of the noise in plumbing systems is usually caused by turbulent flow, but conditions sometimes exist, particularly in nearly closed valves, which give rise to the phenomenon of cavitation, which results in greatly increased noise levels. *Cavitation* is the formation and subsequent collapse of cavities (bubbles) within the flow of water through and past a restriction in the flow. For cavitation to occur, a local restriction in the water flow must exist which results in localized high velocities and low pressures. At a particular velocity, the pressure is low enough that vapor bubbles are formed. As these bubbles move past the restriction, the velocity decreases and the pressure increases, resulting in the sudden collapse of the bubbles, with extreme local pressure fluctuations.

The cavitation phenomenon is illustrated in Fig. 20.2, which shows the pressure variation and velocity variation in a partially opened globe valve in a plumb-

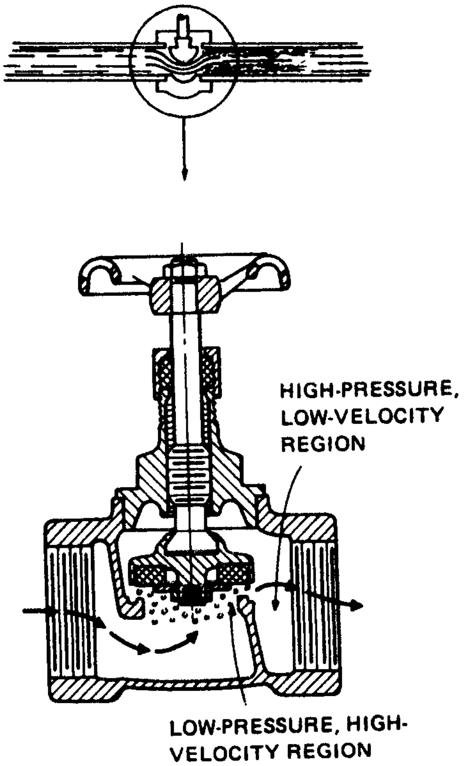


FIG. 20.2 Formation of cavitation in a plumbing system containing a partially opened globe valve. Regions of high-velocity flow and low pressure lead to the generation of cavitation.

ing system. Such a variation in the pressure leads to the formation of cavitation within the flowing water. Cavitation develops downstream of the partially opened valve when the pressure at the minimum area (highest velocity) is reduced to the vapor pressure, about 0.26 psi (18 kPa) for water at 60°F (16°C). If the vapor bubbles are near or in contact with the pipe when they collapse, the forces exerted by the liquid rushing into the cavities create very high localized pressures on the pipe wall. Cavitation is accompanied by vibration and by noise. The forces exerted by the collapsing cavities may result in the pitting of the surfaces on which the cavitation occurs.[1,2] Cavitation usually occurs at discontinuities within most plumbing systems, for example, at bathtub spouts, shower heads, and supply valves.

Water Splash

Water splash on sinks, bathtubs, and shower pans produces significant noise by the impact of the liquid as it strikes the surface. The impact of the water on the surface produces noise in relation to the kinetic energy of the fluid as it strikes the surface. The predominant parameters in this noise generation mechanism include:

1. The velocity of the water as it leaves the spout
2. The height of the spout above the surface
3. The droplet size which strikes the surface
4. The dynamic characteristics of the sink, tub, or shower pan surface (surface density, thickness, shape and size, and elastic properties).

Waste/Water Flow

The flow of waste products and water flow beyond the drain trap has an intermittent character. This is generally the case when the pipe has a long vertical run or an abrupt transition which is located in the wall of neighboring or lower occupied space. Even though the sound level of the waste/water noise may be very low [i.e., 30 to 35 dB(A)], its character may cause embarrassment and concern when experienced over the quiet background noise of a residential unit.

Water Hammer

A sharp, intense noise known as *water hammer* occurs when steady flow in a liquid distribution system is suddenly interrupted, for example, by closing a quick-action valve. When the fluid is in motion throughout the whole piping system, the momentum, even at relatively low flow velocities, can be great. The sudden interruption of flow results in an extremely sharp pressure rise which propagates as a (shock) wave upstream from the valve. The steep wavefront of the excitation can be reflected numerous times back and forth through various parts of the fluid system until the energy finally is dissipated.

To some degree, water hammer occurs in a piping run whenever the flowing water is suddenly interrupted. Such an interruption occurs at the rapid closure of electrical, pneumatic, or spring-loaded (solenoid) valves. In residential structures, it is sometimes experienced during wash and rinse cycles of a washing machine or dishwasher.

Plumbing Components/Equipment and Their Noise-Generation Mechanisms

Table 20.1 provides a summary of various components and pieces of equipment in plumbing systems that are a source of noise. For each, the basic mechanisms of noise generation are identified, and their potential for annoyance is indicated.

Piping Runs. In piping runs, if the piping is in a straight line, the noise resulting from fluid flow is relatively insignificant. However, where there are elbows or tees, and the velocity is significant, a noise problem may arise. The average flow velocity in a turn in a piping system is the same as that in a straight pipe of the same cross-sectional flow area. But because fluid recirculates in a turn, it may accelerate to a very high velocity, causing separation and loud cavitation noise at the lower-pressure (higher-velocity) region on the inside of the turn.

Fixtures. Fixtures such as sinks, bathtubs, showers, and toilets are predominant sources of noise which may create annoyance within buildings. The mechanism of noise generation which may penetrate the building structure involves (1) cavitation at the valves and spouts, (2) water splash on the large bathtub bottom and shower pan, and (3) the intermittent wastewater and particulate flow through, and beyond, the drain trap.

Appliances. Appliances within a residential structure include dishwashers, washing machines, and waste disposal units. These appliances produce vibration which may be transmitted to a neighboring dwelling when the appliance is in contact with a common wall and/or placed directly on a floor separation assembly. Hence, they provide a significant source of potential annoyance within a multifamily building. In addition, appliances are a potential source of water-hammer-generated noise within the building.

Pumps. The primary noise source of pumps involves the hydrodynamic pulsations which are inherent in all pumps. These pulsations are associated with the rotational speed of the pump and the number of its impeller blades. The fundamental frequency of such pump noise is equal to the product of the rotational speed (in revolutions per second) and the number of blades. In addition, high-frequency pump noise results from cavitation caused by the vaporization of the water and the rapid collapse of the vapor bubbles which are shed by the impeller blades. Other sources of pump noise which may impart vibration to the pump's support structure and surrounding area include imbalanced motor bearings, the motor cooling fan, the gearbox, and an imbalanced impeller.

CONTROL OF NOISE IN PLUMBING SYSTEMS

The control of unwanted plumbing noise should be considered an integral part of the building design. In addition, the building construction specification should include minimum acceptable requirements for noise control. The noise control elements of the design and specifications involve:

1. Water flow and piping characteristics
2. Radiation to the structure
3. Selection and mounting of fixtures
4. Pump system isolation
5. Water-hammer noise control

Control of Noise from Water Flow in Piping

Water Pressure. The water pressure in a plumbing system influences the flow noise generated by the piping runs and water supply valves. According to typical building code requirements, the water system supply pressure must be at least 15 psi (100 kPa), but no greater than 80 psi (500 kPa).[3] However, for acceptable system performance, the supply pressure usually must be between 35 and 55 psi (230 and 370 kPa). To minimize the generation of noise, regulation of the supply pressure to the lower value, about 35 psi (230 kPa), is desirable. However, other factors (e.g., building size, number of floors, and number of units) significantly influence plumbing system design and the required supply pressure.

Piping. Flow noise radiation from the piping runs can be minimized by reducing the number of pipe transitions (elbows, tees, y-connections, etc.), thus reducing the opportunity for turbulence and the occurrence of cavitation. Pipe of ½-in diameter is most common in domestic plumbing systems in the U.S.A. However, to minimize noise, ¾-in-diameter pipe is selected when noise control is given a high priority in the building design. The reduction in sound level obtained by the decreased velocity may be as much as 3 to 5 dB.

Control of Noise Radiation from Piping

Pipe Isolation. Noise resulting from the flow of water in pipes may be transmitted from the piping runs to the rooms of the building if the pipes are in direct contact with large radiating surfaces (i.e., walls, ceilings, and floors). Isolation of these piping runs from the structure provides significant noise reduction. For example, a reduction of 10 to 12 dB may be obtained if piping is mounted with foam isolation instead of being rigidly connected to the building structure. Table 20.2 illustrates the various mounting methods and shows the resulting relative reduction in noise radiated from a double-studded party wall. These data show the advantage of isolating the plumbing runs from the structure.[4–8]

All plumbing components should be isolated from the building structure. Resilient material, such as neoprene or fiberglass about ¼ in (0.6 cm) thick, should be employed wherever the piping run passes through the structure (block, stud, joist, or plate) or is in contact in any way with the wallboard or masonry. In addition, it is important to seal around the perimeter of all pipes, faucets, and spouts which penetrate through the walls, floors, and shower stalls. A resilient caulking should be applied as generously as possible. Figures 20.3 through 20.5 indicate methods of ensuring good isolation. These techniques are well worth the increased cost of the plumbing installation.

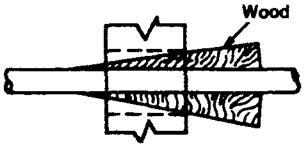
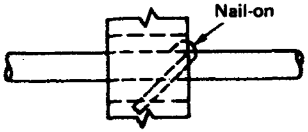
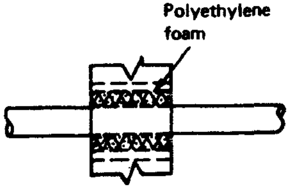
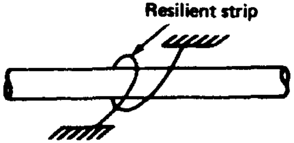
Manufactured Isolators. Manufactured pipe isolators also improve the overall quality of the plumbing installation. However, installation of the isolators as specified by the manufacturer, follow-up inspection to ensure quality control, and procurement of isolators which have a resilient material between the pipe and structure are imperative.

Waste/Water Flow. When polybutylene pipe is used in long vertical waste runs within a wall separation, unacceptable noise may be experienced within adjacent occupied spaces. This noise may be minimized or even eliminated by the use of cast-iron pipe runs which are isolated from the building structure. The methods of isolation are similar to those previously discussed (see Figs. 20.3 through 20.5).

Pipe Lagging or Jacketing. Pipe lagging or jacketing, as shown in Fig. 20.6, iscommon in large commercial and industrial plumbing systems, mainly as a thermal insulation. When used for noise control, reductions in sound level of approx-

TABLE 20.2 Piping-Run Mounting Methods and Noise Reduction Relative to a Rigid Attachment to the Structure

The flow noise is generated by a standard termination fixture.[5]

Method of pipe mounting	Illustration	Noise reduction compared with rigid mounting, dB
Wood wedges: Two wood wedges forced between the pipe and stud		0
J-hook nail-ons: ¾-in J-hook nail-on at each pipe penetration of stud		0
Pipe insulator foam insert: Plastic insulator with polyethylene foam insert (experimental)		−11
Elasic mount: Isolated from studs by a resilient strip		−19

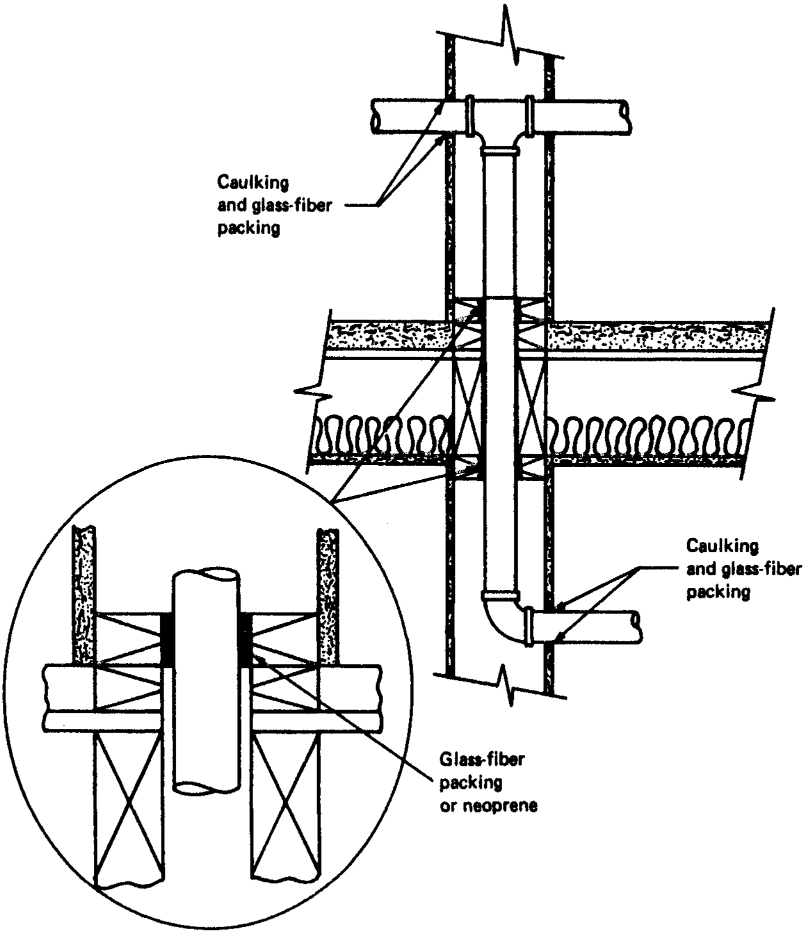


FIG. 20.3 Isolation of water supply or waste piping within a party wall and floor-ceiling assembly.

imately 6 to 10 dB may be obtained when the lagging is properly applied. In general, the lagging should consist of a foam or fiberglass insulation material covered with a $\frac{1}{16}$ to $\frac{1}{8}$-in (0.15- to 0.3-cm)-thick aluminum metal jacket, secured by adhesive or tape. A water-resistant mastic may be used in place of the metal jacket; however, the thickness of the mastic should provide a surface weight equal to the metal jacket application.

Plumbing Wall Chase. Enclosing pipes within a pipe chase is beneficial in controlling the propagation of noise radiated by piping. Plumbing chases should be laid out with adequate space to ensure that piping runs can be supported so that they are not in direct contact with the walls of the pipe chase. For example, while a 2½-in (6.5-cm) waste pipe may be isolated within a 2- × 4-in (5- × 10-cm) stud wall, a 3- to 4-in (7.5- to 10-cm) waste pipe requires a thicker wall construction.

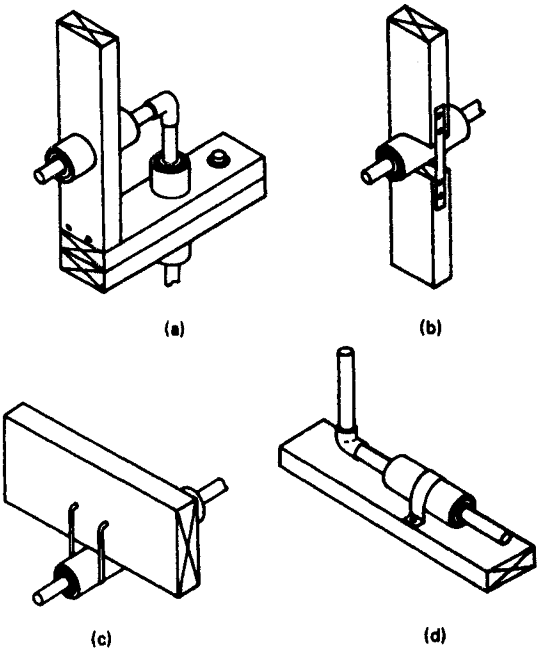


FIG. 20.4 Pipe isolation at (*a*) plates, (*b*) studs, and (*c*) joists. (*d*) Blocking by use of fiberglass jacketing or neoprene pads in wood-stud construction.

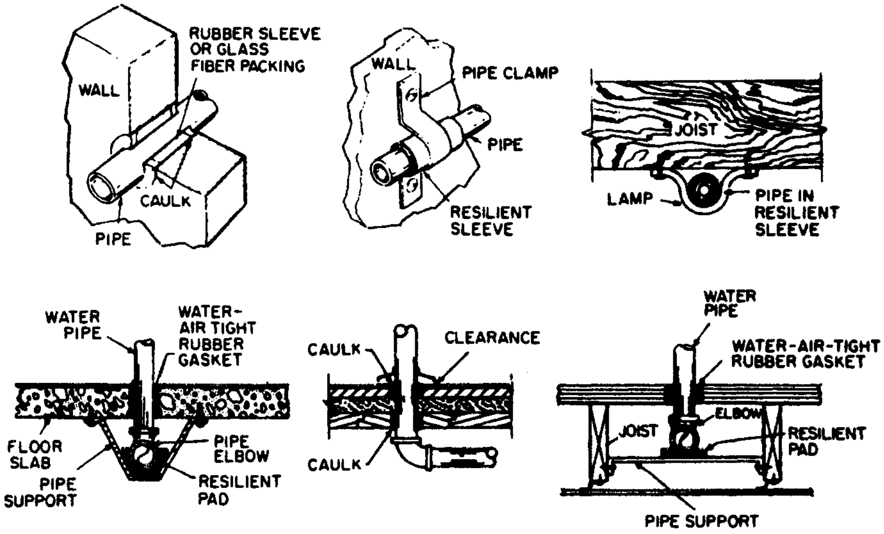


FIG. 20.5 Various techniques for isolating a pipe from the structure which supports it.

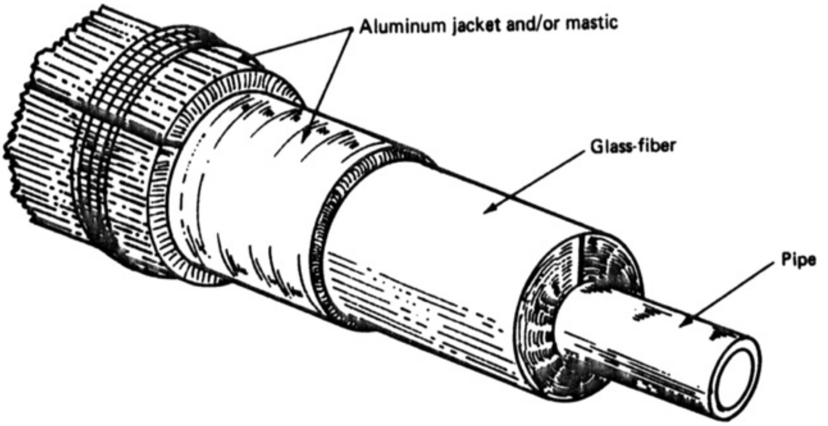


FIG. 20.6 Lagging or jacketing of pipe run to minimize the transmission of flow noise. Mastic, if used in place of metal jacket, should have a thickness such that the surface weight is equal to that of a metal aluminum jacket, $\frac{1}{16}$ to $\frac{1}{8}$ in (0.15 to 0.3 cm). Fiberglass insulation should be 1 to 2 in (2.5 to 5.0 cm) thick, depending on the pipe diameter, and should have insulation density of 3 to 5 lb/ft^3 (50 to 80 kg/m^3).

Low-Noise Fixtures. The following guidelines should be considered when selecting valves (see Chap. 11 of Ref. 3) and taps for the water supply:

- *Gate valves* offer practically no resistance to flow when fully opened; they are not recommended for throttling or flow modulation.
- *Globe valves* are ideal for throttling service; however, where close throttling may occur, as is the case for most valves, excessive noise will be generated.
- *Ball valves* are excellent for no-flow or full-flow applications, since they provide a straight-through flow with a minimum of turbulence.
- *Water taps* that incorporate an aerator in the spout may provide noise reductions of up to 15 dB.[9]

Figure 20.7 indicates the various types of water closet toilet stools. Of these, the siphon vortex and siphon jet are considered the quietest.[10]

Isolation of Fixtures and Appliances. The radiation of water splash noise generated by the impact of water on the bottom of a tub or shower pan may be minimized by isolation of the assembly from the wall and floor structure. Hence, bathtubs and shower pans should be set on resilient pads. Drywall should be installed and fitted as needed to form a well-sealed party wall assembly prior to the installation of the bathtubs and/or shower stalls. Water closets and stools should be isolated from the structure (for example, as in Figs. 20.8 and 20.9). Flexible hoses should be used to connect the appliances (dishwasher, washing machine, etc.) to the water-supply and waste-pipe runs.

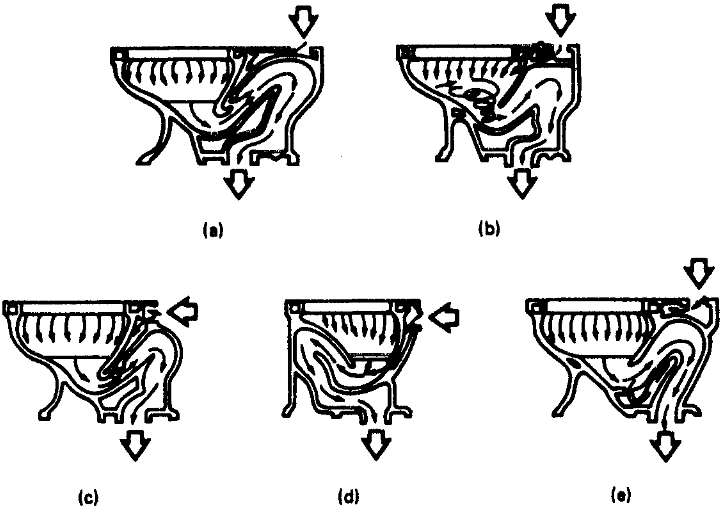


FIG. 20.7 Water closet noise characteristics: (*a*) siphon action, very quiet; (*b*) siphon vortex, quiet; (*c*) reverse trap, moderately noisy; (*d*) wash-down, noisy; (*e*) blowout, very noisy. (After Ref. 10.)

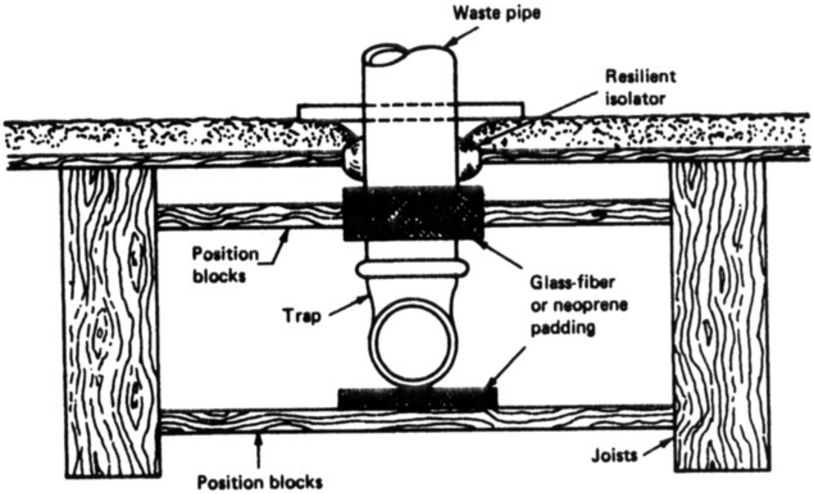


FIG. 20.8 Isolation of the stool or toilet fixture waste pipe to minimize noise transmission.

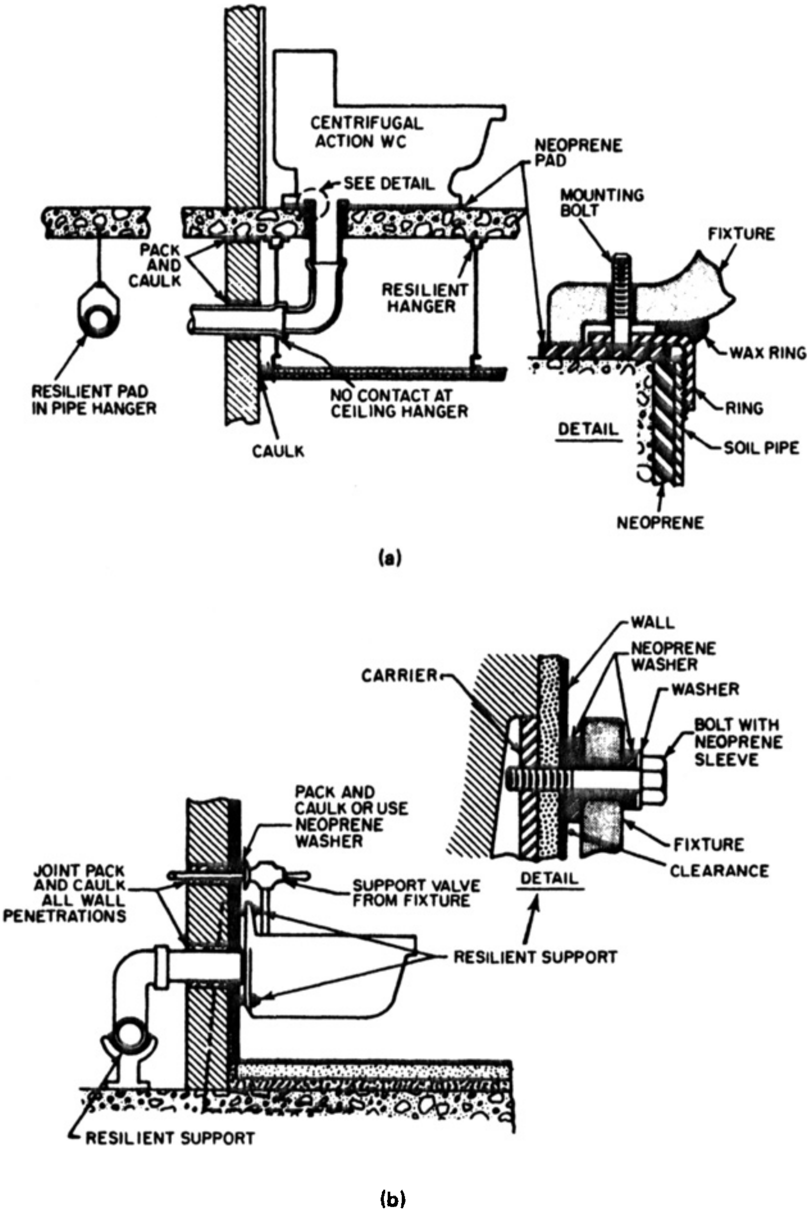


FIG. 20.9 (*a*) Isolation of a toilet for quiet operation. (*b*) Isolation of a sink from the structure which supports it. A detail is shown of a method attachment that does not short the mechanical isolation provided.[6]

Control of Pump System Noise

The vibration isolation of a pump, its support system, and associated piping and electrical services may be achieved by the use of commercially available vibration isolators described in Chap. 29 of Ref. 8. These noise control measures often include the following:

1. Vibration isolators to support the pump and motor, thereby isolating it from the building structure
2. Flexible connectors between the pump and motor and associated piping and electrical connections, as described in Chap. 40 and as shown in Fig. 45.10

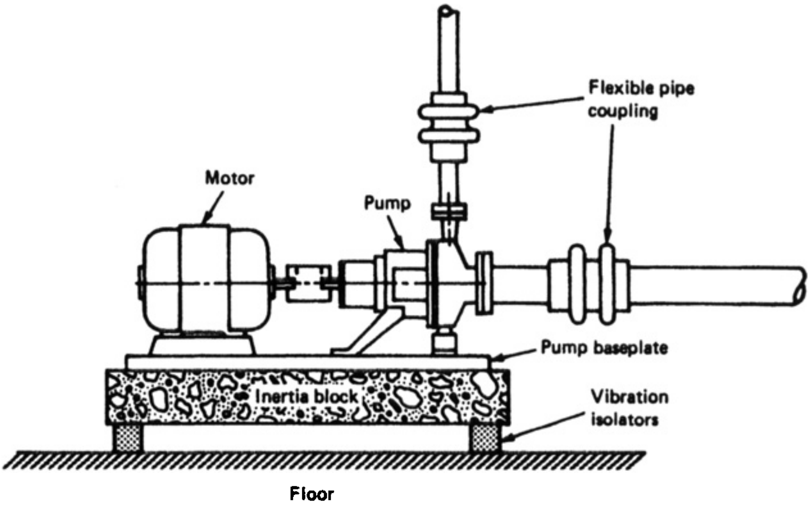


FIG. 20.10 Isolation of a pump (on an inertia block) from the building structure.

3. Resilient hangers to support the piping from the overhead structure or resilient supports to attach the piping to walls or floors as illustrated in Fig. 20.11
4. Isolation of the piping where it penetrates the building walls or floors
5. Inertia blocks, described in Chap. 28 of Ref. 8, as one of the elements in the support for the pump and motor

Water-Hammer Noise Control

The destructive forces associated with water hammer may cause ruptured piping, leaks, weakened connections, damaged valves, etc.[1,11] Water-hammer pulsations associated with washing machines and dishwashers may be partially damped by connecting such machines to the water supply with extra-long flexible hose.

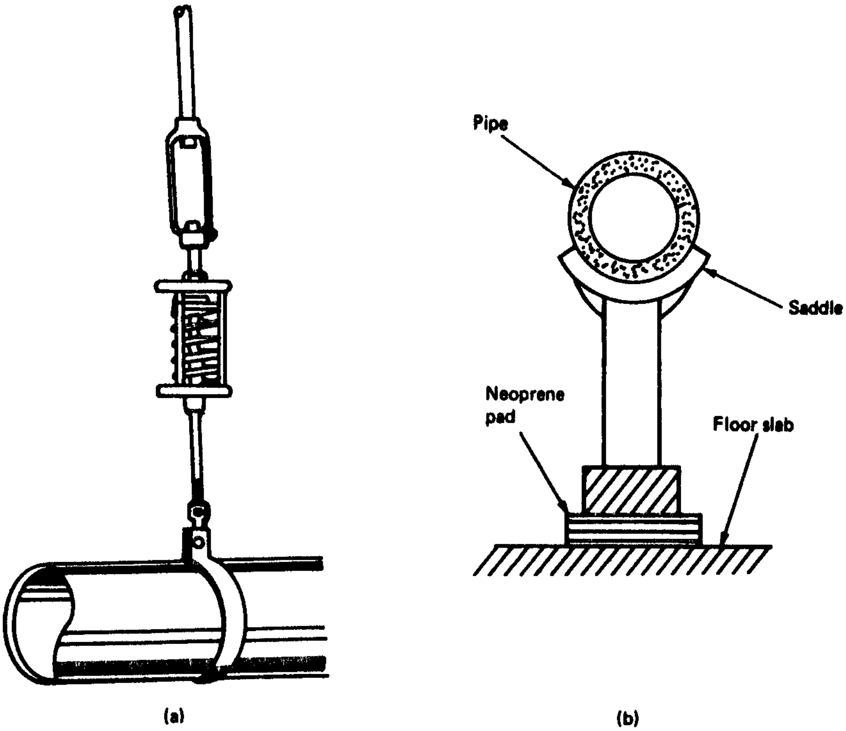


FIG. 20.11 Pipe isolation (*a*) from ceiling by use of hanger with a suitably configured spring isolator and (*b*) from floor by use of saddle with a neoprene pad.

Figure 20.12 illustrates the use of a capped pipe which provides an air chamber for water-hammer suppression. The length of the pipe is 12 to 24 in (30 to 60 cm) and may be of the same or larger diameter than the line it serves. The volume of the air chamber required to serve as an "air cushion" depends on the nominal pipe diameter, the branch line length, and the supply pressure. For example, ½-in pipe, 25 ft (7 to 8 m) in length, operating at a 60 psi (400 kPa) supply pressure requires an air chamber having a volume of 8 in^3 (130 cm^3). If the air chamber becomes filled with water, it becomes ineffective. Commercial devices (called *water-hammer arresters*) are not subject to this limitation because a metal diaphragm separates the air from the water. Water-hammer arresters should be placed close to quick-acting valves and should also be installed at the ends of long pipe runs.

Water-hammer arresters are considered advisable. In some building types they are required where polybutylene water distribution tubing is used in the plumbing system because such tubing may burst when subjected to the sudden pressures generated by water hammer. Consideration should be given to their installation where there are solenoid or other quick-closing valves in the system.[3]

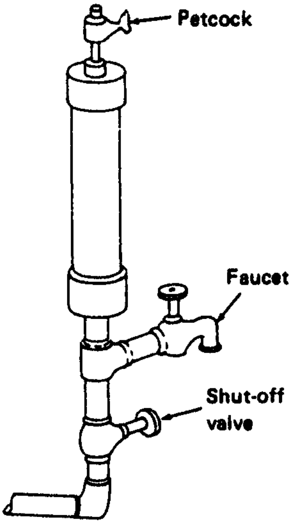


FIG. 20.12 A capped pipe-nipple that serves as a water-hammer arrester. The volume of air within it is used to take up the shock generated by water hammer. Should the air within it be replaced with water, the petcock provides a means of venting the chamber and reactivating the unit.

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