American Society of Plumbing Engineers

Plumbing Engineering Design Handbook

A Plumbing Engineer's Guide to System Design and Specifications

Volume 4

Plumbing Components and Equipment

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1 Plumbing Fixtures

It has been said that without plumbing fixtures, there would be no indoor plumbing. A plumbing fixture is supplied with water, discharges water and/or waste, and performs a function for the user. Each fixture is designed for a specific activity to maintain public health and sanitation.

The standard plumbing fixtures used in a plumbing system include:

- Water closets
- Urinals
- Lavatories
- Kitchen sinks
- Service sinks
- Sinks
- Laundry trays
- Drinking fountains
- Showers
- Bathtubs
- Bidets
- Floor drains
- Emergency fixtures

In addition, fixture fittings used in connection with these plumbing fixtures include:

- Faucets and fixture fittings
- Shower valves
- Tub fillers

FIXTURE MATERIALS

The surface of any plumbing fixture must be smooth, impervious, and easily cleanable to maintain a high level of sanitation. Fixture materials are selected based on these requirements. Common plumbing fixture materials include the following:

- Vitreous china: This is a unique material that is specially suited for plumbing fixtures. Unlike other ceramic materials, vitreous china does not absorb water because it is not porous. Vitreous china plumbing fixture surfaces are glazed. The glazing provides a nice finish that is easily cleaned. Vitreous china is also an extremely strong material. Because vitreous china is nonporous, it has a very high shrinkage rate when fired in a kiln. This accounts for the slight differences among otherwise identical plumbing fixtures.
- Nonvitreous china: Nonvitreous china is a porous ceramic that requires glazing to prevent any water absorption. Use of nonvitreous china for lavatories and similar fixtures is growing in popularity. The advantage of nonvitreous china is its low shrinkage rate, which allows the fixture to be more ornately designed.
- Glass: Tempered glass fixtures are being used in more lavatories. These fixtures tend to be ornately designed and can be found in numerous designs and colors.
- Enameled cast iron: The base of enameled cast iron fixtures is a high-grade cast iron. The exposed surfaces have an enameled coating, which is fused to the cast iron, resulting in a hard, glossy, opaque, and acid-resistant surface. Enameled cast iron plumbing fixtures are heavy, strong, ductile, and long-lasting.
- Porcelain enameled steel: Porcelain enameled steel is a substantially vitreous or glossy inorganic coating that is bonded to sheet steel by fusion. The sheet steel must be designed for the application of the porcelain enamel to produce a high-quality product.
- Stainless steel: A variety of stainless steels are used to produce plumbing fixtures. The different types include 316, 304, 302, 301, 202, 201, and 430. One of the key ingredients in stainless steel is nickel. A higher nickel content tends to produce a superior finish in the stainless steel. Types 302 and 304 have 8 percent nickel and

Type 316 has 10 percent nickel. These are the two most common types.

- Plastic: Plastic is a generic category for a variety of synthetic materials used in plumbing fixtures. The various plastic materials used to produce plumbing fixtures include acrylonitrile butadiene styrene (ABS); polyvinyl chloride (PVC); gel-coated, fiberglass-reinforced plastic; acrylic; cultured marble; cast-filled fiberglass; polyester; cast-filled acrylic; gel-coated plastic; and cultured marble acrylic. Plastics used in plumbing fixtures are subject to numerous tests to determine their quality. Some of the testing includes an ignition (torch) test, a cigarette burn test, a stain-resistance test, and a chemical-resistance test.
- Soapstone: This is an older material used predominantly in the manufacture of laundry trays and service sinks. Soapstone is steatite, which is extremely heavy and very durable.

ACCESSIBILITY

Several federal and plumbing industry codes and standards require certain plumbing fixtures to be accessible to people with disabilities. The federal guidelines are the *Americans with Disabilities Act (ADA) Standards for Accessible Design*. Accessibility standards also are found in American National Standards Institute (ANSI)/International Code Council (ICC) A117.1: *Accessible and Usable Buildings and Facilities*. More information about accessibility requirements can be found in *Plumbing Engineering Design Handbook*, *Volume 1,* Chapter 6.

APPLICABLE STANDARDS

Plumbing fixtures are regulated by nationally developed consensus standards. These standards specify materials, fixture designs, and testing requirements.

While standards for plumbing fixtures are considered voluntary, when they are referenced in plumbing codes the requirements become mandatory. Most fixture manufacturers have their products certified by a third-party testing laboratory as being in conformance with the applicable standard.

Table 1-1 identifies the most common consensus standards regulating plumbing fixtures. A complete list of standards can be found in *Plumbing Engineering Design Handbook*, *Volume 1,* Chapter 2.

LEED AND PLUMBING

The LEED (Leadership in Energy and Environmental Design) program is becoming more common in the construction industry. Many large corporations have committed to certifying all of their new buildings. This program is put forth by the U.S. Green Building Council (USGBC). Its intent is to provide a benchmark for the design of energy-efficient buildings.

The section on water efficiency (WE) applies to plumbing design. The five LEED points are:

- WE Credit 1.1: Water-efficient Landscaping: Reduce by 50 Percent
- WE Credit 1.2: Water-efficient Landscaping: No Potable Water Use or No Irrigation
- WE Credit 2: Innovative Wastewater Technologies
- WE Credit 3.1: Water Use Reduction: 20 Percent Reduction
- WE Credit 3.2: Water Use Reduction: 30 Percent Reduction

These points can be obtained through design and specification of water-efficient products and systems.

Table 1-1 Plumbing Fixture Standards

Plumbing Fixture	Applicable Standard	Fixture Material
Water closet	ANSI/ASME A112.19.2	Vitreous china
	ANSI Z124.4	Plastic
Urinal	ANSI/ASME A112.19.2	Vitreous china
	ANSI Z124.9	Plastic
Lavatory	ANSI/ASME A112.19.1	Enameled cast iron
	ANSI/ASME A112.19.2	Vitreous china
	ANSI/ASME A112.19.3	Stainless steel
	ANSI/ASME A112.19.4	Porcelain enameled steel
	ANSI/ASME A112.19.9	Nonvitreous china
	ANSI Z124.3	Plastic
Sink	ANSI/ASME A112.19.1	Enameled cast iron
	ANSI/ASME A112.19.2	Vitreous china
	ANSI/ASME A112.19.3	Stainless steel
	ANSI/ASME A112.19.4	Porcelain enameled steel
	ANSI/ASME A112.19.9	Nonvitreous china
	ANSI Z124.6	Plastic
Drinking fountain	ANSI/ASME A112.19.1	Enameled cast iron
	ANSI/ASME A112.19.2	Vitreous china
	ANSI/ASME A112.19.9	Nonvitreous china
	ARI 1010	Water coolers
Shower	ANSI Z124.2	Plastic
Bathtub	ANSI/ASME A112.19.1	Enameled cast iron
	ANSI/ASME A112.19.4	Porcelain enameled steel
	ANSI/ASME A112.19.9	Nonvitreous china
	ANSI Z124.1	Plastic
Bidet	ANSI/ASME A112.19.2	Vitreous china
	ANSI/ASME A112.19.9	Nonvitreous china
Floor drain	ANSI/ASME A112.6.3	All materials
Emergency fixtures	ANSI Z358.1	All materials
Faucets and fixture fittings	ANSI/ASME A112.18.1	All materials
Waste fittings	ANSI/ASME A112.18.2	All materials

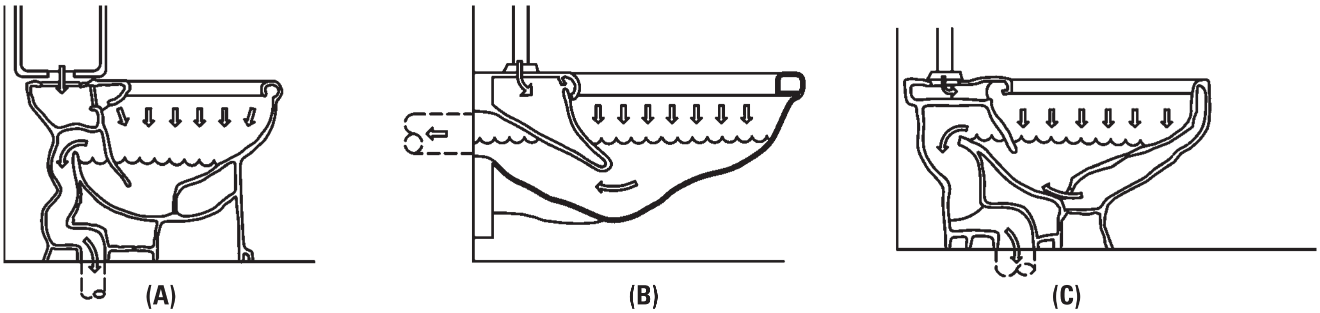


Figure 1-1 The older styles of water closets were identified as (A) reverse trap, (B) blowout, and (C) siphon jet, to name a few. Though still used in the industry, these terms are no longer used in the standards.

In many cases, at least one LEED point can be obtained simply by specifying dual-flush water closets, reduced-flow urinals (0.5 gallons per flush [gpf] or less), and low-flow lavatories (0.5 gallons per minute [gpm]). For more information, visit the USGBC website at www.usgbc.org or turn to Chapter 14 of this volume.

WATER CLOSETS

Passage of the Energy Policy Act of 1992 by the U.S. government changed the way water closets (WCs) are designed. The act imposed a maximum flushing rate of 1.6 gpf (6 liters per flush [lpf]). This was a significant drop in the quantity of water used, which previously was 3.5 gpf, and was considered to be a water savings. Prior to the first enactment of water conservation in the late 1970s, water closets typically flushed between 5 and 7 gallons of water. The greatest water use, 7 gpf, was by blowout water closets. Ultra-low-flow WCs now flush as little as 0.4 gpf (1.5 lpf). Dual-flush models also are available. These give the user the option to flush the full 1.6 gallons for solid waste or one-third less for liquid waste.

With the modification in water flush volume, the style of each manufacturer's water closet changed, and the former terminology for identifying water closets no longer fit. Water closets previously were categorized as blowout, siphon jet, washout, reverse trap, and washdown. Of these styles, the only one currently in use is the siphon jet (see Figure 1-1). This WC uses a jet of water at the bottom of the bowl to induce the siphon, thus clearing the bowl more efficiently.

To meet the new standards, WC manufacturers have re-engineered the bowls and trapways to increase efficiency. The trapways are now glazed and much smoother. Many manufacturers also have increased the size of the trapway to further increase efficiency and facilitate waste removal.

Water closets currently are categorized as the following:

- A close-coupled water closet is one with a two-piece tank and bowl fixture.
- A one-piece water closet is, as the name suggests, one with the tank and bowl as one piece.
- A flushometer water closet is a bowl with a spud connection that receives the connection from a flushometer valve. Flushometer water closets also are referred to as "top spud" or "back spud" bowls depending on the location of the connection for the flushometer valve. (See Figure 1-2.)

The flushing of a water closet may be identified as one of the following:

- In a gravity flush, used with tank-type water closets, the water is not under pressure and flushes by gravity.
- With a flushometer tank, the water is stored in a pressurized vessel and flushed under a pressure

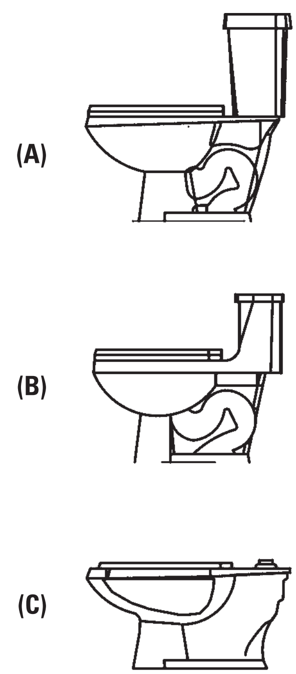


Figure 1-2 Water closets are identified as (A) close coupled, (B) one piece, and (C) flushometer types.

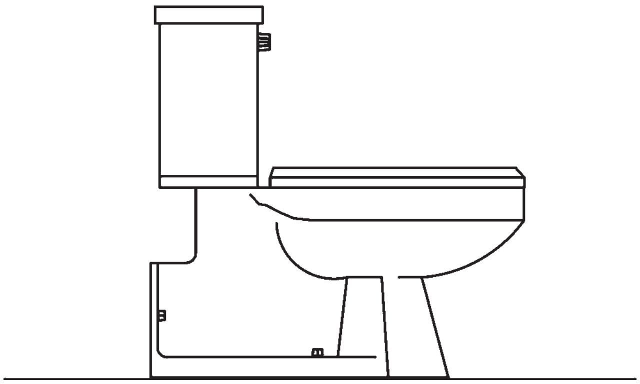


Figure 1-3 A floor-mounted, back outlet water closet is supported on the floor with the piping connection through the back wall.

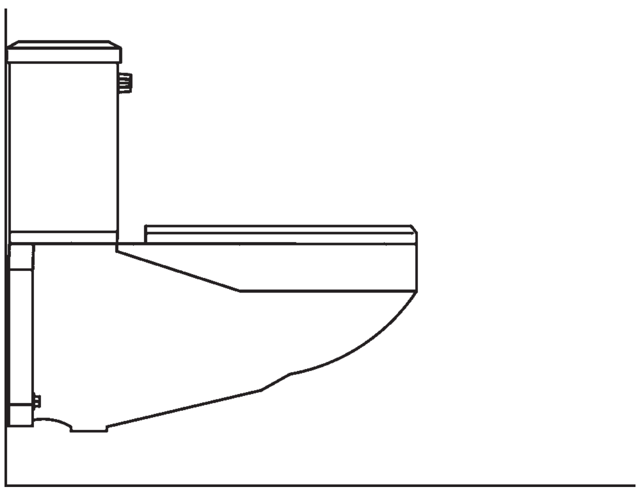


Figure 1-4 A wall-hung water closet attaches to the back wall; the water closet does not contact the floor.

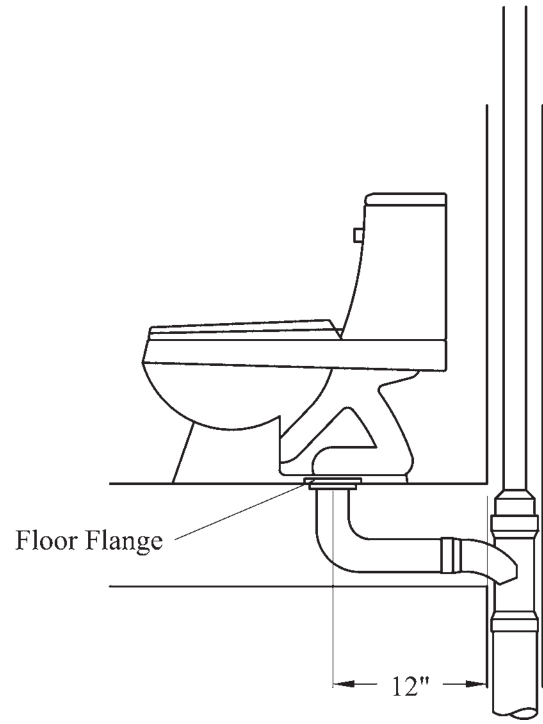


Figure 1-5 The standard rough-in dimension is 12 inches from the centerline of the water closet outlet to the back wall. The floor flange must be permanently secured to the building structure.

ranging between 25 and 35 pounds per square inch (psi).

- A flushometer valve type of flush uses the water supply line pressure to flush the water closet. Because of the demand for a flush of a large volume of water in a short period, the water supply pipe must be larger in diameter than that for gravity or flushometer tank types of flush.

Another distinction used to identify a water closet is the manner of mounting and connection. The common designations for water closets are the following:

- A floor-mounted water closet is supported by the floor and connected directly to the piping through the floor. (See Figure 1-3.)
- A wall-hung water closet is supported by a wall hanger and never comes in contact with the floor. Wall-hung water closets are considered superior for maintaining a clean floor in the toilet room since the water closet doesn't interfere with the cleaning of the floor. (See Figure 1-4.)
- Floor-mounted, back-outlet water closets are supported by the floor yet connect to the piping through the wall. The advantage of the floor-mounted, back-outlet water closet is that floor penetrations are reduced. However, it is difficult for manufacturers to produce a floor-mounted, back-outlet water closet that meets current flushing performance requirements.

Shape and Size

A water closet bowl is classified as either a round front or elongated. An elongated bowl has an opening that extends 2 inches farther to the front of the bowl. Most plumbing codes require elongated bowls for public and employee use. The additional 2 inches provides a larger opening, often called a "target area." With the larger opening, there is a greater likelihood of maintaining a cleaner water closet for each user.

For floor-mounted water closets, the outlet is identified based on the rough-in dimension. The rough-in is the distance from the back wall to the center of the outlet when the water closet is installed. A standard rough-in bowl outlet is 12 inches. Most manufacturers also make water closets with a 10-inch or 14-inch rough-in. (See Figure 1-5.)

The size of the bowl also is based on the height of the bowl's rim measured from the floor.

- A standard water closet has a rim height of 14 to 15 inches. This is the most common water closet to install.
- A child's water closet has a rim height of 10 inches above the floor. Many plumbing codes require these water closets in daycare centers and kindergarten toilet rooms for use by small children.
- A water closet for juvenile use has a rim height of 13 inches.
- A water closet for the physically challenged has a rim height of 18 inches. With the addition of the water closet seat, the fixture is designed to conform to accessibility requirements.

Bariatric Water Closets

Bariatric WCs are made to accommodate overweight and obese people. These WCs support weights of 500 to 1,000 pounds. They are available in vitreous china as well as stainless steel. Wall-hung fixtures require special carriers designed for the increased loads. The chase for wall-hung bariatric WCs need to be deeper to accommodate the larger carriers. The most commonly used bariatric WCs are floor mounted, which can safely accommodate weights in excess of 1,000 pounds. Bariatric WCs should be mounted at the accessibility-required height.

Water Closet Seat

A water closet seat must be designed for the shape of the bowl to which it connects. Two styles of water closet seat are available: solid and split rim. Plumbing codes typically require a split rim seat for public and employee use. The split rim seat is designed to facilitate easy wiping by females and to prevent contact between the seat and the penis with males. This is to maintain a high level of hygiene in public facilities.

Many public water closets have a plastic wrap around the seat. The intent of this seat is to allow a clean surface for each use. The seat is intended to replace the split rim seat in public and employee locations.

Flushing Performance

The flushing performance requirements for a water closet are found in ANSI/American Society of Mechanical Engineers (ASME) A112.19.6: *Hydraulic Performance Requirements for Water Closets and Urinals*. This standard identifies the test protocol that must be followed to certify a water closet. The tests include a ball removal test, granule test, ink test, dye test, water consumption test, trap seal restoration test, water rise test, back pressure test, rim top and seat fouling test, and a drainline carry test.

The ball removal test utilizes 100 polypropylene balls that are ¾ inch in diameter. The water closet must flush at least an average of 75 balls on the initial flush of three different flushes. The polypropylene balls are intended to replicate the density of human feces.

The granule test utilizes approximately 2,500 disc-shaped granules of polyethylene. The initial flush of three different flushes must result in no more than 125 granules on average remaining in the bowl. The granule test is intended to simulate a flush of watery feces (diarrhea).

The ink test is performed on the inside wall of the water closet bowl. A felt-tip marker is used to draw a line around the inside of the bowl. After flushing, no individual segment of line can exceed ½ inch. The total length of the remaining ink line must not exceed 2 inches. This test determines that the water flushes all interior surfaces of the bowl.

The dye test uses a colored dye added to the water closet's trap seal. The concentration of the dye is determined both before and after flushing the water closet. A dilution ratio of 100:1 must be obtained for each flush. This test determines the evacuation of urine in the trap seal.

The water consumption test determines that the water closet meets the federal mandate of 1.6 gpf.

The trap seal restoration test determines that the water closet refills the trap of the bowl after each flush. The remaining trap seal must be a minimum of 2 inches in depth.

The water rise test evaluates the rise of water in the bowl when the water closet is flushed. The water cannot rise above a point 3 inches below the top of the bowl.

The back pressure test is used to determine that the water seal remains in place when exposed to a back pressure (from the outlet side of the bowl) of 2½ inches of water column (wc). This test determines that no sewer gas will escape through the fixture when high pressure occurs in the drainage system piping.

The rim top and seat fouling test determines if the water splashes onto the top of the rim or seat of the water closet. This test ensures that the user does not encounter a wet seat when using the water closet.

The drainline carry test determines the performance of the water closet's flush. The water closet is connected to a 4-inch drain 60 feet in length pitched ¼ inch per foot. The same 100 polypropylene balls used in the flush test are used in the drainline carry test. The average carry distance of all the polypropylene balls must be 40 feet. This test determines the ability of the water closet to flush the contents in such a manner that they properly flow down the drainage piping.

A proposed bulk media test is a test of a large quantity of items placed in the bowl. The bowl cannot be stopped up by the bulk media during the flush, and a certain flushing performance of the bulk media

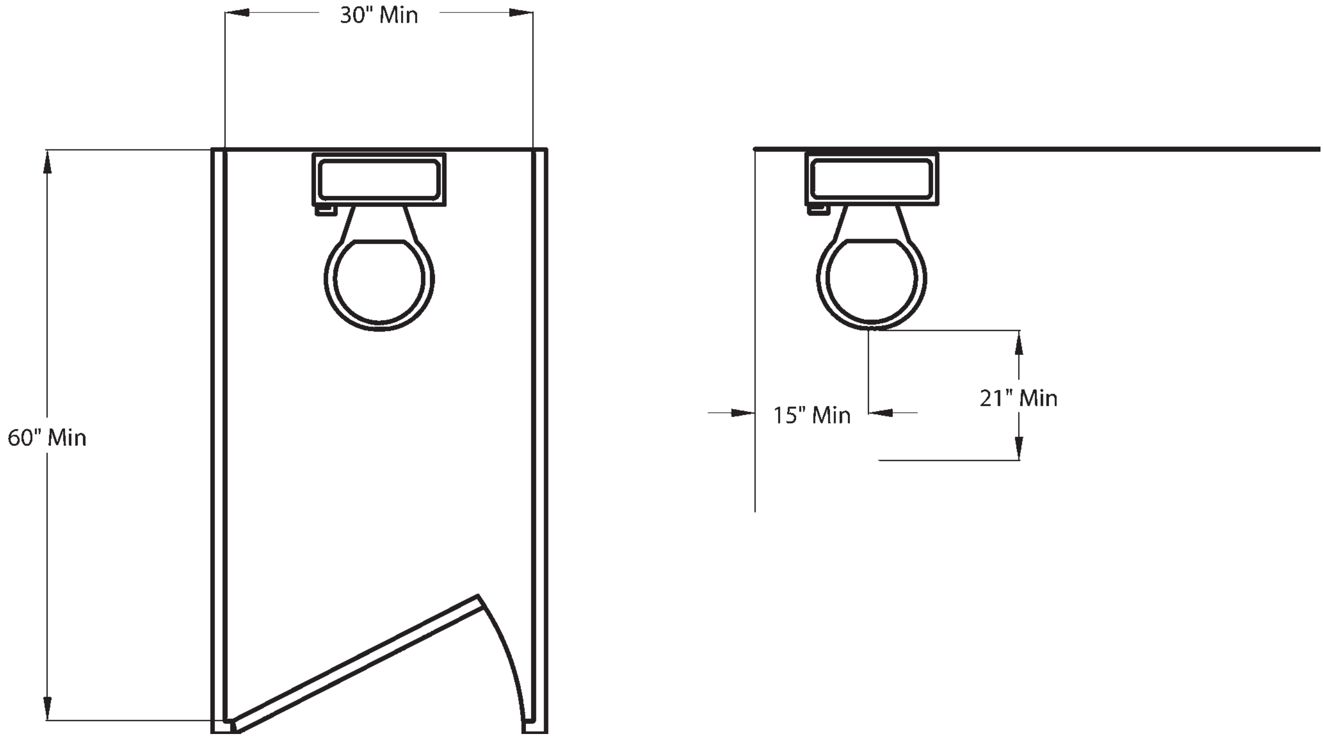


Figure 1-6 The minimum size water closet compartment is 30 in. × 60 in. Spacing is required from the centerline of the water closet to a side wall or obstruction and from the front lip of the water closet to any obstruction.

is required. The debate over this test is the repeatability of the test. It is expected that, after round robin testing is completed, the test will be added to the standard.

In Canada, water closets must conform to Canadian Standards Association (CSA) B45 Series 02: *Plumbing Fixtures*. While Canada does not have a federal mandate requiring 1.6-gpf water closets, many areas require these water closets. Canada does require a bulk media test for water closet flush performance.

Installation Requirements

The water closet must be properly connected to the drainage piping system. For floor-mounted water closets, a water closet flange is attached to the piping and permanently secured to the building. For wood-frame buildings, the flange is screwed to the floor. For concrete floors, the flange sits on the floor.

Noncorrosive closet bolts connect the water closet to the floor flange. The seal between the floor flange and the water closet is made with either a wax ring or an elastomeric sealing connection. The connection formed between the water closet and the floor must be sealed with caulking or tile grout.

For wall-hung water closets, the fixture must connect to a wall carrier. The carrier must transfer the loading of the water closet to the floor. A wall-hung water closet must be capable of supporting a load of 500 pounds at the end of the water closet. When the water closet is connected to the carrier, none of this load can be transferred to the piping system. Water closet carriers must conform to ANSI/ASME A112.6.1: *Supports for Off-the-Floor Plumbing Fixtures for Public Use.* For bariatric WCs, the loads as listed by the manufacturers vary from 650 to 1,000 pounds. These carriers must conform to ANSI/ASME A112.6.1 as well.

The minimum spacing required for a water closet is 15 inches from the centerline of the bowl to the side wall and 21 inches from the front of the water closet to any obstruction in front of the water closet. The standard dimension for a water closet compartment is 30 inches wide by 60 inches long. The water closet must be installed in the center of the standard compartment. The minimum distance required between water closets is 30 inches (see Figure 1-6).

The 1.6-gpf flushing requirement has affected the piping connection for back-to-back water closet installations. With a 3.5-gpf water closet, the common fitting used to connect back-to-back water closets was either a 3-inch double sanitary tee or a 3-inch double fixture fitting. With the superior flushing of the 1.6-gpf water closet, the plumbing codes have prohibited the installation of a double sanitary tee or double fixture fitting for back-to-back water closets. The only acceptable fitting is the double combination wye and eighth bend. The fitting, however, increases the spacing required between the floor and the ceiling.

The minimum spacing required to use a double sanitary tee fitting is 30 inches from the centerline of

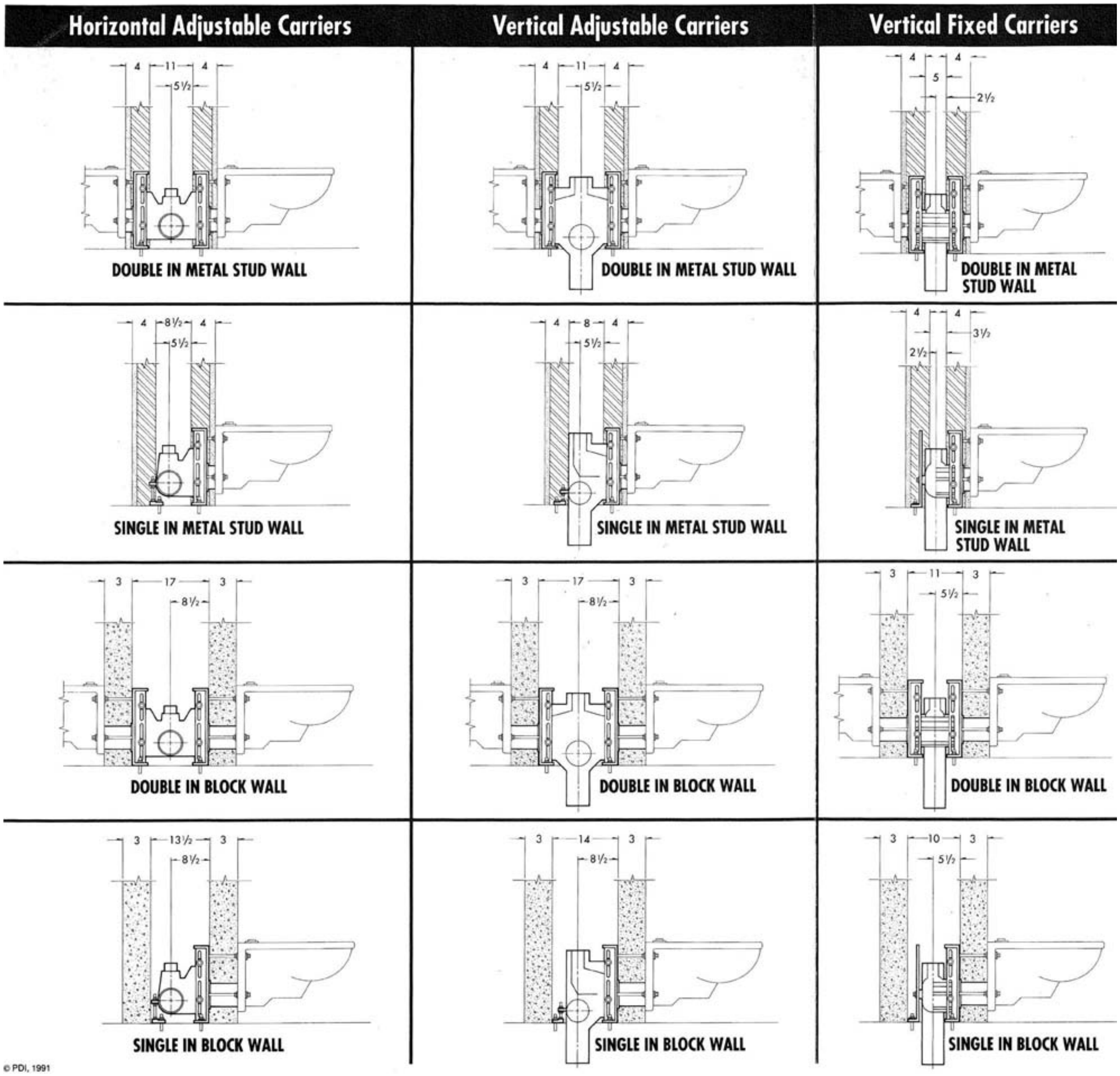


Figure 1-7 Minimum Chase Sizes for Carriers

Courtesy of Plumbing and Drainage Institute

the water closet outlet to the entrance of the fitting. This spacing rules out a back-to-back water closet connection.

One of the problems associated with short pattern fittings is the siphon action created in the initial flush of the water closet. This siphon action can draw the water out of the trap of the water closet connected to the other side of the fitting. Another potential problem is the interruption of flow when flushing a water closet. The flow from one water closet can propel water across the fitting, interfering with the other water closet.

Proper clearances within chases for wall-hung carriers should be maintained. Figure 1-7 shows the minimum chase sizes for carriers (as published by the Plumbing and Drainage Institute [PDI]). Carrier sizes vary by manufacturer. Always check before committing to chase size. Also, wall-hung bariatric carriers require more space than indicated by PDI. Bariatric chases should be coordinated with the specified carrier manufacturer.

Flushing Systems

Gravity Flush

The most common means of flushing a water closet is a gravity flush (see Figure 1-8). This is the flush with a tank-type water closet, described above, wherein the water is not pressurized in the tank. The tank stores a quantity of water to establish the initial flush of the bowl. A trip lever raises either a flapper or a ball, allowing the flush to achieve the maximum siphon in the bowl. After the flush, the flapper or ball reseals, closing off the tank from the bowl. On the dual-flush WC, the trip lever raises the flapper or ball a bit less, which results in a reduced-volume flush.

The ballcock, located inside the tank, controls the flow of water into the tank. A float mechanism opens and closes the ballcock. The ballcock directs the majority of the water into the tank and a smaller portion of water into the bowl to refill the trap seal. The ballcock must be an antisiphon ballcock conforming to American Society of Sanitary Engineering (ASSE) 1002: *Performance Requirements for Antisiphon Fill Valves for Water Closet Tanks*. This prevents the contents of the tank from being siphoned back into the potable water supply. Dual-flush systems are being used to meet LEED criteria. This type of system gives the user the option to flush with one-third less water when flushing only liquid waste.

Flushometer Tank

A flushometer tank (see Figure 1-8) has the same outside appearance as a gravity tank. However, inside the tank is a pressure vessel that stores the water for flushing. The water in the pressure vessel must be a minimum of 25 psi to operate properly. Thus, the line pressure on the connection to the flushometer tank must be a minimum of 25 psi. A pressure regulator prevents the pressure in the vessel from rising above 35 psi (typical of most manufacturers).

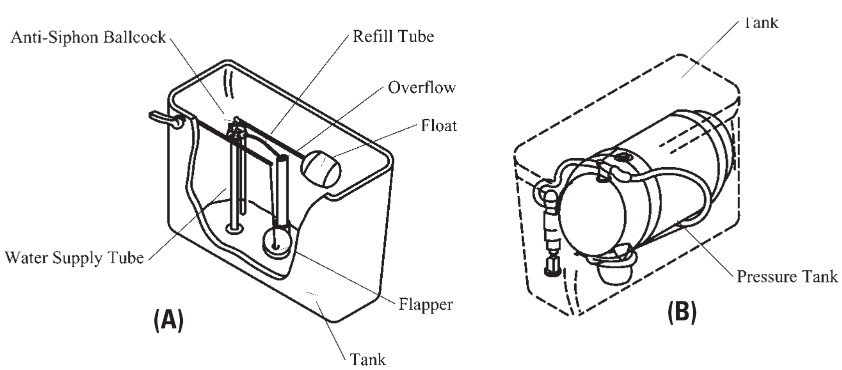


Figure 1-8 (A) A Gravity Tank and (B) a Flushometer Tank

The higher pressure from the flushometer tank results in a flush similar to a flushometer valve. One of the differences between the flushometer tank and the flushometer valve is the sizing of the water distribution system. The water piping to a flushometer tank is sized the same as the water piping to a gravity flush tank. Typically, the individual water connection is ½ inch in diameter. For a flushometer valve, there is a high flow rate demand, resulting in a large piping connection. A typical flushometer valve for a water closet has a connection of 1 inch in diameter.

The flushometer tank WC tends to be noisier than the gravity tank WC. Their advantage over gravity tanks is that the increased velocity of the waste stream provides as much as a 50 percent increase in drainline carry. In long horizontal run situations, this means fewer sewer/drainline blockages.

Flushometer Valve

A flushometer valve also is referred to as a "flush valve." The valve is designed with upper and lower chambers separated by a diaphragm. The water pressure in the upper chamber keeps the valve in the closed position. When the trip lever is activated, the water in the upper chamber escapes to the lower chamber, starting the flush. The flush of 1.6 gallons passes through the flush valve. The valve is closed by line pressure as water reenters the upper chamber.

For 1.6-gpf water closets, flushometer valves are set to flow 25 gpm at peak to flush the water closet. The flushing cycle is very short, lasting 4 to 5 seconds. The water distribution system must be properly designed to allow the peak flow during heavy use of the plumbing system.

Flushometer valves have either a manual or an automatic means of flushing. The most popular manual means of flushing is a handle mounted on the side of the flush valve. Automatic, electronic sensor flushometer valves are available in a variety of styles. The sensor-operated valves can be battery operated or directly connected to the power supply of the building.

URINALS

A urinal was developed as a fixture to expedite the use of a toilet room. It is designed for the removal of urine and the quick exchange of users. The Energy Policy Act of 1992 included requirements for the water consumption of urinals. A urinal is restricted to a maximum water use of 1.0 gpf. This change in water consumption resulted in a modified design of the fixture. Some urinals now use 0.5 gpf or less.

One of the main concerns in the design of a urinal is the maintenance of a sanitary fixture. The fixture must contain the urine, flush it down the drain, and wash the exposed surfaces. Prior to the passage of the Energy Policy Act of 1992, urinals were developed using large quantities of water to flush the contents. This included a blowout model that could readily remove any of the contents thrown into the urinal in addition to urine. Blowout urinals were popular in high-traffic areas such as assembly buildings. However, these blowout urinals required more than 1 gallon of water to flush. Newer fixtures identified as blowout urinals do not have the same forceful flush. Low-flow (0.5 gpf), ultra-low-flow (0.125 gpf), and waterless urinals are becoming more common in LEED-certified buildings.

Urinal Styles

Urinals are identified as blowout, siphon jet, washout, stall, washdown, and waterless. A stall urinal is a type of washdown urinal. Blowout, siphon-jet, and washout urinals all have integral traps. Stall and washdown urinals have an outlet to which an external trap is connected. Many plumbing codes prohibit the use of stall and washdown urinals in public and employee toilet rooms. One of the concerns with stall and washdown urinals is the ability to maintain a high level of sanitation after each flush. Waterless urinals are gaining acceptance by code enforcement bodies, but are not allowed in all jurisdictions.

The style identifies the type of flushing action in the urinal. Blowout and siphon-jet types rely on complete evacuation of the trap. Blowout urinals tend to force the water and waste from the trap to the drain. Siphon-jet urinals create a siphon action to evacuate the trap. Washout urinals rely on a water exchange to flush, with no siphon action or complete evacuation of the trapway. Stall and washdown urinals have an external trap. The flushing action is a water exchange; however, it is a less efficient water exchange than that of a washout urinal.

Urinals with an integral trap must be capable of passing a ¾-inch-diameter ball. The outlet connection is typically 2 inches in diameter. Stall and washdown urinals can have a 1½-inch outlet with an external 1½-inch trap.

Waterless urinals are used in many jurisdictions as a means to reduce water consumption. Waterless urinals utilize a cartridge filled with a biodegradable liquid sealant. Urine is heavier than the sealant, so it flows through the cartridge while leaving the sealant. According to manufacturer literature, a typical cartridge lasts for 7,000 uses. Waterless urinals are also inexpensive to install. The waste and vent piping are the same, but no water piping is required. The inside walls of the urinal must be washed with a special solution on a periodic basis for proper sanitation.

Flushing Performance

The flushing performance for a urinal is regulated by ANSI/ASME A112.19.6. There are three tests for urinals: the ink test, dye test, and water consumption test.

In the ink test, a felt-tip marker is utilized to draw a line on the inside wall of the urinal. The urinal is flushed, and the remaining ink line is measured. The total length of the ink line cannot exceed 1 inch, and no segment can exceed ½ inch in length.

The dye test uses a colored dye to evaluate the water exchange rate in the trap. After one flush, the trap must have a dilution ratio of 100:1. The dye test is performed only on urinals with an integral trap. This includes blowout, siphon-jet, and washout urinals. It is not possible to dye test stall and washdown urinals since they have external traps. This is one of the concerns that has resulted in the restricted use of these fixtures.

The water consumption test determines that the urinal flushes with 1 gallon of water or less.

Installation Requirements

The minimum spacing required between urinals is 30 inches center to center. The minimum spacing between a urinal and the sidewall is 15 inches. This spacing provides access to the urinal without the user coming in contact with the user of the adjacent fixture. The minimum spacing required in front of the urinal is 21 inches (see Figure 1-9).

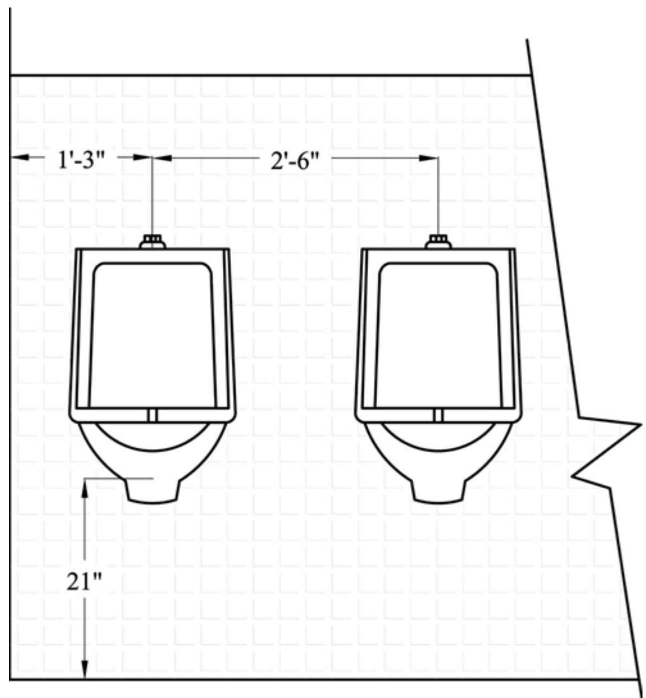


Figure 1-9 Urinal spacing must be adequate to allow adjacent users to access the urinals without interference.

For urinals with an integral trap, the outlet is located 21 inches above the floor for a standard-height installation. Stall urinals are mounted on the floor. Wall-hung urinals must be mounted on carriers that transfer the weight of the urinal to the floor. The carrier also connects the urinal to the waste piping system. Sufficient room should be provided in the chase for the carrier. Figure 1-10 shows minimum chase sizes as recommended by PDI.

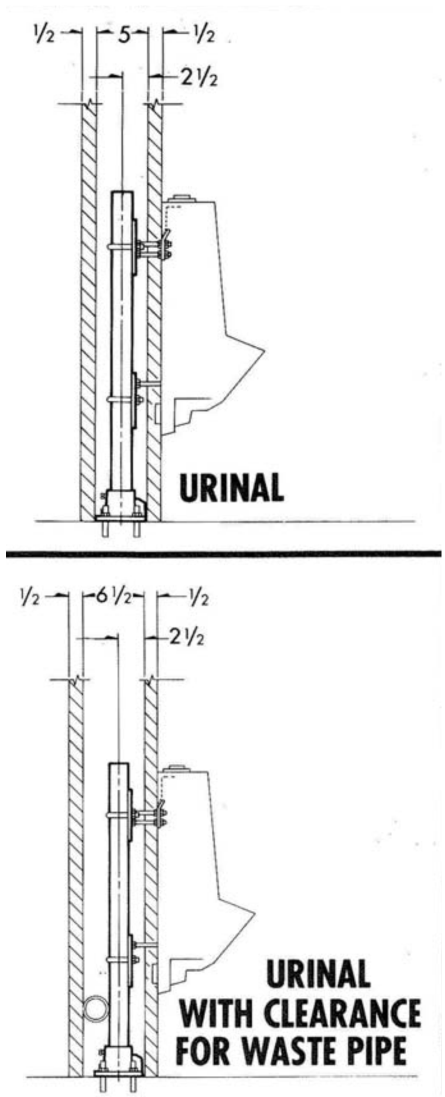


Figure 1-10 Minimum Chase Sizes for Urinals
Courtesy of Plumbing and Drainage Institute

Many plumbing codes require urinals for public and employee use to have a visible trap seal. This refers to blowout, siphon-jet, or washout urinals.

Flushing Requirements

With the federal requirements for water consumption, urinals must be flushed with a flushometer valve. The valve can be either manually or automatically actuated.

A urinal flushometer valve has a lower flush volume and flow rate than a water closet flushometer valve. The total volume is 1 gpf, and the peak flow rate is 15 gpm. The water distribution system must be properly sized for the peak flow rate for the urinal.

Urinal flushometer valves operate the same as water closet flushometer valves. For additional information, see the discussion of flushing systems under "Water Closets" earlier in this chapter.

LAVATORIES

A lavatory is a washbasin used for personal hygiene. In public locations, a lavatory is intended to be used for washing one's hands and face. Residential lavatories are intended for hand and face washing, shaving, applying makeup, cleaning contact lenses, and similar hygienic activities.

Lavatory faucet flow rates are regulated as part of the Energy Policy Act of 1992. The original flow rate established by the government was 2.5 gpm at 80 psi for private-use lavatories and 0.5 gpm, or a cycle discharging 0.25 gallons, for public-use lavatories. Now the regulations require 2.2 gpm at 60 psi for private (and residential) lavatories and 0.5 gpm at 60 psi, or a cycle discharging 0.25 gallons, for public lavatories.

Lavatory faucets are also available with electronic valves. These faucets can reduce water usage by supplying water only when hands are inside the bowl.

Size and Shape

Manufacturers produce lavatories in every conceivable size and shape: square, round, oblong, rectangular, shaped for corners, with or without ledges, decorative bowls, and molded into countertops.

The standard outlet for a lavatory is 1¼ inches in diameter. The standard lavatory has three holes on the ledge for the faucet. With a typical faucet, the two outside holes are 4 inches apart. The faucets installed in these lavatories are called 4-inch centersets. When spread faucets are to be installed, the spacing between the two outer holes is 8 inches.

For many years, the fixture standards required lavatories to have an overflow. This requirement was based on the use of the fixture whereby the basin was filled prior to cleaning. If a user left the room while the lavatory was being filled, the water would not overflow onto the floor.

Studies have shown that lavatories are rarely used in this capacity. It is more common to not fill the basin with water during use. As a result, overflows became an optional item for lavatories. Some plumbing codes, however, still require overflows for lavatories.

To avoid a hygiene problem with the optional overflows, the fixture standard added a minimum size for the overflow. The minimum cross-sectional area must be 1⅛ inch.

Another style of lavatory is the circular or semicircular group washup. The plumbing codes consider every 20 inches of space along a group washup to be equivalent to one lavatory.

Installation

The standard height of a lavatory is 31 inches above the finished floor. A spacing of 21 inches is required in front of the lavatory to access the fixture (see Figure 1-11).

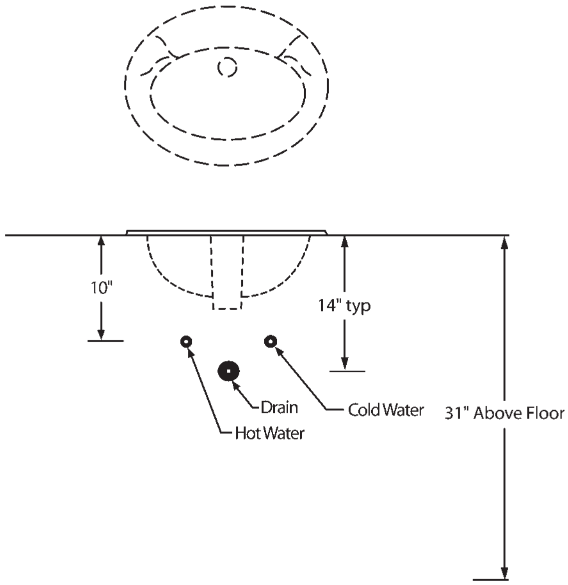


Figure 1-11 Recommended Installation Dimensions for a Lavatory

Lavatories can be counter mounted, under-counter mounted, or wall hung. When lavatories are wall hung in public and employee facilities, they must be connected to a carrier that transfers the weight of the fixture to the floor. Proper clearances within chases for wall-hung lavatories should be maintained. Figure 1-12 shows recommended minimum chase sizes as recommended by PDI.

KITCHEN SINKS

A kitchen sink is used for culinary purposes. The two distinct classifications of kitchen sink are residential and commercial. Residential kitchen sinks can be installed in commercial buildings, typically in kitchens used by employees. Commercial kitchen sinks are designed for restaurant and food-handling establishments.

The Energy Policy Act of 1992 regulates the flow rate of faucets for residential kitchen sinks. The original flow rate was 2.5 gpm at 80 psi. The fixture standards have since modified the flow rate to 2.2 gpm at 60 psi.

Residential Kitchen Sinks

Common residential kitchen sinks are single- or double-compartment (or bowl) sinks. No standard dimension for the size of the sink exists; however, most kitchen sinks are 22 inches measured from the front edge to the rear edge. For single-compartment sinks, the most common width of the sink is 25 inches. For double-compartment kitchen sinks, the most common width is 33 inches. The common depth of the compartments is 9 to 10 inches. Accessible sinks are 5.5 to 6.5 inches deep.

Most plumbing codes require the outlet of a residential kitchen sink to be 3½ inches in diameter. This is to accommodate the installation of a food waste grinder.

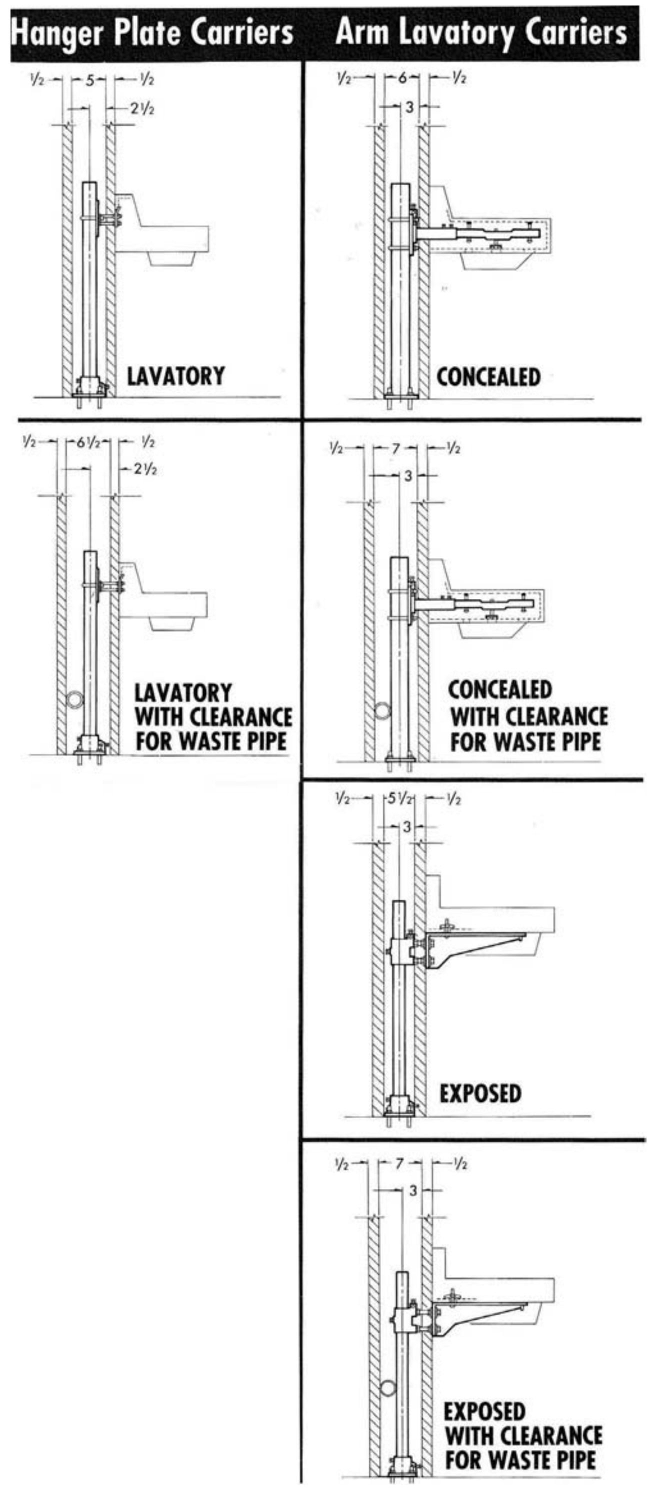


Figure 1-12 Minimum Chase Sizes for Lavatories
Courtesy of Plumbing and Drainage Institute

Some specialty residential kitchen sinks have three compartments. Typically, the third compartment is smaller and does not extend the full depth of the other compartments.

Kitchen sinks have one, three, or four holes for the installation of a faucet. Some single-lever faucets require only a one hole for installation. The three-hole arrangement is for a standard two-handle valve installation. The four holes are designed to allow the installation of a side spray or other kitchen appurtenance such as a soap dispenser.

The standard installation height for a residential kitchen sink is 36 inches above the finished floor. Most architects tend to follow the 6-foot triangle rule when locating a kitchen sink. The sink is placed no more than 6 feet from the range and 6 feet from the refrigerator (see Figure 1-13).

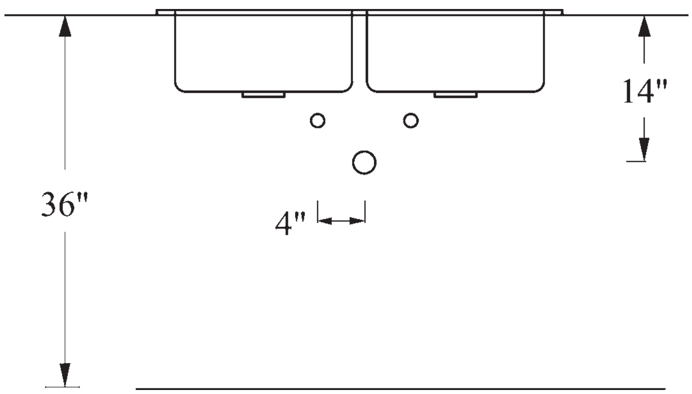


Figure 1-13 Standard dimensions for a kitchen sink include a counter height of 36 inches above the finished floor.

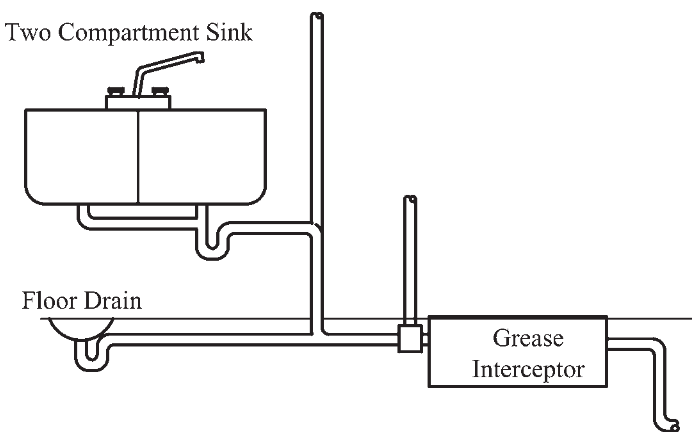


Figure 1-14 When grease-laden waste is possible, the sink must discharge to a grease interceptor.

Residential kitchen sinks mount either above or below the counter. Counter-mounted kitchen sinks are available with a self-rimming ledge or a sink frame.

Commercial Kitchen Sinks

Commercial kitchen sinks are typically larger in size and have a deeper bowl than residential kitchen sinks. The depth of the bowl ranges from 16 to 20 inches for most commercial kitchen sinks. Commercial kitchen sinks are often freestanding sinks with legs to support the sink.

In commercial kitchens, three types of sinks typically are provided: hand sinks, prep sinks, and triple-basin sinks. Prep sinks usually are single basin and are used in conjunction with food preparation. Triple-basin sinks are used for washing pots, pans, and utensils.

Because of health authority requirements, most commercial kitchen sinks are stainless steel. Another health authority requirement is for either a two- or three-compartment sink in every commercial kitchen.

The more popular requirement is a three-compartment sink. The historical requirement for a three-compartment sink dates back to the use of the first compartment for dishwashing, the second compartment for rinsing the dishes, and the third compartment for sanitizing the dishes. With the increased use of dishwashers in commercial kitchens, some health codes have modified the requirements for a three-compartment sink.

Commercial kitchen sinks used for food preparation are required to connect to the drainage system through an indirect waste. This prevents the possibility of contaminating food in the event of a drainline backup resulting from a stoppage in the line.

Commercial kitchen sinks that could discharge grease-laden waste must connect to either a grease interceptor or a grease trap (see Figure 1-14). Plumbing codes used to permit the grease trap to serve as the trap for the sink if it was located within 60 inches of the sink. Most plumbing codes have since modified this requirement by mandating a trap for each kitchen sink. The grease trap no longer is permitted to serve as a trap. A separate trap provides better protection against the escape of sewer gas. An alternative to this is to spill the sink into an indirect waste drain that flows to a grease trap.

SERVICE SINKS

A service sink is a general-purpose sink intended to be used for facilitating the cleaning or decorating of a building. The sink is commonly used to fill mop buckets and dispose of their waste. It also is used for cleaning paint brushes, rollers, and paper-hanging equipment.

There is no standard size, shape, or style of a service sink. They are available both wall mounted and floor mounted. Mop basins, installed on the floor, qualify as service sinks in the plumbing codes.

A service sink typically is located in a janitor's storage closet or a separate room for use by custodial employees. The plumbing codes do not specify the location or a standard height for installing a service sink. Furthermore, the flow rate from the service sink faucet has no limitations.

Service sinks are selected based on the anticipated use of the fixture and the type of building in which it is installed. The plumbing codes require either a 1½-inch or 2-inch trap for the service sink.

SINKS

A general classification for fixtures that are neither kitchen sinks nor service sinks is simply "sinks." This category contains those fixtures typically not required but installed for the convenience of the building users. Some installations include doctors' offices, hospitals, laboratories, photo-processing facilities, quick marts, and office buildings.

Sinks come in a variety of sizes and shapes. There are no height or spacing requirements, and the flow rate from the faucet is not regulated. Most plumbing codes require a 1½-inch drain connection.

LAUNDRY TRAYS

A laundry tray, or laundry sink, is located in the laundry room and used in conjunction with washing clothes. The sink has either one or two compartments. The depth of the bowl is typically 14 inches. There are no standard dimensions for the size of laundry trays; however, most single-compartment laundry trays measure 22 inches by 24 inches, and most double-compartment laundry trays measure 22 inches by 45 inches.

Plumbing codes permit a domestic clothes washer to discharge into a laundry tray. The minimum size for a trap and outlet for a laundry tray is 1½ inch.

At one time, laundry trays were made predominantly of soapstone. Today, the majority of laundry trays are plastic. However, stainless steel, enameled cast iron, and porcelain enameled steel laundry trays also are available.

FAUCETS

Every sink and lavatory needs a faucet to direct and control the flow of water into the fixture. A faucet performs the simple operations of opening, closing, and mixing hot and cold water. While the process is relatively simple, fixture manufacturers have developed extensive lines of faucets.

Faucet Categories

Faucets are categorized by application. The types of faucets include lavatory faucets, residential kitchen sink faucets, laundry faucets, sink faucets, and commercial faucets. The classification "commercial faucets" includes commercial kitchen faucets and commercial sink faucets. It does not include lavatory faucets. All lavatories are classified the same, whether they are installed in residential or commercial buildings. It should be noted, however, that some lavatory faucet styles are used strictly in commercial applications. These include self-metering lavatory faucets that discharge a specified quantity of water and electronic lavatories that operate on sensors.

Flow Rates

The flow rates are regulated for lavatories and noncommercial kitchen sinks. Table 1-2 identifies the flow rate limitations of faucets.

Table 1-2 Faucet Flow Rate Restrictions

Type of Faucet	Maximum Flow Rate
Kitchen faucet	2.2 gpm @ 60 psi
Lavatory faucet	2.2 gpm @ 60 psi
Lavatory faucet (public use)	0.5 gpm @ 60 psi
Lavatory faucet (public use, metering)	0.25 gal per cycle

Backflow Protection

In addition to controlling the flow of water, a faucet must protect the potable water supply against backflow. This is often a forgotten requirement, since most faucets rely on an air gap to provide protection against backflow. When an air gap is provided between the outlet of the faucet and the flood-level rim of the fixture (by manufacturer design), no additional protection is necessary.

Backflow protection becomes a concern whenever a faucet has a hose thread outlet, a flexible hose connection, or a pull-out spray connection. For these styles of faucet, additional backflow protection is necessary. The hose or hose connection eliminates the air gap by submerging the spout or outlet in a nonpotable water source.

The most common form of backflow protection for faucets not having an air gap is the use of a vacuum breaker. Many manufacturers include an atmospheric vacuum breaker in the design of faucets that require additional backflow protection. The standard atmospheric vacuum breaker must conform to ASSE 1001: *Performance Requirements for Atmospheric-type Vacuum Breakers*.

Faucets with pull-out sprays or gooseneck spouts can be protected by a vacuum breaker or a backflow system that conforms to ANSI/ASME A112.18.3: *Performance Requirements for Backflow Protection Devices and Systems in Plumbing Fixture Fittings*. This standard specifies testing requirements for a faucet to be certified as protecting the water supply against backflow. Many of the new pull-out spray kitchen faucets are listed in ANSI/ASME A112.18.3. These faucets have a spout attached to a flexible hose whereby the spout can detach from the faucet body and be used similarly to a side spray.

Side-spray kitchen faucets must have a diverter that is listed in ASSE 1025: *Performance Require-*

ments for Diverters for Plumbing Faucets with Hose Spray, Antisiphon Type, Residential Applications. The diverter ensures that the faucet switches to an air gap whenever the pressure in the supply line decreases.

The most important installation requirement is the proper location of the backflow preventer (or the maintenance of the air gap). When atmospheric vacuum breakers are installed, they must be located a minimum distance above the flood-level rim of the fixture, as specified by the manufacturer.

DRINKING FOUNTAINS

A drinking fountain is designed to provide drinking water to users. The two classifications of drinking fountains are water coolers and drinking fountains. A water cooler has a refrigerated component that chills the water. A drinking fountain is a nonrefrigerated water dispenser.

Drinking fountains and water coolers come in many styles. The height of a drinking fountain is not regulated, except for accessible drinking fountains conforming to ANSI/ICC A117.1. For grade school installations, drinking fountains typically are installed 30 inches above the finished floor to the rim of the fountain. In other locations, the drinking fountain is typically 36 to 44 inches above the finished floor. (See Figure 1-15.)

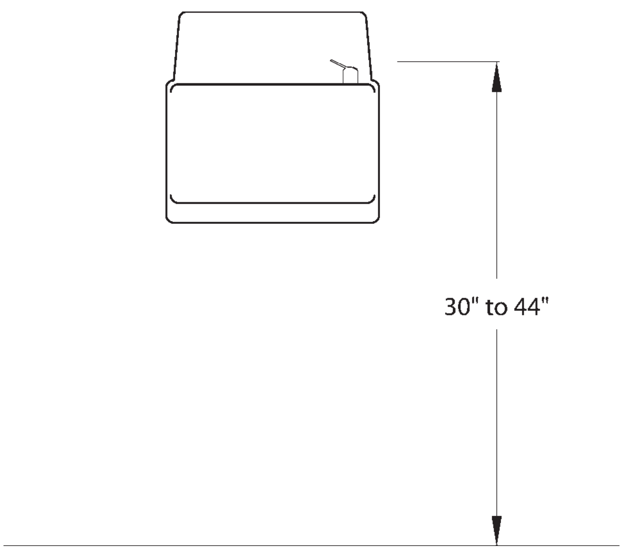


Figure 1-15 Drinking fountain height can vary depending on the application.

Space must be provided in front of the drinking fountain to allow proper access to the fixture. Plumbing codes prohibit drinking fountains from being installed in toilets or bathrooms.

The water supply to a drinking fountain is ⅜ inch or ½ inch in diameter. The drainage connection is 1¼ inches.

Many plumbing codes permit bottled water or the service of water in a restaurant to be substituted for the installation of a drinking fountain.

SHOWERS

A shower is designed to allow full-body cleansing. The size and configuration of a shower must permit an individual to bend at the waist to clean lower-body extremities. Plumbing codes require a minimum size shower enclosure of 30 inches by 30 inches. The codes further stipulate that a shower must have a 30-inch-diameter circle within the shower to allow free movement by the bather.

The water flow rate for showers is regulated by the Energy Policy Act of 1992. The maximum permitted flow rate from a shower valve is 2.5 gpm at 80 psi.

Three different types of shower are available: prefabricated shower enclosure, prefabricated shower base, and built-in-place shower. Prefabricated shower enclosures are available from plumbing fixture manufacturers in a variety of sizes and shapes. Prefabricated shower bases are the floors of the showers designed so that the walls can be either prefabricated assemblies or built-in-place ceramic walls. Built-in-place showers are typically ceramic installations for both the floor and walls.

Prefabricated shower enclosures and prefabricated shower bases have a drainage outlet designed for a connection to a 2-inch drain. Certain plumbing codes have lowered the shower drain size to 1½ inches. The connection to a 1½-inch drain also can be made with prefabricated showers.

A built-in-place shower allows the installation of a shower of any shape and size. The important installation requirement for a built-in-place shower is the shower pan. (See Figure 1-16.) The pan is placed on the floor prior to the installation of the ceramic base. The pan must turn up at the sides of the shower a minimum of 2 inches above the finished threshold of the shower (except the threshold entrance). The materials commonly used to make a shower pan include sheet lead, sheet copper, PVC sheet, and chlorinated polyethylene sheet. The sheet goods commonly are referred to as a waterproof membrane.

At the drainage connection to the shower pan, weep holes are required to be installed at the base of the shower pan. The weep holes and shower pan are intended to serve as a backup drain in the event that the ceramic floor leaks or cracks.

SHOWER VALVES

Shower valves must be thermostatic mixing, pressure balancing, or a combination of thermostatic mixing and pressure balancing and conform to ASSE 1016: *Performance Requirements for Automatic Compensating Valves for Individual Showers and Tub/Shower*

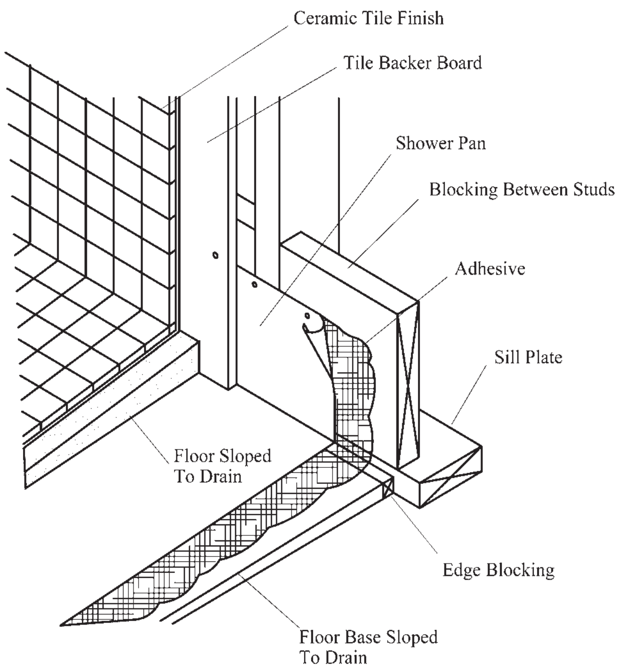


Figure 1-16 Built-in-place showers require a pan below the floor. The drain must have weep holes at the shower pan level.

Combinations. Shower valves control the flow and temperature of the water, as well as any variation in the temperature of the water. These valves provide protection against scalding as well as sudden changes in water temperature, which can cause slips and falls.

A pressure-balancing valve maintains a constant temperature of the shower water by constantly adjusting the pressure of the hot and cold water supply. If the pressure on the cold water supply changes, the hot water supply balances to the equivalent pressure setting. When tested, a pressure-balancing valve cannot have a fluctuation in temperature that exceeds 3°F. If the cold water shuts off completely, the hot water shuts off as well.

Thermostatic mixing valves adjust the temperature of the water by maintaining a constant temperature once the water temperature is set. This is accomplished by thermally sensing controls that modify the quantity of hot and cold water to keep the set temperature.

The difference between a thermostatic mixing valve and a pressure-balancing valve is that a thermostatic mixing valve adjusts the temperature when the temperature of either the hot or cold water fluctuates. With a pressure-balancing valve, when the temperature of either the hot or cold water changes, the temperature of the shower water changes accordingly.

The maximum flow rate permitted for each shower is 2.5 gpm at 80 psi. If body sprays are added to the shower, the total water flow rate is still 2.5 gpm at 80 psi.

The shower valve typically is located 48 to 50 inches above the floor. The installation height for a showerhead ranges from 65 to 84 inches above the floor of the shower. The standard height is 78 inches for showers used by adult males.

BATHTUBS

The bathtub was the original fixture used to bathe or cleanse one's body. Eventually, the shower was added to the bathtub to expedite the bathing process. The standard installation is a combination tub/shower. Some installations come with a separate whirlpool bathtub and shower; however, it is still common to have a whirlpool bathtub with an overhead shower as the main bathing fixture.

Bathtubs tend to be installed within residential units only. The standard bathtub size is 5 feet long by 30 inches wide, with a depth of 14 to 16 inches (see Figure 1-17). However, a variety of sizes and shapes of bathtubs and whirlpool bathtubs is available. The drain can be either a left-hand (drain hole on the left side as you face the bathtub) or right-hand outlet. When whirlpool bathtubs are installed, the controls for the whirlpool must be accessible.

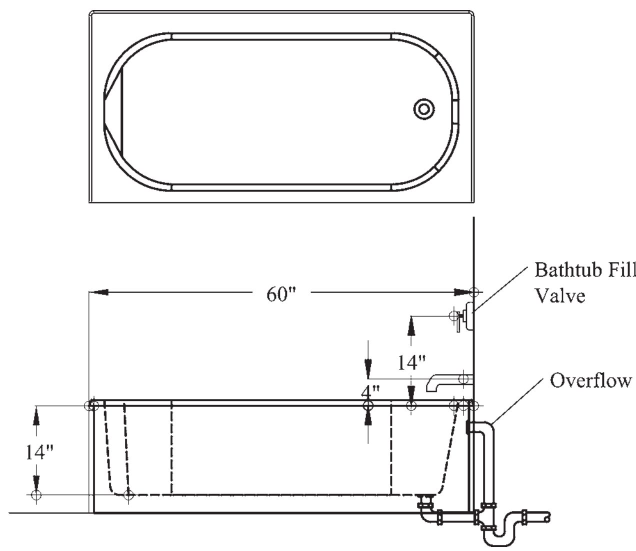


Figure 1-17 A standard bathtub is 5 ft in length.

All bathtubs must have an overflow drain. This is necessary since the bathtub often is filled while the bather is not present. Porcelain enameled steel and enameled cast-iron bathtubs are required to have a slip-resistant base to prevent slips and falls. Plastic bathtubs are not required to have the slip-resistant surface since the plastic is considered to have an inherent slip resistance. However, slip resistance can be specified for plastic bathtub surfaces.

Bathtub Fill Valve

The two types of bathtub fill valve are the tub filler and the combination tub and shower valve. Tub and shower valves must be pressure-balancing, thermostatic mixing, or combination pressure-balancing and thermostatic mixing valves conforming to ASSE 1016. The tub filler is not required to meet these requirements, although pressure-balancing and thermostatic mixing tub filler valves are available.

The spout of the tub filler must be properly installed to maintain a 2-inch air gap between the outlet and the flood-level rim of the bathtub. If this air gap is not maintained, the outlet must be protected from backflow by some other means. Certain decorative tub fillers have an atmospheric vacuum breaker installed to protect the opening that is located below the flood-level rim.

The standard location of the bathtub fill valve is 14 inches above the top rim of the bathtub. The spout typically is located 4 inches above the top rim of the bathtub to the centerline of the pipe connection.

BIDET

The bidet is a fixture designed for cleaning the perineal area. The bidet often is mistaken to be a fixture designed for use by the female population only. However, the fixture is meant for both male and female cleaning. The bidet has a faucet that comes with or without a water spray connection. When a water spray is provided, the outlet must be protected against backflow since the opening is located below the flood-level rim of the bidet. Manufacturers provide a decorative atmospheric vacuum breaker that is located on the deck of the bidet.

Bidets are vitreous china fixtures that are mounted on the floor. The fixture, being similar to a lavatory, has a 1¼-inch drainage connection. Access must be provided around the bidet to allow a bather to straddle the fixture and sit down on the rim. Most bidets have a flushing rim to cleanse the fixture after each use.

The bidet is used only for external cleansing. It is not designed for internal body cleansing. This often is misunderstood since the body spray may be referred to as a "douche" (the French word for shower).

FLOOR DRAINS

A floor drain is a plumbing fixture that is the exception to the definition of a plumbing fixture. There is no supply of cold and/or hot water to a floor drain. Every other plumbing fixture has a water supply. Floor drains typically are provided as an emergency fixture in the event of a leak or overflow of water. They also are used to assist in the cleaning of a toilet or bathroom.

Floor drains are available in a variety of shapes and sizes. The minimum size drainage outlet required by the plumbing code is 2 inches. Most plumbing codes do not require floor drains; it is considered an optional fixture that the plumbing engineer may consider installing. Most public toilet rooms have at least one floor drain. Floor drains also are used on the lower levels of commercial buildings and in storage areas, commercial kitchens, and areas subject to potential leaks. Floor drains also may serve as indirect waste receptors for condensate lines, overflow lines, and similar indirect waste lines.

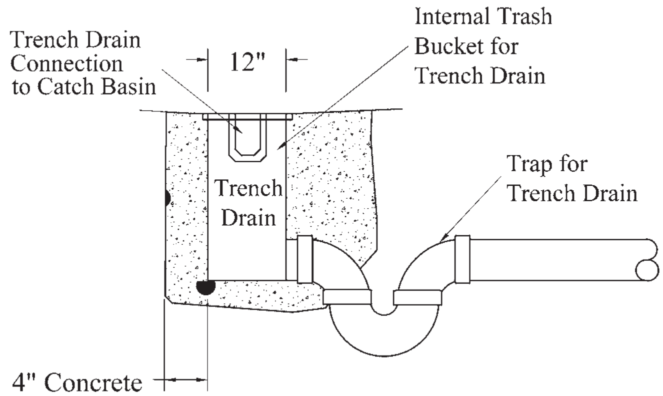


Figure 1-18 A trench drain can be used as a floor drain in a building. A separate trap is required for each section of trench drain.

A trench drain is considered a type of floor drain (see Figure 1-18). Trench drains are continuous drains that can extend for a number of feet in length. Trench drains are popular in indoor parking structures and factory and industrial areas. Each section of a trench drain must have a separate trap.

When floor drains are installed for emergency purposes, the lack of use can result in the evaporation of the trap seal and the escape of sewer gas. Floor drain traps subject to such evaporation are required to be protected with trap seal primer valves or devices.

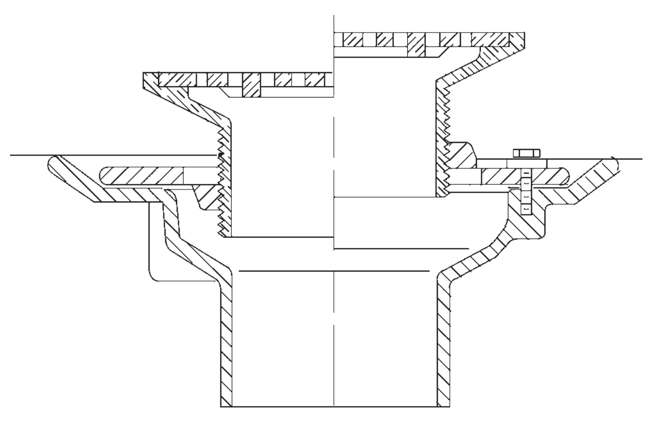


Figure 1-19 Floor Drain

Source: Courtesy of Jay R. Smith Company.

Figure 1-20 Emergency Shower
Source: Courtesy of Haws Corporation.

These valves or devices ensure that the trap seal remains intact and prevents the escape of sewer gas. (See Figure 1-19.)

EMERGENCY FIXTURES

The two types of emergency fixture are the emergency shower and the eyewash station. Combination emergency shower and eyewash stations also are available. These fixtures are designed to wash a victim with large volumes of water in the event of a chemical spill or burn or another hazardous material spill.

Emergency fixtures typically are required by Occupational Safety and Health Administration (OSHA) regulations. In industrial buildings and chemical laboratories, emergency fixtures are sometimes added at the owner's request in addition to the minimum number required by OSHA.

An emergency shower also is called a "drench shower" because of the large volume of water discharged through the emergency shower (see Figure 1-20). A typical low-end flow rate through an emergency shower is 25 gpm, but the flow rate can be as high as 100 gpm. The minimum size water connection is 1 inch. The showerhead typically is installed 7 feet above the finished floor.

Eyewash stations are for washing the eyes. Unlike in emergency showers, in eyewash stations the water flow rate is gentle so that the eyes can remain open during the washing process. The flow rates for an eyewash station range from 1.5 to 6 gpm.

Most plumbing codes do not require a drain for emergency showers and eyewash stations. This is to allow greater flexibility in the location of the fixtures and the spot cleanup of any chemicals that may be washed off the victim.

The standard regulating emergency fixtures is ANSI Z358.1: *Emergency Eyewash and Shower Equipment*. This standard requires the water supply to emergency fixtures to be tepid. The temperature of tepid water is assumed to be in the range of 85°F to 95°F. When controlling the water temperature, the thermostatic control valve must permit full flow of cold water in the event of a failure of the hot water supply. This can be accomplished with the use of a fail-safe thermostatic mixing valve or a bypass valve for the thermostatic mixing valve. Since showers and eyewash stations are for extreme emergencies, a supply of water to the fixtures always must be available.

MINIMUM FIXTURE REQUIREMENTS FOR BUILDINGS

The minimum number of required plumbing fixtures for buildings is specified in the plumbing codes. See Table 1-3, which reprints Table 403.1 of the International Plumbing Code, and Table 1-4, which reprints Table 4-1 of the Uniform Plumbing Code.

Both the International Plumbing Code and the Uniform Plumbing Code base the minimum number of plumbing fixtures on the occupant load of the building. It should be recognized that the occupant load and occupancy of the building are sometimes significantly different. For example, in an office building, the occupancy is typically 25 percent of the occupant load. The fixture tables have taken this into account in determining the minimum number of fixtures required. Most model plumbing codes do not provide occupancy criteria. The occupant load rules can be found in the building codes.

Single-occupant Toilet Rooms

The International Plumbing Code has added a requirement for a single-occupant toilet room for use by both sexes. This toilet room is also called a "unisex toilet room." The single-occupant toilet room must be designed to meet the accessible fixture requirements of ANSI/ICC A117.1. The purpose of the single-occupant toilet room is to allow a husband to help a wife or vice versa. It also allows a father to oversee a daughter or a mother to oversee a son. These rooms are especially important for those temporarily incapacitated and the severely incapacitated.

The International Plumbing Code requires the single-occupant toilet room in mercantile and assembly buildings when the total number of water closets required (both men and women) is six or more. When installed in airports, the facilities must be located to allow use before an individual passes through the security checkpoint.

Another feature typically added to single-occupant toilet rooms is a diaper-changing station. This allows either the mother or the father to change a baby's diaper in privacy. To allow all possible uses of the single-occupant toilet room, the rooms often are identified as family toilet rooms. This is to clearly indicate that the rooms are not reserved for the physically challenged.

Table 1-3 Minimum Number of Required Plumbing Fixtures

No.	Classification	Occupancy	Description	Water Closets (Urinals See Section 419.2)		Lavatories		Bathtubs/ Showers	Drinking Fountain (See Section 410.1)	Other
				Male	Female	Male	Female			
1	Assembly (see Sections 403.2, 403.4 and 403.4.1)	A-1[d]	Theaters and other buildings for the performing arts and motion pictures	1 per 125	1 per 65	1 per 200		—	1 per 500	1 service sink
		A-2[d]	Nightclubs, bars, taverns, dance halls and buildings for similar purposes	1 per 40	1 per 40	1 per 75		—	1 per 500	1 service sink
			Restaurants, banquet halls and food courts	1 per 75	1 per 75	1 per 200		—	1 per 500	1 service sink
		A-3[d]	Auditoriums without permanent seating, art galleries, exhibition halls, museums, lecture halls, libraries, arcades and gym- nasiums	1 per 125	1 per 65	1 per 200		—	1 per 500	1 service sin
			Passenger terminals and transportation facilities	1 per 500	1 per 500	1 per 750		—	1 per 1,000	1 service sink
			Places of worship and other religious services.	1 per 150	1 per 75	1 per 200		—	1 per 1,000	1 service sink
		A-4	Coliseums, arenas, skating rinks, pools and tennis courts for indoor sporting events and activities	1 per 75 for the first 1,500 and 1 per 120 for the remainder exceeding 1,500	1 per first for the first r 60 and 1 per 60 for the remainder exceeding 1,500	1 per 200	1 per 150	—	1 per 1,000	1 service sink
		A-5	Stadiums, amusement parks, bleachers and grandstands for outdoor sporting events and activities	1 per 75 for the first 1,500 and 1 per 120 for the remainder exceeding 1,500	1 per 40 for the first 1,500 and 1 per 60 for the remainder exceeding 1,500	1 per 200	1 per 150	—	1 per 1,000	1 service sink
2	Business (see Sections 403.2, 403.4 and 403.4.1)	B	Buildings for the transaction of business, professional services, other services involving merchandise, office buildings, banks, light industrial and similar uses	1 per 25 for the first 50 and 1 per 50 for the remainder exceeding 50		1 per 40 for the first 80 and 1 per 80 for the remainder exceeding 80		—	1 per 100	1 service sink

No.	Classification	Occupancy	Description	Water Closets (Urinals See Section 419.2)		Lavatories		Bathtubs/ Showers	Drinking Fountain (See Section 410.1)	Other
				Male	Female	Male	Female			
3	**Educational**	**E**	Educational facilities	1 per 50		1 per 50		—	1 per 100	1 service sink
4	**Factory and industrial**	**F-1 and F-2**	Structures in which occupants are engaged in work fabricating, assembly or processing of products or materials	1 per 100		1 per 100		(see Section 411)	1 per 400	1 service sink
5	**Institutional**	**I-1**	Residential care	1 per 10		1 per 10		1 per 8	1 per 100	1 service sink
		I-2	Hospitals ambulatory nursing home patientsb	1 per roomc		1 per roomc		1 per 15	1 per 100	1 service sink per floor
			Employees, other than residential care[b]	1 per 25		1 per 35		—	1 per 100	—
			Visitors, other than residential care	1 per 75		1 per 100		—	1 per 500	—
		I-3	Prisonsb	1 per cell		1 per cell		1 per 15	1 per 100	1 service sink
		I-3	Reformitories detention centers, and correctional centersb	1 per 15		1 per 15		1 per 15	1 per 100	1 service sink
		I-4	Adult day care and child care	1 per 15		1 per 15		—	1 per 100	1 service sink
6	**Mercantile (see Sections 403.2, 403.4, 403.4.1 and 403.4.2)**	**M**	Retail stores, service stations, shops, salesrooms, markets and shopping centers	1 per 500		1 per 750		—	1 per 1,000	1 service sink
7	**Residential**	**R-1**	Hotels, motels, boarding houses (transient)	1 per sleeping unit		1 per sleeping unit		1 per sleeping unit	—	1 service sink
		R-2	Dormitories, fraternities, sororities and boarding houses (not transient)	1 per 10		1 per 10		1 per 8	1 per 100	1 service sink
		R-2	Apartment house	1 per dwelling unit		1 per dwelling unit		1 per dwelling unit	—	1 kitchen sink per dwelling unit; 1 automatic clothes washer connection per 20 dwelling units
		R-3	One- and two-family dwellings	1 per dwelling unit		1 per dwelling unit		1 per dwelling unit	—	1 kitchen sink per dwelling unit; 1 automatic clothes washer connection per dwelling unit
		R-4	Residential care/assisted living facilities	1 per 10		1 per 10		1 per 8	1 per 100	1 service sink
8	**Storage (see Sections 403.2, 403.4 and 403.4.1)**	**S-2**	Structures for the storage of goods, warehouses, storehouse and freight depots. Low and Moderate Hazard	1 per 100		1 per 100		Section 411	1 per 1,000	1 sink

a. The fixtures shown are based on one fixture being the minimum required for the number of persons indicated or any fraction of the number of persons indicated. The number of occupants shall be determined by the International Building Code.

b. Toilet facilities for employees shall be separate from facilities for inmates or patients.

c. A single-occupant toilet room with one water closet and one lavatory serving not more than two adjacent patient sleeping units shall be permitted where such room is provided with direct access from each patient room and with provisions for privacy.

d. The occupant load for seasonal outdoor seating and entertainment areas shall be included when determining the minimum number of facilities required.

Table 1-4 Minimum Plumbing Facilities

Each building shall be provided with sanitary facilities, including provisions for persons with disabilities as prescribed by the Department Having Jurisdiction. For requirements for persons with disabilities, ICC/ANSI A117.1, Accessible and Usable Buildings and Facilities, may be used.

The total occupant load shall be determined by minimum exiting requirements. The minimum number of fixtures shall be calculated at fifty (50) percent male and fifty (50) percent female based on the total occupant load.

The occupant load and use of the building or space under consideration shall first be established using the Occupant Load Factor Table A. Once the occupant load and uses are determined, the requirements of Section 412.0 and Table 4-1 shall be applied to determine the minimum number of plumbing fixtures required.

This table applies to new buildings, additions to a bui ding, changes of occupancy or type in an existing building resulting in increased occupant load (example: change an assembly room from fixed seating to open seating). Exception: New cafeterias for employee use are the only use exempted from this requirement.

Type of Building or Occupancy[2]	Water Closets[14] (Fixtures per Person)	Urinals[5, 10] (Fixtures per Person)	Lavatories (Fixtures per Person)	Bathtubs or Showers (Fixtures per Person)	Drinking Fountains[3, 13, 18] (Fixtures per Person)
Assembly places – theatres, auditoriums, convention halls, etc. – for permanent employee use	Male Female 1: 1-15 1: 1-15 2: 16-35 3: 16-35 3: 36-55 4: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 0: 1-9 1: 10-50 Add one fixture for each additional 50 males.	Male Female 1 per 40 1 per 40		
Assembly places – theatres, auditoriums, convention Halls, etc. – for public use	Male Female 1: 1-100 3: 1-50 2: 101-200 4: 51-100 3: 201-400 8: 101-200 11: 201-400 Over 400, add one fixture lor each additional 500 males and 1 for each additional 125 females.	Male 1: 1-100 2: 101-200 3: 201-400 4: 401-600 Over 600, add 1 fixture for each additional 300 males.	Male Female 1: 1-200 1: 1-200 2: 201-400 2: 201-400 3: 401-750 3: 401-750 Over 750, add one fixture for each additional 500 persons.		1: 1-150 2: 151-400 3: 401-750 Over 750, add one fixture for each additional 500 persons.
Dormitories[9] – School or labor[17]	Male Female 1 per 10 1 per 8 Add 1 fixture for each additional 25 males (over 10) and 1 for each additional 20 females (over 8).	Male 1 per 25 Over 150, add 1 fixture for each additional 50 males.	Male Female 1 per 12 1 per 12 Over 12, add one fixture fo each additional 20 males and 1 for each 15 additional females.	1 per 8 For females, add 1 bathtub per 30. Over 150, add 1 bathtub per 20.	1 per 150[12]
Dormitories – for staff use[17]	Male Female 1: 1-15 1: 1-15 2: 16-35 3: 16-35 3: 36-55 4: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 1 per 50	Male Female 1 per 40 1 per 40	1 per 8	
Dwellings[4] Single dwelling	1 per dwelling		1 per dwelling	1 per dwelling	
Multiple dwelling or apartment house[17]	1 per dwelling or apartment unit		1 per dwelling or apartment unit	1 per dwelling or apartment unit	
Hospital waiting rooms	1 per room		1 per room		1 per 150[12]
Hospitals – for employee use	Male Female 1: 1-15 1: 1-15 2: 16-35 3: 16-35 3: 36-55 4: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 0: 1-9 1: 10-50 Add one fixture for each additional 50 males.	Male Female 1 per 40 1 per 40		
Hospitals Individual room Ward room	1 per room 1 per 8 patients		1 per room 1 per 10 patients	1 per room 1 per 20 patients	1 per 150[12]
Industrial[6] warehouses, workshops, foundries, and similar establishments – for employee use	Male Female 1: 1-10 1: 1-10 2: 11-25 2: 11-25 3: 26-50 3: 26-50 4: 51-75 4: 51-75 5: 76-100 5: 76-100 Over 100, add 1 fixture for each additional 30 persons.		Up to 100, 1 per 10 persons Over 100, 1 per 15 persons	1 shower for each 15 persons exposed to excessive heat or to skin contain- ination with poison- sus, infectious, or irritating material	1 per 150[12]
Institutional – other than hospitals or penal institutions (on each occupied floor)	Male Female 1 per 25 1 per 20	Male 0: 1-9 1: 10-50 Add one fixture far each additional 50 males.	Male Female 1 per 10 1 per 10	1 per 8	1 per 150[12]
Institutional – other than hospitals or penal institutions (on each occupied floor) – for employee use	Male Female 1: 1-15 1: 1-15 2: 16-35 3: 16-35 3: 36-55 4: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 0: 1-9 1: 10-50 Add one fixture for each additional 50 males.	Male Female 1 per 40 1 per 40	1 per 8	1 per 150[12]
Office or public buildings	Male Female 1: 1-100 3: 1-50 2: 101˙200 4: 51-100 3: 201-400 8: 101-200 11: 201-400 Over 400, add one fixture for each additional 500 males and 1 for each additional 150 females.	Male 1: 1-100 2: 101-200 3: 201-400 4: 401-600 Over 600, add 1 fixture for each additional 300 males.	Male Female 1: 1-200 1: 1-200 2: 201-400 2: 201-400 3: 401-750 3: 401-750 Over 750, add one fixture for each additional 500 persons.		1 per 150[12]
Office or public buildings – for employee use	Male Female 1: 1-15 1: 1-15 2: 16-35 3: 16-35 3: 36-55 4: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 0: 1-9 1: 10-50 Add one fixture for each additional 50 males.	Male Female 1 per 40 1 per 40		

Type of Building or Occupancy[2]	Water Closets[14] (Fixtures per Person)	Urinals[5, 10] (Fixtures per Person)	Lavatories (Fixtures per Person)	Bathtubs or Showers (Fixtures per Person)	Drinking Fountains[3, 13, 18] (Fixtures per Person)
Penal institutions – for employee use	Male Female 1: 1-15 1: 1-15 2: 16-35 3: 16-35 3: 36-55 4: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 0: 1-9 1: 10-50 Add one fixture for each additional 50 males.	Male Female 1 per 40 1 per 40		1 per 150[12]
Penal institutions – for prison use					
Cell	1 per cell	Male	1 per cell		1 per cell block floor
Exercise room	1 per exercise room	1 per exercise room	1 per exercise room		1 per exercise room
Public or professional offices[15]	Same as Office or Public Buildings for employee use[15]	Same as Office or Public Buildings for employee use[15]	Same as Office or Public Buildings for employee use[15]		Same as Office or Public Buildings for employee use[15]
Restaurants, pubs, and lounges[11, 15, 16]	Male Female 1: 1-50 1: 1-50 2: 51-150 2: 51-150 3: 151-300 4: 151-300 Over 300, add 1 fixture for each additional 200 persons.	Male 1: 1-150 Over 150, add 1 fixture for each additional 150 males.	Male Female 1: 1-150 1: 1-150 2: 151-200 2: 151-200 3: 201-400 3: 201-400 Over 400, add 1 fixture for each additional 400 persons.		
Retail or Wholesale Stores	Male Female 1: 1-100 1: 1-25 2: 101-200 2: 26-100 3: 201-400 4: 101-200 6: 201-300 8: 301-400 Over 400, add one fixture for each additional 500 males and one for each 150 females	Male 0: 0-25 1: 26-100 2: 101-200 3: 201-400 4: 401-600 Over 600, add one fixture for each additional 300 males	One for each two water closets		0: 1-30[17] 1: 31-150 One additional drinking fountain for each 150 persons thereafter
Schools – for staff use All schools	Male Female 1: 1-15 1: 1-15 2: 16-35 2: 16-35 3: 36-55 3: 36-55 Over 55, add 1 fixture for each additional 40 persons.	Male 1 per 50	Male Female 1 per 40 1 per 40		
Schools – for student use Nursery	Male Female 1: 1-20 1: 1-20 2: 21-50 2: 21-50 Over 50, add 1 fixture for each additional 50 persons.		Male Female 1: 1-25 1: 1-25 2: 26-50 2: 26-50 Over 50, add 1 fixture for each additional 50 persons.		1 per 150
Elementary	Male Female 1 per 30 1 per 25	Male 1 per 75	Male Female 1 per 35 1 per 35		1 per 150
Secondary	Male Female 1 per 40 1 per 30	Male 1 per 35	Male Female 1 per 40 1 per 40		1 per 150
Others (colleges, universities, adult centers, etc.)	Male Female 1 per 40 1 per 30	Male 1 per 35	Male Female 1 per 40 1 per 40		1 per 150
Worship places educational and activities Unit	Male Female 1 per 150 1 per 75	Male 1 per 150	1 per 2 water closets		1 per 150
Worship places principal assembly place	Male Female 1 per 150 1 per 75	Male 1 per 150	1 per 2 water closets		1 per 150

Source: 2006 Uniform Plumbing Code, International Association of Plumbing and Mechanical Officials

1. The figures shown are based upon one (1) fixture being the minimum required for the number of persons indicated or any fraction thereof.
2. Building categories not shown on this table shall be considered separately by the Authority Having Jurisdiction.
3. Drinking fountains shall not be installed in toilet rooms.
4. Laundry trays. One (1) laundry tray or one (1) automatic washer standpipe for each dwelling unit or one (1) laundry tray or one (1) automatic washer standpipe, or combination thereof, for each twelve (12) apartments. Kitchen sinks, one (1) for each dwelling or apartment unit.
5. For each urinal added in excess of the minimum required, one water closet may be deducted. The number of water closets shall not be reduced to less than two-thirds (2/3) of the minimum requirement.
6. As required by ANSI Z4.1, Sanitation in Places of Employment.
7. Where there is exposure to skin contamination with poisonous, infectious, or irritating materials, provide one (1) lavatory for each five (5) persons.
8. Twenty-four (24) lineal inches (610 mm) of wash sink or eighteen (16) inches (457 mm) of a circular basin, when provided with water outlets for such space, shall be considered equivalent to one (1) lavatory.
9. Laundry trays, one (1) for each fifty (50) persons. Service sinks, one (1) for each hundred (100) persons.
10. General. In applying this schedule of facilities, consideration shall be given to the accessibility of the fixtures. Conformity purely on a numerical basis may not result in an installation suited to the needs of the individual establishment. For example, schools should be provided with toilet facilities on each floor having classrooms.
    a. Surrounding materials, wall, and floor space to a point two (2) feet (610 mm) in front of urinal lip and four (4) feet (1219 mm) above the floor, and at least two (2) feet (610 mm) to each side of the urinal shall be lined with nonabsorbent materials.
    b. Trough urinals shall be prohibited.
11. A restaurant is defined as a business that sells food to be consumed on the premises.
    a. The number of occupants for a drive-in restaurant shall be considered as equal to the number of parking stalls.
    b. Employee toilet facilities shall not be included in the above restaurant requirements. Hand-washing facilities shall be available in the kitchen for employees.
12. Where food is consumed indoors, water stations may be substituted for drinking fountains. Offices, or public buildings for use by more than six (6) persons shall have one (1) drinking fountain for the first one hundred fifty (150) persons and one (1) additional fountain for each three hundred (300) persons thereafter.
13. There shall be a minimum of one (1) drinking fountain per occupied floor in schools, theatres, auditoriums, dormitories, offices, or public buildings.
14. The total number of water closets for females shall be at least equal to the total number of water closets and urinals required for males. This requirement shall not apply to Retail or Wholesale Stores.
15. For smaller-type Public and Professional Offices such as banks, dental offices, law offices, real estate offices, architectural offices, engineering offices, and similar uses. A public area in these offices shall use the requirements for Retail or Wholesale Stores.
16. A unisex facility (one water closet and one lavatory) may be used when the customer occupant load for the dining area, including outdoor seating area, is 10 or less and the total number of employees for the space is 4 or less.
17. Recreation or community room in multiple dwellings or apartment buildings, regardless or their occupant load, shall be permitted to have separate single-accommodation facilities in common-use areas within tracts or multi-family residential occupancies where the use of these areas is limited exclusively to owners, residents, and their guests. Examples are community recreation or multi-purpose areas in apartments, condos, townhouses, or tracts.
18. A drinking fountain shall not be required in occupancies of 30 or less. When a drinking fountain is not required, then footnotes 3,12, and 13 are not applicable.

2 Piping Systems

The selection of piping materials depends on the pressure, velocity, temperature, and corrosiveness of the medium conveyed within, initial cost, installation costs, operating costs, and good engineering practice. This chapter provides information and guidance regarding common types of pipe materials. The information is offered for general applications of the various pipe materials. It should be noted that plumbing codes and regulations differ from one state to another and should be referred to prior to the beginning of any design.

INSTALLATION

Pipes should be neatly arranged—straight, parallel, or at right angles to walls—and cut accurately to established measurements. Pipes should be worked into place without springing or forcing. Sufficient headroom should be provided to enable the clearing of lighting fixtures, ductwork, sprinklers, aisles, passageways, windows, doors, and other openings. Pipes should not interfere with access to maintain equipment.

Pipes should be clean (free of cuttings and foreign matter inside), and exposed ends of piping should be covered during site storage and installation. Split, bent, flattened, or otherwise damaged pipe or tubing should not be used. Sufficient clearance should be provided from walls, ceilings, and floors to permit the welding, soldering, or connecting of joints and valves. A minimum of 6 to 10 inches (152.4 to 254 millimeters) of clearance should be provided. Installation of pipe over electrical equipment, such as switchgear, panel boards, and elevator machine rooms, should be avoided. Piping systems should not interfere with safety or relief valves.

A means of draining the piping systems should be provided. A ½-inch or ¾-inch (12.7-mm or 19.1-mm) hose bib (provided with a threaded end and vacuum breaker) should be placed at the lowest point of the piping system for this purpose. Constant grades should be maintained for proper drainage, and piping systems should be free of pockets due to changes in elevation.

SPECIFICATION

Only new materials should be specified. A typical piping specification should include the following items:

- Type of system
- Type of material
- Applicable standards
- Wall thickness
- Method of joining
- Methods of support
- Type of end connection
- Type of weld or solder
- Bolting
- Gasket materials
- Testing

Piping usually is tested at 1.5 times the working pressure of the system. It should not be buried, concealed, or insulated until it has been inspected, tested and approved. All defective piping is to be replaced and retested.

Note: All domestic water piping and fittings must conform to National Sanitation Foundation (NSF) 61: *Drinking Water System Components*.

CAST IRON SOIL PIPE

Cast iron soil pipe primarily is used for sanitary drain, waste, vent, and storm systems. The extra-heavy class often is used for underground applications. Cast iron soil pipe used in the United States is classified into two major types: hub and spigot and hubless (no hub). Cast iron soil pipe is made of gray cast iron with a compact close grain. Three classifications arc used: XH (extra heavy), SV (service), and hubless.

The reference standards for cast iron soil pipe are:

- American Society for Testing and Materials (ASTM) A74: *Standard Specification for Cast Iron Soil Pipe and Fittings*

- ASTM A888: *Standard Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications*
- Cast Iron Soil Pipe Institute (CISPI) 301: *Standard Specification for Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications*
- CISPI 310: *Specification for Coupling for Use in Connection with Hubless Cast Iron Soil Pipe and Fittings for Sanitary and Storm Drain, Waste, and Vent Piping Applications*
- ASTM A74: *Standard Specification for Cast Iron Soil Pipe and Fittings*
- ASTM C564: *Standard Specification for Rubber Gaskets for Joining Cast Iron Soil Pipe and Fittings*
- ASTM C1540: *Standard Specification for Heavy-duty Shielded Couplings Joining Hubless Cast Iron Soil Pipe and Fittings*

Hub and Spigot Pipe, No-hub Pipe and Fittings

Hub and spigot pipe and fittings have hubs into which the spigot (plain end) of the pipe or fitting is inserted. Hub and spigot pipe and fittings are available in two classes or thicknesses: service (SV) and extra heavy (XH). Sizes include 2-inch to 15-inch (50.8-mm to 381-mm) diameters and 5-foot or 10-foot (1.5-meter

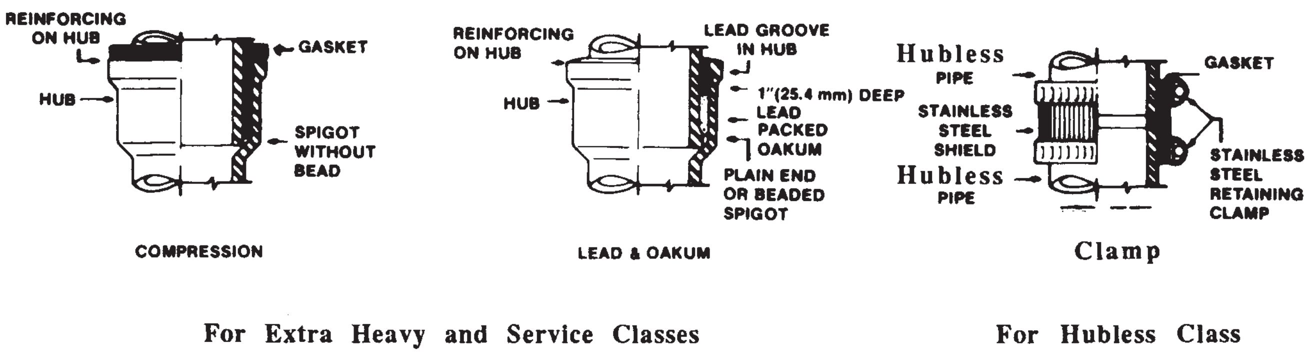


Figure 2-1 Cast Iron Soil Pipe Joints

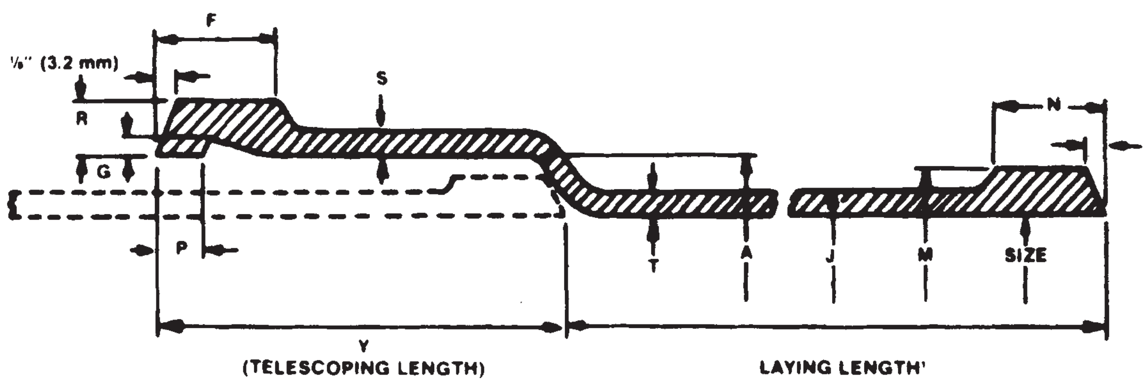


Figure 2-2 Cast Iron Soil Pipe (extra-heavy and service classes)

Notes : 1. Laying length, all sizes:single hub 5 ft; double hub 5 ft less Y, 5-ft lengths; single hub 10 ft; double hub 10 ft less Y, for 10 ft lengths. 2. If a bead is provided on the spigot end, M may be any diameter between J and M. 3. Hub ends and spigot ends can be made with or without draft, and spigot ends can be made with or without spigot bead.

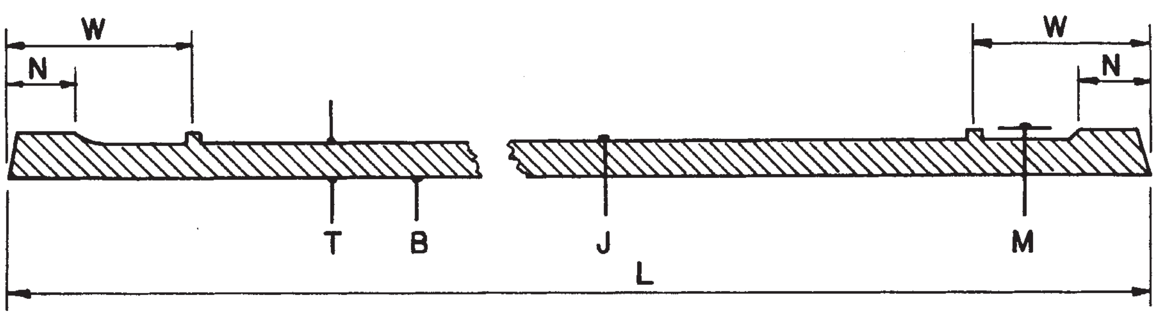


Figure 2-3 Hubless Cast Iron Soil Pipe and Fittings

or 3.1-meter) lengths for extra heavy and service pipe. It is available in single and double hub. Service and extra heavy classes have different outside diameters and are not readily interchangeable. These two different types of pipe and fittings can be connected with adapters available from the manufacturer. (See Tables 2-1 and 2-2.)

The following methods of joining are used:

- Rubber (neoprene) compression gasket
- Molten lead and oakum

Hubless Pipe and Fittings

Hubless cast iron soil pipe and fittings are simply pipe and fittings manufactured without a hub. The method of joining these pipes and fittings utilizes a hubless coupling, which slips over the plain ends of the pipe and fittings and is tightened to seal the joint. Hubless cast iron soil pipe and fittings are made in only one class, or thickness. Hubless cast iron pipe and fittings include 1½-inch to 15-inch (38.1-mm to 254-mm) diameters, and the pipe is manufactured in 5-foot to 10-foot (1.5-m to 3.1-m) lengths. Piping is also available with beaded ends. Many varied configurations of fittings are available ranging in size and shape. (See Figures 2-1, 2-2, and 2-3 and Table 2-3.)

Couplings for use in joining hubless pipe and fittings are also available in these size ranges from various manufacturers.

The following methods of joining are used:

- No-hub shielded couplings
- Heavy-duty shielded couplings

DUCTILE IRON WATER AND SEWER PIPE

Ductile iron pipe primarily is used in water and sewer systems for underground and industrial applications. Ductile iron pipe is a high-strength material and is not as brittle as cast iron pipe. It is available in seven classes (50–56) and in 3-inch to 64-inch (76-mm to 1,626-mm) diameters. The pipe is manufactured with bell ends and has lengths of either 18 feet or 20 feet (5.49 m or 6.1 m). Pressure ratings for the working pressure are available in all sizes to 350 pounds per square inch (psi) (2,414 kilopascals [kPa]). (See Table 2-4.)

Cement-lined piping typically is required for water distribution systems. The cement lining provides a protective barrier between the potable water supply and the ductile iron pipe to prevent impurities and

Table 2-1 Dimensions of Hubs, Spigots, and Barrels for Extra-heavy Cast Iron Soil Pipe and Fittings

Nominal Inside Diameter Size (in.)	Inside Diameter of Hub (in.)	Outside Diameter of Spigot[a] (in.)	Outside Diameter of Barrel (in.)	Telescoping Length (in.)	Thickness of Barrel (in.)	
	A	M	J	Y	T (nominal)	T (minimum)
2	3.06	2.75	2.38	2.50	0.19	0.16
3	4.19	3.88	3.50	2.75	0.25	0.22
4	5.19	4.88	4.50	3.00	0.25	0.22
5	6.19	5.88	5.50	3.00	0.25	0.22
6	7.19	6.88	6.50	3.00	0.25	0.22
8	9.50	9.00	8.62	3.50	0.31	0.25
10	11.62	11.13	10.75	3.50	0.37	0.31
12	13.75	13.13	12.75	4.25	0.37	0.31
15	16.95	16.25	15.88	4.25	0.44	0.38

Nominal Inside Diameter Size (in.)	Thickness of Hub (in.)		Width of Hub Bead[b] (in.)	Width of Spigot Bead[b] (in.)	Distance from Lead Groove to End, Pipe and Fittings (in.)	Depth of Lead Groove (in.)	
	Hub Body S (minimum)	Over Bead R (minimum)	F	N	P	G (minimum)	G (maximum)
2	0.18	0.37	0.75	0.69	0.22	0.10	0.19
3	0.25	0.43	0.81	0.75	0.22	0.10	0.19
4	0.25	0.43	0.88	0.81	0.22	0.10	0.19
5	0.25	0.43	0.88	0.81	0.22	0.10	0.19
6	0.25	0.43	0.88	0.81	0.22	0.10	0.19
8	0.34	0.59	1.19	1.12	0.38	0.15	0.22
10	0.40	0.65	1.19	1.12	0.38	0.15	0.22
12	0.40	0.65	1.44	1.38	0.47	0.15	0.29
15	0.46	0.71	1.44	1.38	0.47	0.15	0.22

Note: Laying length, all sizes: single hub 5 ft; double hub 5 ft less Y, 5-ft lengths; single hub 10 ft; double hub 10 ft less Y, for 10 ft lengths.

[a] If a bead is provided on the spigot end, M may be any diameter between J and M.

[b] Hub ends and spigot ends can be made with or without draft, and spigot ends can be made with or without spigot bead.

Table 2-1(M) Dimensions of Hubs, Spigots, and Barrels for Extra-heavy Cast Iron Soil Pipe and Fittings

Nominal Inside Diameter Size (in.)	Inside Diameter of Hub (mm)	Outside Diameter of Spigot[a] (mm)	Outside Diameter of Barrel (mm)	Telescoping Length (mm)	Thickness of Barrel (mm)	
	A	M	J	Y	T (nominal)	T (minimum)
2	77.72	69.85	60.45	63.50	4.83	4.06
3	106.43	98.55	88.90	69.85	6.35	5.59
4	131.83	123.95	114.30	76.20	6.35	5.59
5	157.23	149.35	139.70	76.20	6.35	5.59
6	182.63	174.75	165.10	76.20	6.35	

Nominal Inside Diameter Size (in.)	Thickness of Hub (mm)		Width of Hub Bead[b] (mm)	Width of Spigot Bead[b] (mm)	Distance from Lead Groove to End, Pipe and Fittings (mm)	Depth of Lead Groove (mm)	
	Hub Body S (minimum)	Over Bead R (minimum)	F	N	P	G (minimum)	G (maximum)
2	4.57	9.40	19.05	17.53	5.59	2.54	4.83
3	6.35	10.92	20.57	19.05	5.59	2.54	4.83
4	6.35	10.92	22.35	20.57	5.59	2.54	4.83
5	6.35	10.92	22.35	20.57	5.59	2.54	4.83
6	6.35	10.92	22.35	20.57	5.59	2.54	4.83
8	8.64	14.99	30.23	28.45	9.65	3.81	5.59
10	10.16	16.51	30.23	28.45	9.65	3.81	5.59
12	10.16	16.51	36.54	35.05	11.94	3.81	5.59
15	11.68	18.03	36.54	35.05	11.94	3.81	5.59

Note: Laying length, all sizes: single hub 1.5 m; double hub 1.5 m less Y, 1.5 m lengths; single hub 3.1 m; double hub 3.1 m less Y, for 3.1 m lengths.

[a] If a bead is provided on the spigot end, M may be any diameter between J and M.

[b] Hub ends and spigot ends can be made with or without draft, and spigot ends can be made with or without spigot bead.

Table 2-2 Dimensions of Hubs, Spigots, and Barrels for Service Cast Iron Soil Pipe and Fittings

Nominal Inside Diameter Size (in.)	Inside Diameter of Hub (in.)	Outside Diameter of Spigot[a] (in.)	Outside Diameter of Barrel (in.)	Telescoping Length (in.)	Thickness of Barrel (in.)	
	A	M	J	Y	T (nominal)	T (minimum)
2	2.94	2.62	2.30	2.50	0.17	0.14
3	3.94	3.62	3.30	2.75	0.17	0.14
4	4.94	4.62	4.30	3.00	0.18	0.15
5	5.94	5.62	5.30	3.00	0.18	0.15
6	6.94	6.62	6.30	3.00	0.18	0.15
8	9.25	8.75	8.38	3.50	0.23	0.17
10	11.38	10.88	10.50	3.50	0.28	0.22
12	13.50	12.88	12.50	4.25	0.28	0.22
15	16.95	16.00	15.88	4.25	0.36	0.30

Nominal Inside Diameter Size (in.)	Thickness of Hub (in.)		Width of Hub Bead[b] (in.)	Width of Spigot Bead[b] (in.)	Distance from Lead Groove to End, Pipe and Fittings (in.)	Depth of Lead Groove (in.)	
	Hub Body S (minimum)	Over Bead R (minimum)	F	N	P	G (minimum)	G (maximum)
2	0.13	0.34	0.75	0.69	0.22	0.10	0.19
3	0.16	0.37	0.81	0.75	0.22	0.10	0.19
4	0.16	0.37	0.88	0.81	0.22	0.10	0.19
5	0.16	0.37	0.88	0.81	0.22	0.10	0.19
6	0.18	0.37	0.88	0.81	0.22	0.10	0.19
8	0.19	0.44	1.19	1.12	0.38	0.15	0.22
10	0.27	0.53	1.19	1.12	0.38	0.15	0.22
12	0.27	0.53	1.44	1.38	0.47	0.15	0.22
15	0.30	0.58	1.44	1.38	0.47	0.15	0.22

Note: Laying length, all sizes: single hub 5 ft; double hub 5 ft less Y, 5-ft lengths; single hub 10 ft; double hub 10 ft less Y, for 10 ft lengths.

[a] If a bead is provided on the spigot end, M may be any diameter between J and M.

[b] Hub ends and spigot ends can be made with or without draft, and spigot ends can be made with or without spigot bead.

Table 2-2(M) Dimensions of Hubs, Spigots, and Barrels for Service Cast Iron Soil Pipe and Fittings

Nominal Inside Diameter Size (in.)	Inside Diameter of Hub (mm)	Outside Diameter of Spigot [a] (mm)	Outside Diameter of Barrel (mm)	Telescoping Length (mm)	Thickness of Barrel (mm)	
	A	M	J	Y	T (nominal)	T (minimum)
2	74.68	66.55	58.42	63.50	4.32	3.56
3	100.08	91.95	83.82	69.85	4.32	3.56
4	125.48	117.35	109.22	76.20	4.57	3.81
5	150.88	142.75	134.62	76.20	4.57	3.81
6	176.28	168.15	160.02	76.20	5.57	

Diameter Size (in.)	Inside of Hub (mm)		Spigot Bead [b] (mm)	Lead Groove to End (mm)	Lead Groove (mm)	
	Hub Body S (minimum)	Over Bead R (minimum)	F	P	G (minimum)	G (maximum)
2	3.30	8.64	19.05	5.59	2.54	4.83
3	4.06	9.40	20.57	5.59	2.54	4.83
4	4.06	9.40	22.35	5.59	2.54	4.83
5	4.06	9.40	22.35	5.59	2.54	4.83
6	4.57	9.40	22.35	5.59	2.54	4.83
8	4.83	11.26	30.23	9.65	3.81	5.59
10	6.86	13.46	30.23	9.65	3.81	5.59
12	6.86	13.46	36.58	11.94	3.81	5.59
15	7.62	14.73	36.58	11.94	3.81	5.59

Note: Laying length, all sizes: single hub 1.5 m; double hub 1.5 m less Y, 1.5 m lengths; single hub 3.1 m; double hub 3.1 m less Y, for 3.1 m lengths.

[a] If a bead is provided on the spigot end, M may be any diameter between J and M.

[b] Hub ends and spigot ends can be made with or without draft, and spigot ends can be made with or without spigot bead.

Table 2-3 Dimensions of Spigots and Barrels for Hubless Pipe and Fittings

Nom. Size	Inside Diam. Barrel		Outside Diam. Barrel		Outside Diam. Spigot		Width Spigot Bead		Thickness of Barrel				Gasket Positioning Lug		Laying Length, L[a, b]	
(in.)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	(in.)	
	B		J		M		N		T-Nom.		T-Min.		W		5 Ft	10 Ft
1½	1.50	38.1	1.90	48.26	1.96	48.78	0.25	6.35	0.16	3.3	0.13	0.33	1.13	28.7	60	120
2	1.96	49.8	2.35	59.69	2.41	61.21	0.25	6.35	0.16	3.3	0.13	0.33	1.13	28.7	60	120
3	2.96	75.2	3.35	85.09	3.41	86.61	0.25	6.35	0.16	3.3	0.13	0.33	1.13	28.7	60	120
4	3.94	100.08	4.38	111.25	4.44	112.78	0.31	7.87	0.19	3.81	0.15	0.38	1.13	28.7	60	120
5	4.94	125.48	5.30	134.62	5.36	136.14	0.31	7.87	0.19	3.81	0.15	0.38	1.50	38.1	60	120
6	5.94	150.88	6.30	160.02	6.36	161.54	0.31	7.87	0.19	3.81	0.15	0.38	1.50	38.1	60	120
8	7.94	201.68	8.38	212.85	8.44	214.38	0.31	7.87	0.23	4.32	0.17	0.43	2.00	50.8	60	120
10	10.00	254	10.56	268.22	10.62	269.75	0.31	7.87	0.28	5.59	0.22	0.56	2.00	50.8	60	120
12	11.94	303.28	12.50	317.5	12.62	320.55	0.31	7.87	0.28	5.59	0.22		2.75	69.85	60	120
15	15.11	383.79	15.83	402.08	16.12	409.55	0.31	7.87	0.36	7.62	0.30		2.75	69.85	60	120

[a] Laying lengths as listed are for pipe only.

[b] Laying lengths may be either 5 ft 0 in. or 10 ft 0 in. (1.5 or 3.1 m) long.

contaminants from leaching into the water supply.

The reference standards for ductile iron pipe are:

- American National Standards Institute (ANSI)/American Water Works Association (AWWA) C104/A21.4: *Cement Mortar Lining for Ductile Iron Pipe and Fittings for Water*
- ANSI/AWWA C105/A21.5: *Polyethylene Encasement for Ductile Iron Pipe Systems*
- ANSI/AWWA C110/A21.10: *Ductile Iron and Gray Iron Fittings for Water*
- ANSI/AWWA C111/A21.11: *Rubber Gasket Joints for Ductile Iron Pressure Pipe and Fittings*
- ANSI/AWWA C115/A21.15: *Flanged Ductile Iron Pipe with Ductile Iron or Gray Iron Threaded Flanges*
- ANSI/AWWA C116/A21.16: *Protective Fusion-bonded Epoxy Coatings for the Interior and Exterior Surfaces of Ductile Iron and Gray Iron Fittings for Water Supply Service*
- ANSI/AWWA C150/A21.50: *Thickness Design of Ductile Iron Pipe*
- ANSI/AWWA C151/A21.51: *Ductile Iron Pipe, Centrifugally Cast, for Water or Other Liquids*
- ANSI/AWWA C153/A21.53: *Ductile Iron Compact Fittings for Water Service*
- ANSI/AWWA C600: *Installation of Ductile Iron Water Mains and Their Appurtenances*
- AWWA C651: *Disinfecting Water Mains*
- ASTM A716: *Standard Specification for Ductile Iron Culvert Pipe*
- ASTM A746: *Standard Specification for Ductile Iron Gravity Sewer Pipe*

The methods of joining are:

- Push-on rubber (neoprene) compression gasket
- Mechanical
- Flanged

Special joints are also available, such as restrained, ball and socket, and grooved and shouldered. (See Figure 2-4.)

Table 2-4 Standard Minimum Pressure Classes of Ductile Iron Single-thickness Cement-lined Pipe

Size (in.)	Pressure Rating (psi)	Nominal Wall Thickness (in.)	Pipe O.D. (in.)	Weight in Pounds			
				Per Foot Plain End	Flange	Fastite Bell	Maximum Length
4	350+	0.32	4.8	13.8	13	10	262
6	350+	0.34	6.9	21.4	17	15	450
8	350+	0.36	9.05	30.1	27	21	635
10	350+	0.38	11.1	39.2	38	27	830
12	350+	0.4	13.2	49.2	59	32	1050
14	350+	0.42	15.3	60.1	70	57	1300
16	350+	0.43	17.4	70.1	90	64	1520
18	350+	0.44	19.5	80.6	88	73	1735
20	350+	0.45	21.6	91.5	112	81	1980
24	350+	0.47	25.8	114.4	155	96	2480
30	250	0.51	32	154.4	245	164	3420
36	250	0.58	38.3	210.3	354	214	4670
42	250	0.65	44.5	274	512	289	6140
48	250	0.72	50.8	346.6	632	354	7745
54	250	0.81	57.56	441.9	716	439	9770
60	250	0.83	61.61	485	1113	819	11390
64	250	0.87	65.67	542	1824	932	13320

CONCRETE PIPE

Concrete pipe is used for sanitary sewers, storm sewers, culverts, detention systems, and low-pressure force mains. Reinforced concrete pipe is the most durable and economical of all piping products. It is recommended for installations where low, moderate, or severe cover and/or live load conditions exist and structural failure might endanger life or property. Reinforced pipe, even after ultimate failure, retains its shape and will not collapse. Concrete pipe is installed by site contractors during site preparation more usually than it is installed by the plumbing trade.

This pipe is available in 4-inch to 36-inch (100-mm to 900-mm) diameters. Nonreinforced concrete pipe is not available in all markets. Reinforced concrete pipe is made by the addition of steel wire or steel bars. It is used primarily for sewage and storm drainage and is available in 12-inch to 144-inch (300-mm to 3,600-mm) diameters (see Table 2-5). Concrete pipe is available as a bell and spigot or gasketed bell design.

The reference standards for concrete pipe are:

- ASTM C14: *Standard Specification for Nonreinforced Concrete Sewer, Storm Drain, and Culvert Pipe*
- ASTM C76: *Standard Specification for Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe*
- ASTM C655: *Standard Specification for Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer Pipe*

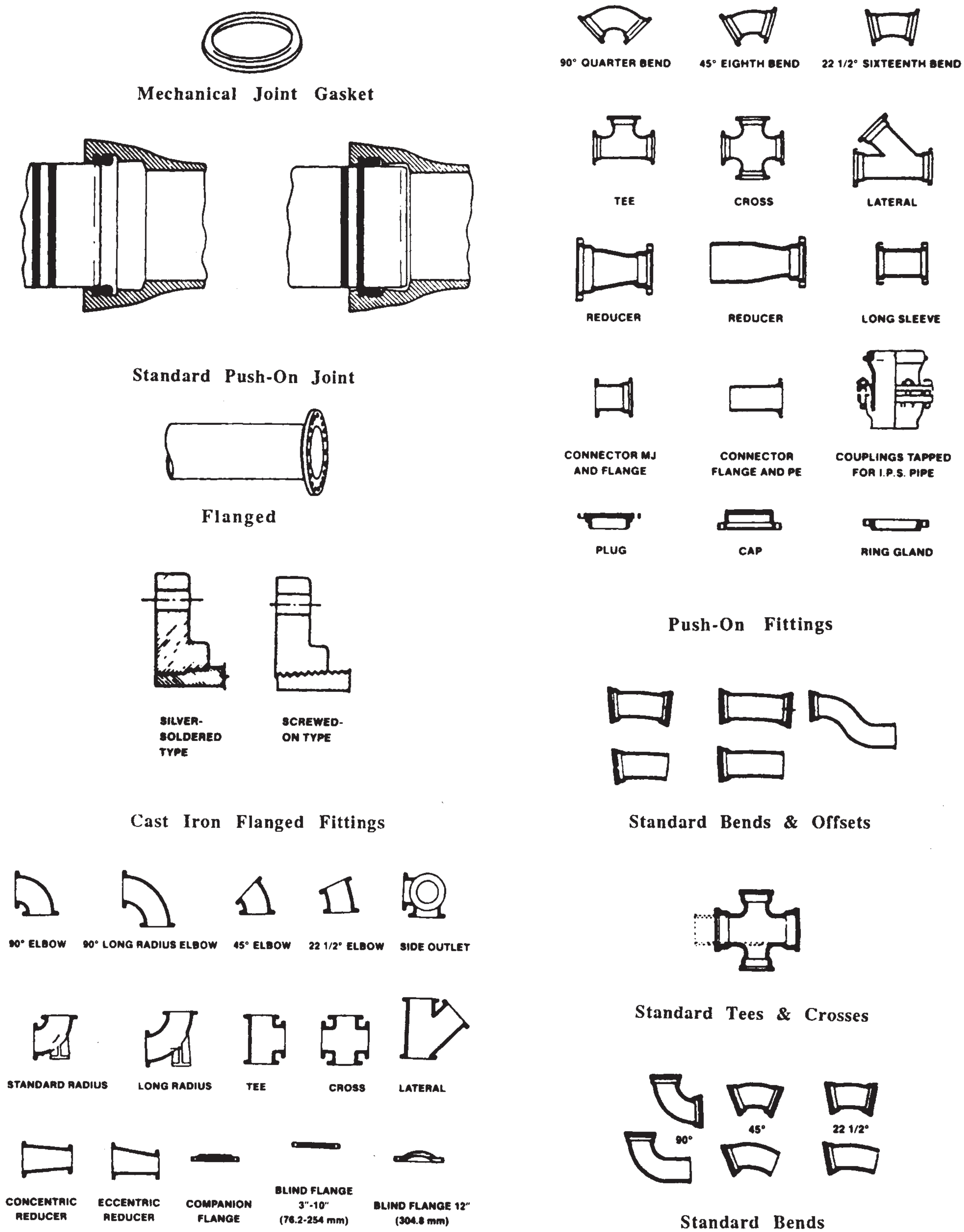


Figure 2-4 Joints and Fittings for Ductile Iron Pipe

Table 2-5 Dimensions and Approximate Weights of Circular Concrete Pipe

Reinforced Concrete Culvert, Storm Drain and Sewer Pipe						
			WALL B		WALL C	
Internal Diameter, in.	Internal Diameter, mm	Waterway Area, square meters	Minimum Wall Thickness, mm	Approximate Weight, Kg/meter	Minimum Wall Thickness, mm	Approximate Weight, Kg/meter
8*	200	0.03	51	90	—	—
10*	250	0.05	51	130	—	—
12	300	0.07	51	140	—	—
15	375	0.11	57	190	—	—
18	450	0.16	64	250	—	—
21	525	0.22	70	320	—	—
24	600	0.29	76	390	95	545
27	675	0.37	83	480	102	625
30	750	0.46	89	570	108	710
33	825	0.55	95	670	114	820
36	900	0.66	102	780	121	975
42	1050	0.89	114	1020	133	1205
48	1200	1.17	127	1290	146	1505
54	1350	1.48	140	1590	159	1800
60	1500	1.82	152	1925	171	2190
66	1650	2.21	165	2295	184	2580
72	1800	2.62	178	2695	197	3000
78	1950	3.08	190	3125	210	3585
84	2100	3.57	203	3585	222	3960
90	2250	4.1	216	4075	235	4495
96	2400	4.67	229	4600	248	4990
102	2550	5.27	241	5180	260	5595
108	2700	5.91	254	5750	273	6190

Table 2-6 Commercially Available Lengths of Copper Plumbing Tube

The first of the three principal classes of copper tubular products is commonly referred to as "commodity tube." It includes types K (heaviest), L (standard), and M (lightest) wall thickness schedules as classified by ASTM B88, *Specification for Seamless Copper Water Tube*; type DWV of ASTM B306, *Specification for Copper Drainage Tube (DWV)*; and medical gas tube of ASTM B819, *Specification for Seamless Copper Tube for Medical Gas Systems.* In each case, the actual outside diameter is 1/8 in. (0.32 cm) larger than the nominal or standard size.

Copper Tube—Types, Standards, Applications, Tempers, Lengths

Tube type: Type K
Color code: Green ASTM B88[a]

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
¼ to 8 in.	20 ft	20 ft	¼ to 1 in.	60 ft	100 ft
10 in.	18 ft	18 ft	1¼ and 1½ in.	60 ft	—
12 in.	12 ft	12 ft	2 in.	40 ft	45 ft
Standard applications[c]: Domestic water service and distribution, fire protection, solar, fuel/fuel oil, HVAC, snow melting					

Tube type: Type L
Color code: Blue ASTM B88

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
¼ to 8 in.	20 ft	20 ft	¼ to 1 in.	60 ft	100 ft
12 in.	18 ft	18 ft	1¼ and 1½ in.	60 ft	—
—	—	—	2 in.	40 ft	45 ft
Standard applications[c]: Domestic water service and distribution, fire protection, solar, fuel/fuel oil, HVAC, snow melting, natural gas, liquefied petroleum gas					

Table 2-6 Commercially Available Lengths of Copper Plumbing Tube (continued)

Tube type: Type M
Color code: Red ASTM B88

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
¼ to 12 in.	20 ft	—	—	—	—
Standard applications[c]: Domestic water service and distribution, fire protection, solar, fuel/fuel oil, HVAC, snow melting					

Tube type: DWV
Color code: Yellow ASTM B306

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
¼ to 8 in.	20 ft	—	—	—	—
Standard applications[c]: Drain, waste, and vent, solar, HVAC					

Tube type: ACR
Color code: Blue ASTM B280

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
⅜ to 4⅛ in.	20 ft	[d]	⅛ and 1⅝ in.	50 ft	—
Standard applications[c]: Air-conditioning, refrigeration, natural gas, liquefied petroleum gas					

Tube type: OXY, MED, OXY/MED, OXY/ACR, ACR/MED
Color code: (K) Green, (L) Blue ASTM B819

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
¼ to 8 in.	20 ft	N/A	—	—	—
Standard applications[c]: Medical gas					

Tube type: Type G
Color code: Yellow ASTM B837

Commercially Available Lengths[b]					
Straight Lengths			Coils		
Pipe Diameter	Drawn	Annealed	Pipe Diameter	Drawn	Annealed
⅜ to 1⅛ in.	12 ft	12 ft	⅜ to ⅞ in.	60 ft	100 ft
Standard applications[c]: Natural gas, liquefied petroleum gas					

a Tube made to other ASTM standards is also intended for plumbing applications, although ASTM B88 is by far the most widely used. ASTM B698: *Standard Classifications* lists six plumbing tube standards, including ASTM B88.
b Individual manufacturers may have commercially available lengths in addition to those shown in this table.
c Many other copper and copper alloy tubes and pipes are available for specialized applications. For information on these products, contact the Copper Development Association.
d Available as special order only.

- ASTM C443: *Standard Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets*

The methods of joining are:

- Rubber (elastomeric) gasket
- Cement plaster (becoming obsolete)

COPPER PIPE

Copper pipe is for water supply; drain, waste, and vent (DWV); boiler feed lines; refrigeration; and similar purposes.

The reference standards for copper pipe include the following:

- ASTM B88: *Standard Specification for Seamless Copper Water Tube*
- ASTM B280: *Standard Specification for Seamless Copper Tube for Air-conditioning and Refrigeration Field Service*
- ASTM B306: *Standard Specification for Copper Drainage Tube (DWV)*
- ASTM B819: *Standard Specification for Seamless Copper Tube for Medical Gas Systems*
- ASTM B837: *Standard Specification for Seamless Copper Tube for Natural Gas and Liquified Petroleum (LP) Gas Fuel Distribution Systems*
- American Society of Mechanical Engineers (ASME) B16.22: *Wrought Copper and Copper Alloy Solder Joint Pressure Fittings*
- ASME B16.18: *Cast Copper Alloy Solder Joint Pressure Fittings*
- ASTM B75: *Standard Specification for Seamless Copper Tube*
- ASTM B584: *Standard Specification for Copper Alloy Sand Castings for General Applications*
- ASME B16.29: *Wrought Copper and Wrought Copper Alloy Solder Joint Drainage Fittings (DWV)*
- ASME B16.23: *Cast Copper Alloy Solder Joint Drainage Fittings (DWV)*
- National Fire Protection Association (NFPA) 99: *Standard for Healthcare Facilities*
- NFPA 99C: *Standard on Gas and Vacuum Systems*

Copper Water Tube

Copper water tube is a seamless, almost pure copper material manufactured to the requirements of ASTM B88. It has three basic wall thickness dimensions, designated as Types K, L, and M, with Type K being the thickest, Type L being of intermediate thickness, and Type M being the thinnest. All three types of tube are commonly manufactured from copper alloy C12200, which has a chemical composition of a minimum of 99.9 percent copper (Cu) and silver (Ag) combined and a maximum allowable range of phosphorous (P) of 0.015–0.040 percent.

Seamless copper water tube is manufactured in sizes of ¼-inch to 12-inch (6.35-mm to 304.8-mm) (nominal) diameter. Types K and L are manufactured in drawn temper (hard) of ¼-inch to 12-inch (6.35-mm to 304.8-mm) and annealed temper (soft) coils of ¼-inch to 2-inch (6.35-mm to 50.8-mm) (nominal) diameter, while Type M is manufactured only in drawn (hard) temper of ¼-inch to 12-inch (6.35-mm to 304.8-mm) (nominal) diameter. See Table 2-6 for the commercially available lengths of copper plumbing tube. See Tables 2-7, 2-8, and 2-9 for dimensional and capacity data for Type K, L, and M copper tube respectively.

Seamless copper water tube of drawn temper is required to be identified with a colored stripe that contains the manufacturer's name or trademark, the type of tube, and the nation of origin. This colored strip is green for Type K, blue for Type L, and red for Type M. In addition to the colored stripe, the tube is incised with the type of tube and the manufacturer's name or trademark at intervals not in excess of 1½ feet. Annealed (soft) coils or straight lengths are not required to be identified with a color stripe.

Fittings in copper water tube may be those conforming to ASME B16.22, ASME B16.18, ASME B16.26: *Cast Copper Alloy Fittings for Flared Copper Tubes,* or ASME B16.24, *Cast Copper Alloy Pipe Flanges and Flanged Fittings, Classes 150, 300, 600, 900, 1,500, and 2,500*. Various other fittings of the compression, grooved, and mechanical type also may be used.

Joints in copper water tube typically are soldered, flared, or brazed, although roll-grooved or mechanical joints also are permitted.

Soldered joints should be installed in accordance with the requirements and procedures detailed in ASTM B828: *Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings,* and the flux used should meet the requirements of ASTM B813: *Standard Specification for Liquid and Paste Fluxes for Soldering of Copper and Copper Alloy Tube*.

The mechanical joining of copper tubing can be accomplished with specially manufactured fittings of different types. One type known as press-connect is fastened with a crimping tool with interchangeable jaws of ½ inch to 4 inches (12.7 mm to 101.6 mm). Another known as push-connect is pushed on the tube to make a connection and is held in place by an internal or integral stainless steel gripper ring. A

Table 2-7 Dimensional and Capacity Data—Type K Copper Tube

Diameter (in.)			Wall thickness (in.)	Cross-sectional area (sq. in.)			Weight per foot (lb)		
Nominal (in.)	Actual inside	Actual outside		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
¼	0.305	0.375	0.035	0.110	0.073	0.034	0.145	0.033	0.167
⅜	0.402	0.500	0.049	0.196	0.127	0.069	0.269	0.055	0.324
½	0.527	0.625	0.049	0.307	0.218	0.089	0.344	0.094	0.438
⅝	0.652	0.750	0.049	0.442	0.334	0.108	0.418	0.145	0.563
¾	0.745	0.875	0.065	0.601	0.436	0.165	0.641	0.189	0.830
1	0.995	1.125	0.065	0.993	0.778	0.216	0.839	0.338	1.177
1¼	1.245	1.375	0.065	1.484	1.217	0.267	1.04	0.53	1.57
1½	1.481	1.625	0.072	2.072	1.722	0.350	1.36	1.22	2.58
2	1.959	2.125	0.083	3.546	3.013	0.533	2.06	1.31	3.37
2½	2.435	2.625	0.095	5.409	4.654	0.755	2.93	2.02	4.95
3	2.907	3.125	0.109	7.669	6.634	1.035	4.00	2.88	6.88
3½	3.385	3.625	0.120	10.321	8.999	1.322	5.12	3.91	9.03
4	3.857	4.125	0.134	13.361	11.682	1.679	6.51	5.07	11.58
5	4.805	5.125	0.160	20.626	18.126	2.500	9.67	7.87	17.54
6	5.741	6.125	0.192	29.453	25.874	3.579	13.9	11.2	25.1
8	7.583	8.125	0.271	51.826	45.138	6.888	25.9	19.6	45.5
10	9.449	10.125	0.338	80.463	70.085	10.378	40.3	30.4	70.7
12	11.315	12.125	0.405	115.395	100.480	14.915	57.8	43.6	101.4

Nominal Diam. (in.)	Circumference (in.)		Ft² of Surface per Lineal Foot		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	Ft³	Gal	1 Ft³	1 Gal	1 Lb of Water
¼	1.178	0.977	0.098	0.081	.00052	.00389	1923	257	30.8
⅜	1.570	1.262	0.131	0.105	.00088	.00658	1136	152	18.2
½	1.963	1.655	0.164	0.138	.00151	.01129	662	88.6	10.6
⅝	2.355	2.047	0.196	0.171	.00232	.01735	431	57.6	6.90
¾	2.748	2.339	0.229	0.195	.00303	.02664	330	37.5	5.28
1	3.533	3.124	0.294	0.260	.00540	.04039	185	24.8	2.96
1¼	4.318	3.909	0.360	0.326	.00845	.06321	118	15.8	1.89
1½	5.103	4.650	0.425	0.388	.01958	.14646	51.1	6.83	0.817
2	6.673	6.151	0.556	0.513	.02092	.15648	47.8	6.39	0.765
2½	8.243	7.646	0.688	0.637	.03232	.24175	30.9	4.14	0.495
3	9.813	9.128	0.818	0.761	.04607	.34460	21.7	2.90	0.347
3 ½	11.388	10.634	0.949	0.886	.06249	.46745	15.8	2.14	0.257
4	12.953	12.111	1.080	1.009	.08113	.60682	12.3	1.65	0.197
5	16.093	15.088	1.341	1.257	.12587	.94151	7.94	1.06	0.127
6	19.233	18.027	1.603	1.502	.17968	1.3440	5.56	0.744	0.089
8	25.513	23.811	2.126	1.984	.31345	2.3446	3.19	0.426	0.051
10	31.793	29.670	2.649	2.473	.48670	3.4405	2.05	0.291	0.033
12	38.073	35.529	3.173	2.961	.69778	5.2194	1.43	0.192	0.023

Table 2-7(M) Dimensional and Capacity Data—Type K Copper Tube

Diameter			Wall thickness (mm)	Cross-sectional area (10^3 mm^2)			Weight per foot (kg)		
Nominal (in.)	Actual inside (mm)	Actual outside (mm)		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
¼	7.90	9.53	0.89	0.071	0.049	0.022	0.216	0.049	0.249
⅜	10.21	12.70	1.25	0.127	0.082	0.045	0.401	0.082	0.483
½	13.39	15.88	1.25	0.198	0.141	0.057	0.512	0.140	0.652
⅝	16.56	19.05	1.25	0.285	0.216	0.070	0.623	0.216	0.839
¾	18.92	22.23	1.65	0.388	0.281	0.107	0.955	0.282	1.236
1	25.27	28.58	1.65	0.641	0.501	0.139	1.250	0.504	1.753
1¼	31.62	34.93	1.65	0.957	0.785	0.172	1.549	0.789	2.339
1½	37.62	41.28	1.83	1.337	1.111	0.226	2.026	1.817	3.843
2	49.76	53.98	2.11	2.288	1.944	0.344	3.068	1.951	5.020
2½	61.85	66.68	2.41	3.490	3.003	0.487	4.364	3.009	7.373
3	73.84	79.38	2.77	4.948	4.280	0.668	5.958	4.290	10.248
3½	85.98	92.08	3.05	6.659	5.806	0.853	7.626	5.824	13.450
4	97.97	104.78	3.40	8.620	7.537	1.083	9.697	7.552	17.248
5	122.05	130.18	4.06	13.307	11.694	1.613	14.404	11.722	26.126
6	145.82	155.58	4.88	19.002	16.693	2.309	20.704	16.682	37.387
8	192.61	206.38	6.88	33.436	29.121	4.444	38.578	29.194	67.772
10	240.01	257.18	8.59	51.912	45.216	6.696	60.027	45.281	105.308
12	287.40	307.98	10.29	74.448	64.826	9.623	86.093	64.942	151.035

Nominal Diam. (in.)	Circumference (mm)		M^2 of surface per Meter		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	(L)	(L)	1 L	1 L	1 kg of Water
¼	29.92	24.82	0.030	0.025	0.048	0.048	20.699	20.696	20.678
⅜	39.88	32.06	0.040	0.032	0.077	0.082	12.228	12.240	12.219
½	49.86	42.04	0.050	0.042	0.140	0.140	7.126	7.135	7.117
⅝	59.82	51.99	0.060	0.052	0.216	0.216	4.639	4.638	4.632
¾	69.80	59.41	0.070	0.059	0.282	0.331	3.552	3.020	3.545
1	89.74	79.35	0.090	0.079	0.502	0.502	1.991	1.997	1.987
1¼	109.68	99.29	0.110	0.099	0.785	0.785	1.270	1.272	1.269
1½	129.62	118.11	0.130	0.118	1.819	1.819	0.550	0.550	0.549
2	169.49	156.24	0.170	0.156	1.944	1.943	0.515	0.515	0.514
2½	209.37	194.21	0.210	0.194	3.003	3.002	0.333	0.333	0.332
3	249.25	231.85	0.249	0.232	4.280	4.279	0.234	0.234	0.233
3½	289.26	270.10	0.289	0.270	5.806	5.805	0.170	0.172	0.173
4	329.01	307.62	0.329	0.308	7.537	7.536	0.133	0.133	0.132
5	408.76	383.24	0.409	0.383	11.694	11.692	0.086	0.085	0.085
6	488.52	457.89	0.489	0.458	16.693	16.690	0.060	0.060	0.060
8	648.03	604.80	0.648	0.605	29.121	29.115	0.034	0.034	0.034
10	807.54	753.62	0.807	0.754	45.216	42.724	0.022	0.023	0.022
12	967.05	902.44	0.967	0.903	64.826	64.814	0.015	0.016	0.015

Table 2-8 Dimensional and Capacity Data—Type L Copper Tube

Diameter (in.)			Wall thickness (in.)	Cross-sectional area (sq. in.)			Weight per foot (lb)		
Nominal (in.)	Actual inside	Actual outside		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
¼	0.315	0.375	0.030	0.110	0.078	0.032	0.126	0.034	0.160
⅜	0.430	0.500	0.035	0.196	0.145	0.051	0.198	0.063	0.261
½	0.545	0.625	0.040	0.307	0.233	0.074	0.285	0.101	0.386
⅝	0.666	0.750	0.042	0.442	0.348	0.094	0.362	0.151	0.513
¾	0.785	0.875	0.045	0.601	0.484	0.117	0.445	0.210	0.665
1	1.025	1.125	0.050	0.993	0.825	0.168	0.655	0.358	1.013
1¼	1.265	1.375	0.055	1.484	1.256	0.228	0.884	0.545	1.429
1½	1.505	1.625	0.060	2.072	1.778	0.294	1.14	0.77	1.91
2	1.985	2.125	0.070	3.546	3.093	0.453	1.75	1.34	3.09
2½	2.465	2.625	0.080	5.409	4.770	0.639	2.48	2.07	4.55
3	2.945	3.125	0.090	7.669	6.808	0.861	3.33	2.96	6.29
3½	3.425	3.625	0.100	10.321	9.214	1.107	4.29	4.00	8.29
4	3.905	4.125	0.110	13.361	11.971	1.390	5.38	5.20	10.58
5	4.875	5.125	0.125	20.626	18.659	1.967	7.61	8.10	15.71
6	5.845	6.125	0.140	29.453	26.817	2.636	10.2	11.6	21.8
8	7.725	8.125	0.200	51.826	46.849	4.977	19.3	20.3	39.6
10	9.625	10.125	0.250	80.463	72.722	7.741	30.1	31.6	61.7
12	11.565	12.125	0.280	115.395	104.994	10.401	40.4	45.6	86.0

Nominal Diam. (in.)	Circumference (in.)		Ft^2 of Surface per Lineal Foot		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	Ft^3	Gal	1 Ft^3	1 Gal	1 Lb of Water
¼	1.178	0.989	0.098	0.082	.00054	.0040	1852	250	29.6
⅜	1.570	1.350	0.131	0.113	.00100	.0075	1000	133	16.0
½	1.963	1.711	0.164	0.143	.00162	.0121	617.3	82.6	9.87
⅝	2.355	2.091	0.196	0.174	.00242	.0181	413.2	55.2	6.61
¾	2.748	2.465	0.229	0.205	.00336	.0251	297.6	40.5	4.76
1	3.533	3.219	0.294	0.268	.00573	.0429	174.5	23.3	2.79
1¼	4.318	3.972	0.360	0.331	.00872	.0652	114.7	15.3	1.83
1½	5.103	4.726	0.425	0.394	.01237	.0925	80.84	10.8	1.29
2	6.673	6.233	0.556	0.519	.02147	.1606	46.58	6.23	0.745
2½	8.243	7.740	0.688	0.645	.03312	.2478	30.19	4.04	0.483
3	9.813	9.247	0.818	0.771	.04728	.3537	21.15	2.83	0.338
3½	11.388	10.760	0.949	0.897	.06398	.4786	15.63	2.09	0.251
4	12.953	12.262	1.080	1.022	.08313	.6218	12.03	1.61	0.192
5	16.093	15.308	1.341	1.276	.12958	.9693	7.220	1.03	0.123
6	19.233	18.353	1.603	1.529	.18622	1.393	5.371	0.718	0.0592
8	25.513	24.465	2.126	2.039	.32534	2.434	3.074	0.411	0.0492
10	31.793	30.223	2.649	2.519	.50501	3.777	1.980	0.265	0.0317
12	38.073	36.314	3.173	3.026	.72912	5.454	1.372	0.183	0.0219

Table 2-8(M) Dimensional and Capacity Data—Type L Copper Tube

Diameter			Wall thickness (mm)	Cross-sectional area (10^3 mm^2)			Weight per foot (kg)		
Nominal (in.)	Actual inside (mm)	Actual outside (mm)		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
¼	8.00	9.53	0.76	0.071	0.050	0.021	0.188	0.051	0.239
⅜	10.92	12.70	0.89	0.127	0.094	0.033	0.295	0.094	0.389
½	13.84	15.88	1.02	0.198	0.150	0.048	0.425	0.150	0.575
⅝	16.92	19.05	1.07	0.285	0.225	0.061	0.539	0.225	0.764
¾	19.94	22.23	1.14	0.388	0.312	0.076	0.678	0.313	0.991
1	26.04	28.58	1.27	0.641	0.532	0.108	0.976	0.533	1.509
1¼	32.13	34.93	1.40	0.957	0.810	0.147	1.317	0.812	2.129
1½	38.23	41.28	1.52	1.337	1.147	0.190	1.698	1.147	2.845
2	50.42	53.98	1.78	2.288	1.996	0.292	2.607	1.996	4.603
2½	62.61	66.68	2.03	3.490	3.077	0.412	3.694	3.083	6.777
3	74.80	79.38	2.29	4.948	4.392	0.556	4.960	4.409	9.369
3½	87.00	92.08	2.54	6.659	5.945	0.714	6.390	5.958	12.348
4	99.19	104.78	2.79	8.620	7.723	0.897	8.014	7.745	15.759
5	123.83	130.18	3.18	13.307	12.038	1.269	11.335	12.065	23.400
6	148.46	155.58	3.56	19.002	17.301	1.701	15.193	17.278	32.471
8	196.22	206.38	5.08	33.436	30.225	3.211	28.747	30.237	58.984
10	244.48	257.18	6.35	51.912	46.917	4.994	44.834	47.068	91.902
12	293.75	307.98	7.11	74.448	67.738	6.710	60.176	67.921	128.097

Nominal Diam. (in.)	Circumference (mm)		M^2 of surface per Meter		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	(L)	(L)	1 L	1 L	1 kg of Water
¼	29.92	25.12	0.030	0.025	0.050	0.050	19.935	20.132	19.872
⅜	39.88	34.29	0.040	0.034	0.093	0.093	10.764	10.710	10.742
½	49.86	43.46	0.050	0.044	0.151	0.150	6.645	6.652	6.626
⅝	59.82	53.11	0.060	0.053	0.225	0.225	4.448	4.445	4.438
¾	69.80	62.61	0.070	0.063	0.312	0.312	3.203	3.261	3.196
1	89.74	81.76	0.090	0.082	0.532	0.533	1.878	1.876	1.873
1¼	109.68	100.89	0.110	0.101	0.810	0.810	1.235	1.232	1.229
1½	129.62	120.04	0.130	0.120	1.149	1.149	0.870	0.870	0.866
2	169.49	158.32	0.170	0.158	1.995	1.994	0.501	0.502	0.500
2½	209.37	196.60	0.210	0.197	3.077	3.077	0.325	0.325	0.324
3	249.25	234.87	0.249	0.235	4.393	4.392	0.228	0.228	0.227
3½	289.26	273.30	0.289	0.273	5.944	5.943	0.168	0.168	0.169
4	329.01	311.46	0.329	0.312	7.723	7.722	0.130	0.130	0.129
5	408.76	388.82	0.409	0.389	12.038	12.037	0.078	0.083	0.083
6	488.52	466.17	0.489	0.466	17.301	17.298	0.058	0.058	0.040
8	648.03	621.41	0.648	0.621	30.225	30.225	0.033	0.033	0.033
10	807.54	767.66	0.807	0.768	46.917	46.903	0.021	0.021	0.021
12	967.05	922.38	0.967	0.922	67.738	67.728	0.015	0.015	0.015

Table 2-9 Dimensional and Capacity Data—Type M Copper Tube

Diameter (in.)			Wall thickness (in.)	Cross-sectional area (sq. in.)			Weight per foot (lb)		
Nominal (in.)	Actual inside	Actual outside		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
⅜	0.450	0.500	0.025	0.196	0.159	0.037	0.145	0.069	0.214
½	0.569	0.625	0.028	0.307	0.254	0.053	0.204	0.110	0.314
¾	0.811	0.875	0.032	0.601	0.516	0.085	0.328	0.224	0.552
1	1.055	1.125	0.035	0.993	0.874	0.119	0.465	0.379	0.844
1¼	1.291	1.375	0.042	1.48	1.31	0.17	0.682	0.569	1.251
1½	1.527	1.625	0.049	2.07	1.83	0.24	0.94	0.83	1.77
2	2.009	2.125	0.058	3.55	3.17	0.38	1.46	1.35	2.81
2½	2.495	2.625	0.065	5.41	4.89	0.52	2.03	2.12	4.15
3	2.981	3.125	0.072	7.67	6.98	0.69	2.68	3.03	5.71
3½	3.459	3.625	0.083	10.32	9.40	0.924	3.58	4.08	7.66
4	3.935	4.125	0.095	13.36	12.15	1.21	4.66	5.23	9.89
5	4.907	5.125	0.109	20.63	18.90	1.73	6.66	8.20	14.86
6	5.881	6.125	0.122	29.45	25.15	2.30	8.92	11.78	20.70
8	7.785	8.125	0.170	51.83	47.58	4.25	16.5	20.7	37.2
10	9.701	10.125	0.212	80.46	73.88	6.58	25.6	32.1	57.7
12	11.617	12.125	0.254	115.47	105.99	9.48	36.7	46.0	82.7

Nominal Diam. (in.)	Circumference (in.)		Ft² of Surface per Lineal Foot		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	Ft³	Gal	1 Ft³	1 Gal	1 Lb of Water
⅜	1.570	1.413	0.131	0.118	0.00110	0.00823	909	122	14.5
½	1.963	1.787	0.164	0.149	0.00176	0.01316	568	76.0	9.09
¾	2.748	2.547	0.229	0.212	0.00358	0.02678	379	37.3	4.47
1	3.533	3.313	0.294	0.276	0.00607	0.04540	164.7	22.0	2.64
1¼	4.318	4.054	0.360	0.338	0.00910	0.06807	109.9	14.7	1.76
1½	5.103	4.795	0.425	0.400	0.01333	0.09971	75.02	10.0	1.20
2	6.673	6.308	0.556	0.526	0.02201	0.16463	45.43	6.08	0.727
2½	8.243	7.834	0.688	0.653	0.03396	0.25402	29.45	3.94	0.471
3	9.813	9.360	0.818	0.780	0.04847	0.36256	20.63	2.76	0.330
3½	11.388	10.867	0.949	0.906	0.06525	0.48813	15.33	2.05	0.246
4	12.953	12.356	1.080	1.030	0.08368	0.62593	11.95	1.60	0.191
5	16.093	15.408	1.341	1.284	0.13125	0.98175	7.62	1.02	0.122
6	19.233	18.466	1.603	1.539	0.18854	1.410	5.30	0.709	0.849
8	25.513	24.445	2.126	2.037	0.33044	2.472	3.03	0.405	0.484
10	31.793	30.461	2.649	2.538	0.51306	3.838	1.91	0.261	0.312
12	38.073	36.477	3.173	3.039	0.73569	5.503	1.36	0.182	0.217

Table 2-9(M) Dimensional and Capacity Data—Type M Copper Tube

Diameter				Cross-sectional area (10^3 mm^2)			Weight per foot (kg)		
Nominal (in.)	Actual inside (mm)	Actual outside (mm)	Wall thickness (mm)	Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
⅜	11.43	12.70	0.64	0.127	0.103	0.024	0.216	0.103	0.319
½	14.45	15.88	0.71	0.198	0.164	0.034	0.304	0.164	0.468
¾	20.60	22.23	0.81	0.388	0.333	0.055	0.489	0.334	0.823
1	26.80	28.58	0.89	0.641	0.564	0.077	0.693	0.565	1.258
1¼	32.79	34.93	1.07	0.955	0.845	0.110	1.016	0.848	1.864
1½	38.79	41.28	1.25	1.336	1.181	0.155	1.400	1.236	2.636
2	51.03	53.98	1.47	2.290	2.045	0.245	2.175	2.011	4.186
2½	63.38	66.68	1.65	3.490	3.155	0.336	3.024	3.158	6.182
3	75.2	79.38	1.83	4.948	4.503	0.445	3.992	4.513	8.505
3½	87.86	92.08	2.11	6.658	6.065	0.596	5.332	6.077	11.409
4	99.95	104.78	2.41	8.619	7.839	0.781	6.941	7.790	14.731
5	124.64	130.18	2.77	13.310	12.194	1.116	9.920	12.214	22.134
6	149.38	155.58	3.10	19.000	16.226	1.484	13.286	17.546	30.832
8	197.74	206.38	4.32	33.439	30.697	2.742	24.577	30.833	55.410
10	246.41	257.18	5.39	51.910	47.664	4.245	38.131	47.813	85.944
12	295.07	307.98	6.45	74.497	68.381	6.116	54.665	68.517	123.182

Nominal Diam. (in.)	Circumference (mm)		M^2 of surface per Meter		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	(L)	(L)	1 L	1 L	1 kg of Water
⅜	39.88	35.89	0.040	0.036	0.102	0.102	9.784	9.825	9.735
½	49.86	45.39	0.050	0.045	0.164	0.163	6.114	6.120	6.103
¾	69.80	64.69	0.070	0.065	0.033	0.333	4.080	3.004	3.001
1	89.74	84.15	0.090	0.084	0.564	0.564	1.773	1.772	1.772
1¼	109.68	102.97	0.110	0.103	0.845	0.845	1.183	1.184	1.182
1½	129.62	121.79	0.130	0.122	1.238	1.238	0.808	0.805	0.806
2	169.49	160.22	0.170	0.160	2.045	2.044	0.489	0.490	0.488
2½	209.37	198.98	0.210	0.199	3.155	3.154	0.317	0.317	0.316
3	249.25	237.74	0.249	0.238	4.503	4.502	0.222	0.222	0.222
3½	289.26	276.02	0.289	0.276	6.62	6.062	0.165	0.165	0.165
4	329.01	313.84	0.329	0.314	7.774	7.773	0.129	0.129	0.128
5	408.76	391.36	0.409	0.391	12.194	12.191	0.082	0.082	0.082
6	488.52	469.04	0.489	0.469	17.516	17.509	0.057	0.057	0.570
8	648.03	620.90	0.648	0.621	30.699	30.697	0.033	0.033	0.325
10	807.54	773.71	0.807	0.774	47.665	47.660	0.021	0.021	0.210
12	967.05	926.52	0.967	0.926	68.348	68.336	0.015	0.015	0.146

Table 2-10 Dimensional Data—Type DWV Copper Tube

Nominal Size	Nominal Dimensions						Calculated Values, Based on Nominal Dimensions							
	Outside Diameter		Inside Diameter		Wall Thickness		Cross Sectional Area of Bore		External Surface		Internal Surface		Weight kg	
(in.)	(in.)	(mm)	(in.)	(mm)	(in.)	(mm)	($in.^2$)	(cm^2)	(ft^2/lin ft)	(m^2/m)	(ft^2/lin ft)	(m^2/m)	(/lf)	(/m)
1¼	1.375	34.93	1.295	32.89	.040	1.02	1.32	8.52	0.360	0.03	0.339	0.03	0.65	0.29
1½	1.625	41.28	1.541	39.14	.042	1.07	1.87	12.06	0.425	0.04	0.403	0.04	0.81	0.37
2	2.125	53.98	2.041	51.84	.042	1.07	3.27	21.10	0.556	0.05	0.534	0.05	1.07	0.49
3	3.125	79.38	3.030	76.96	.045	1.14	7.21	46.52	0.818	0.08	0.793	0.07	1.69	0.77
4	4.125	104.78	4.009	101.83	.058	1.47	12.6	81.29	1.08	0.10	1.05	0.10	2.87	1.30
5	5.125	130.18	4.981	126.52	.072	1.83	19.5	125.81	1.34	0.12	1.30	0.12	4.43	2.01
6	6.125	155.58	5.959	151.36	.083	2.11	27.9	180.00	1.60	0.15	1.56	0.15	6.10	2.77
8	8.125	206.38	7.907	200.84	.109	2.77	49.1	316.77	2.13	0.20	2.07	0.19	10.6	4.81

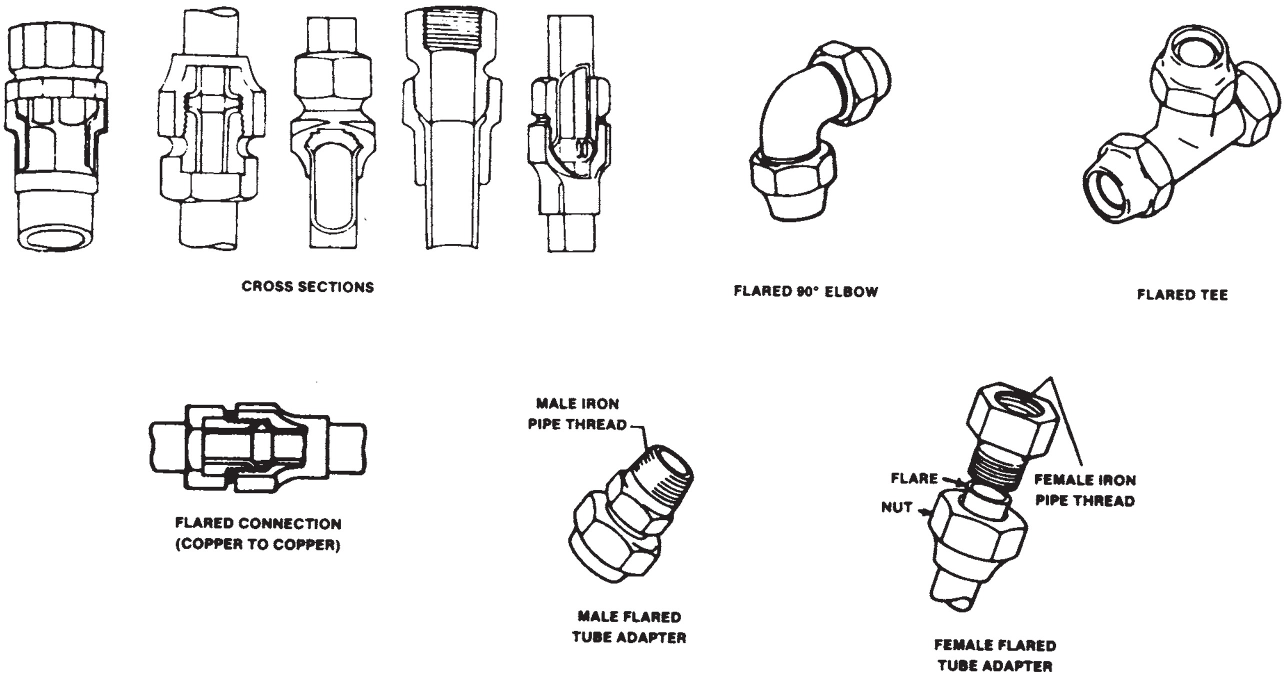


Figure 2-5 Copper Tube Flared Fittings

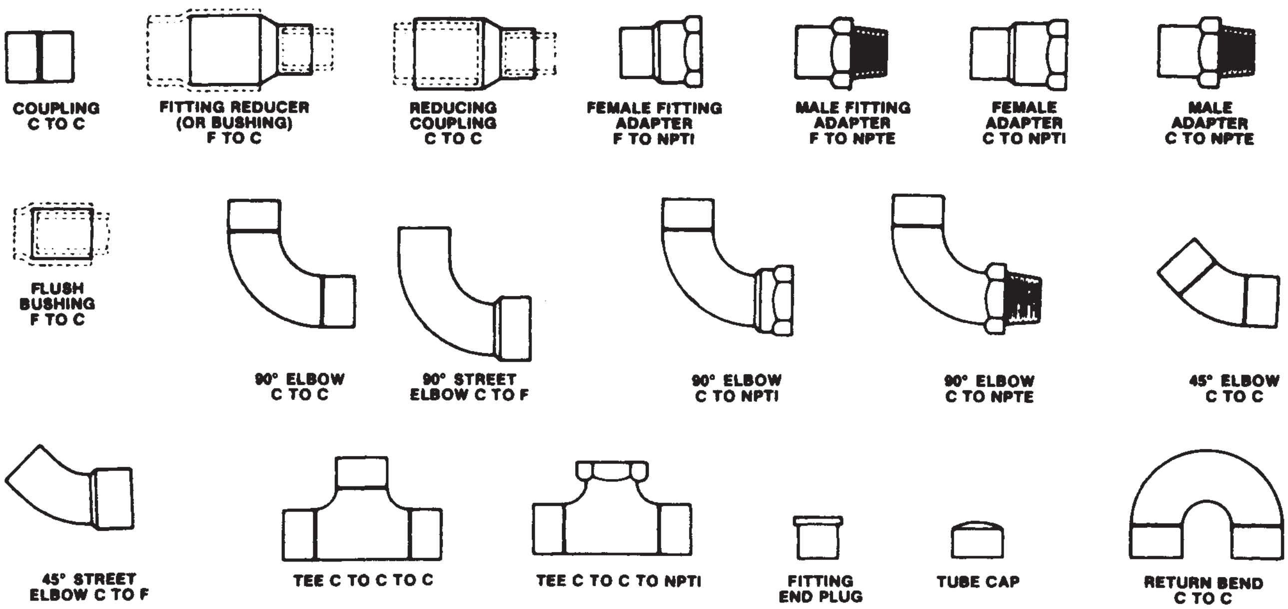


Figure 2-6 Copper and Bronze Joints and Fittings

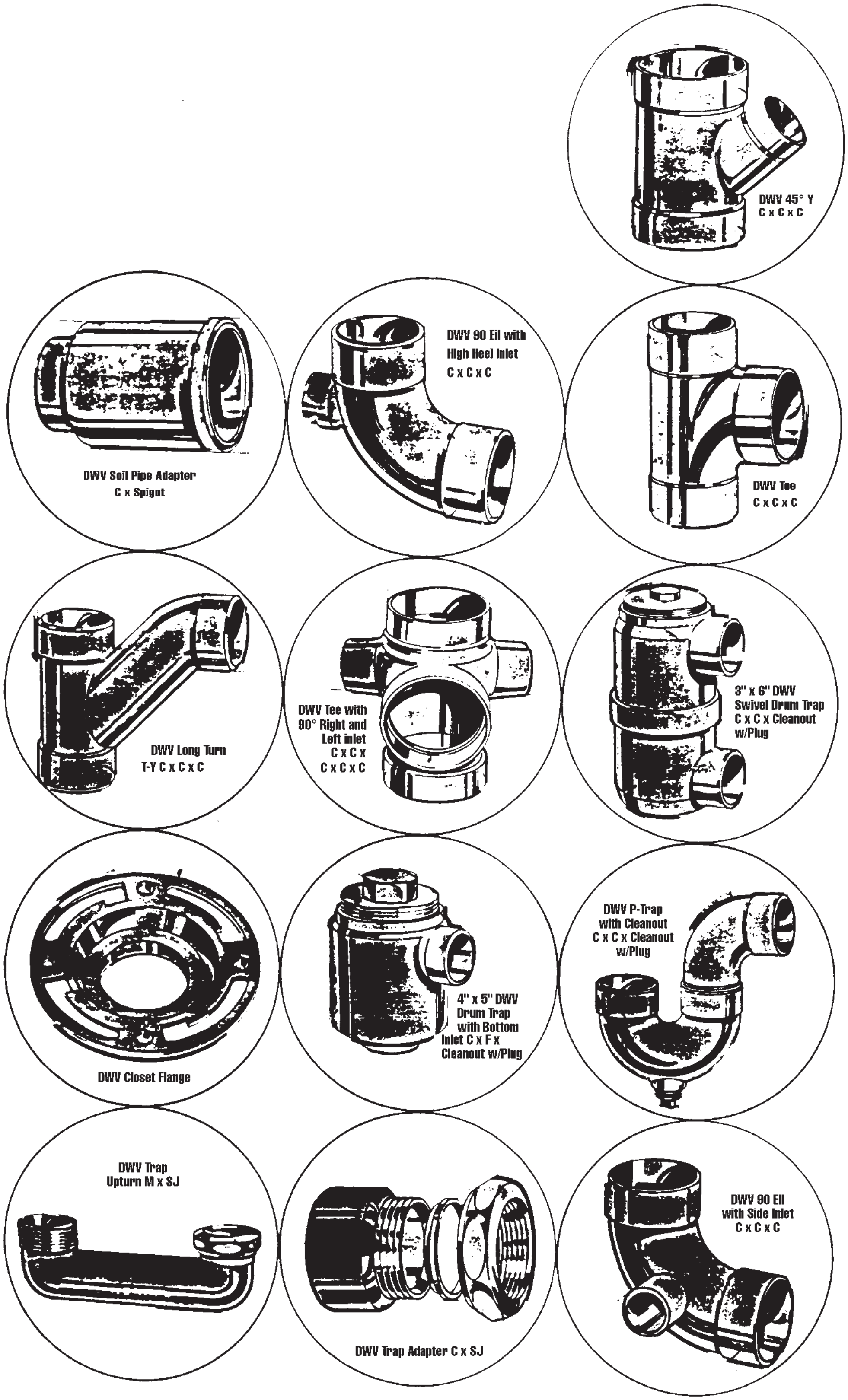


Figure 2-7 Copper Drainage Fittings

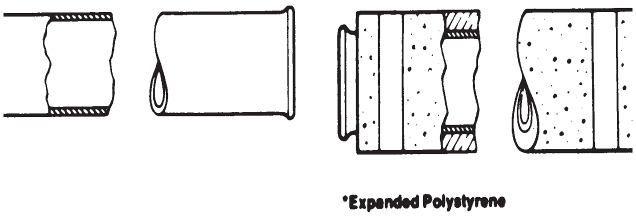


Figure 2-8 Standard Glass Pipe

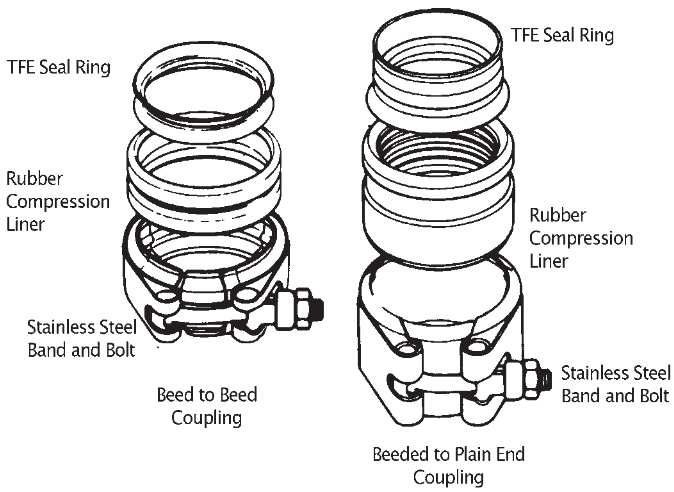


Figure 2-9 Standard Glass Pipe Couplings

third method is accomplished by roll-grooving the end of the tube and using a gasketed fitting

O-rings in fittings are to be ethylene propylene diene monomer (EPDM) or hydrogenated nitrile butadiene rubber (HNBR). (See Figures 2-5 and 2-6.)

The methods of joining are:

- Soldered
- Flared
- Brazed
- Roll-grooved and mechanical coupling
- Press-type fitting
- Push-type fitting
- T-drill

Copper Drainage Tube

Copper drainage tube for DWV applications is a seamless copper tube conforming to the requirements of ASTM B306. Copper drainage tube is furnished in drawn (hard) temper only in sizes of 1¼ inch to 8 inches (31.8 mm to 203.2 mm). It is required to be identified by a yellow stripe giving the manufacturer's name or trademark, the nation of origin, and the letters "DWV." It also is required to be incised with the manufacturer's name or trademark and the letters "DWV" at intervals no greater than 1½ feet.

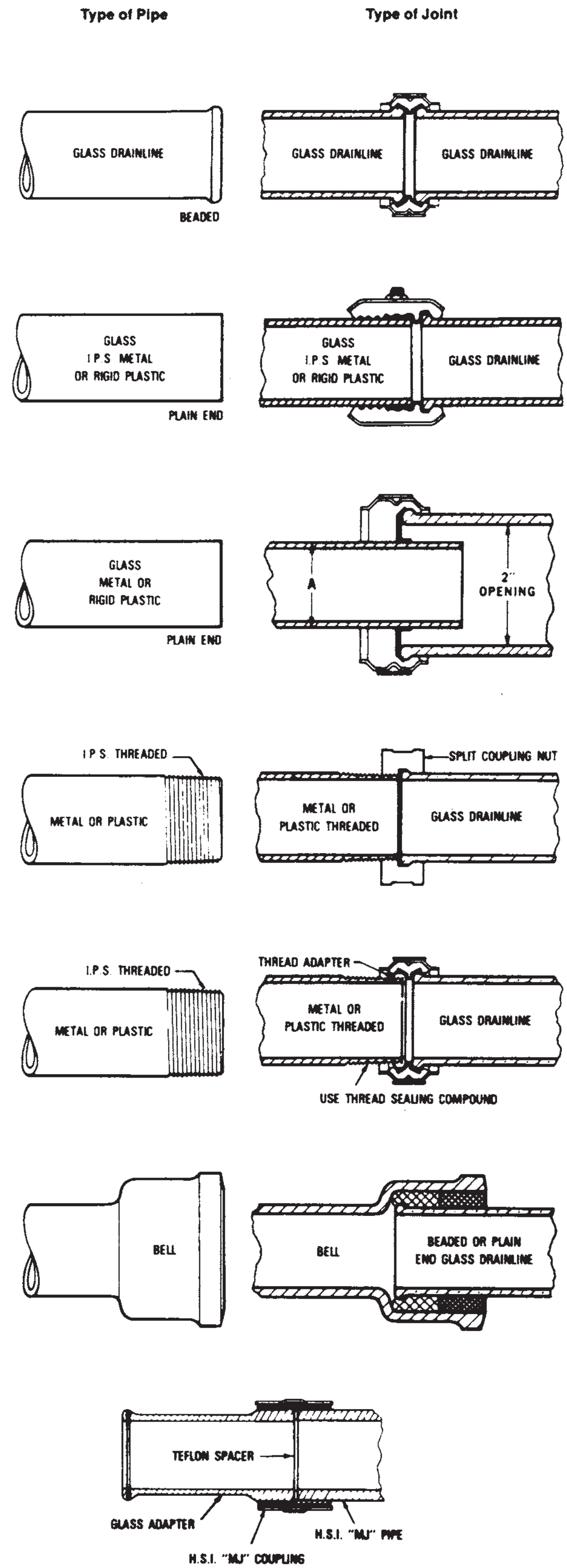


Figure 2-10 Typical Glass Pipe Joint Reference Chart

See Table 2-10 for dimensional data for Type DWV copper tube.

Fittings for use with drainage pipe are usually those conforming to either ASME B16.23 or ASME B16.29. They are required to carry the incised mark "DWV."

Joints for drainage applications can be soldered or brazed. (See Figure 2-7.)

Medical Gas Tube

Medical gas tube is shipped cleaned and capped and is furnished in Type K or L wall thickness in drawn (hard) temper only.

Medical gas tube is identified with an incised mark containing the manufacturer's name or trademark at intervals not in excess of 1½ feet. It is color-coded green for Type K and blue for Type L.

Fittings for medical gas tube may be those conforming to ASME B16.22, ASME B16.18 (where wrought copper fittings are not available), or ASME B16.50: *Wrought Copper and Copper Alloy Braze-joint Pressure Fittings*. They also may be fittings meeting the requirements of Manufacturers Standardization Society (MSS) SP-73: *Brazing Joints for Copper and Copper Alloy Pressure Fittings*.

The methods of joining are:

- Brazing
- Specialized mechanical compression coupling

Joints in medical gas systems are of the socket/lap type and are normally brazed with copper-phosphorous or copper-phosphorous-silver (BCuP) brazing alloys while being purged with oil-free nitrogen.

Natural and Liquefied Petroleum

Natural and liquefied petroleum pipe is furnished in Type G wall thickness. It is color-coded yellow per ASTM B837.

The methods of joining are:

- Brazing
- Compression fittings
- Specialized mechanical compression coupling

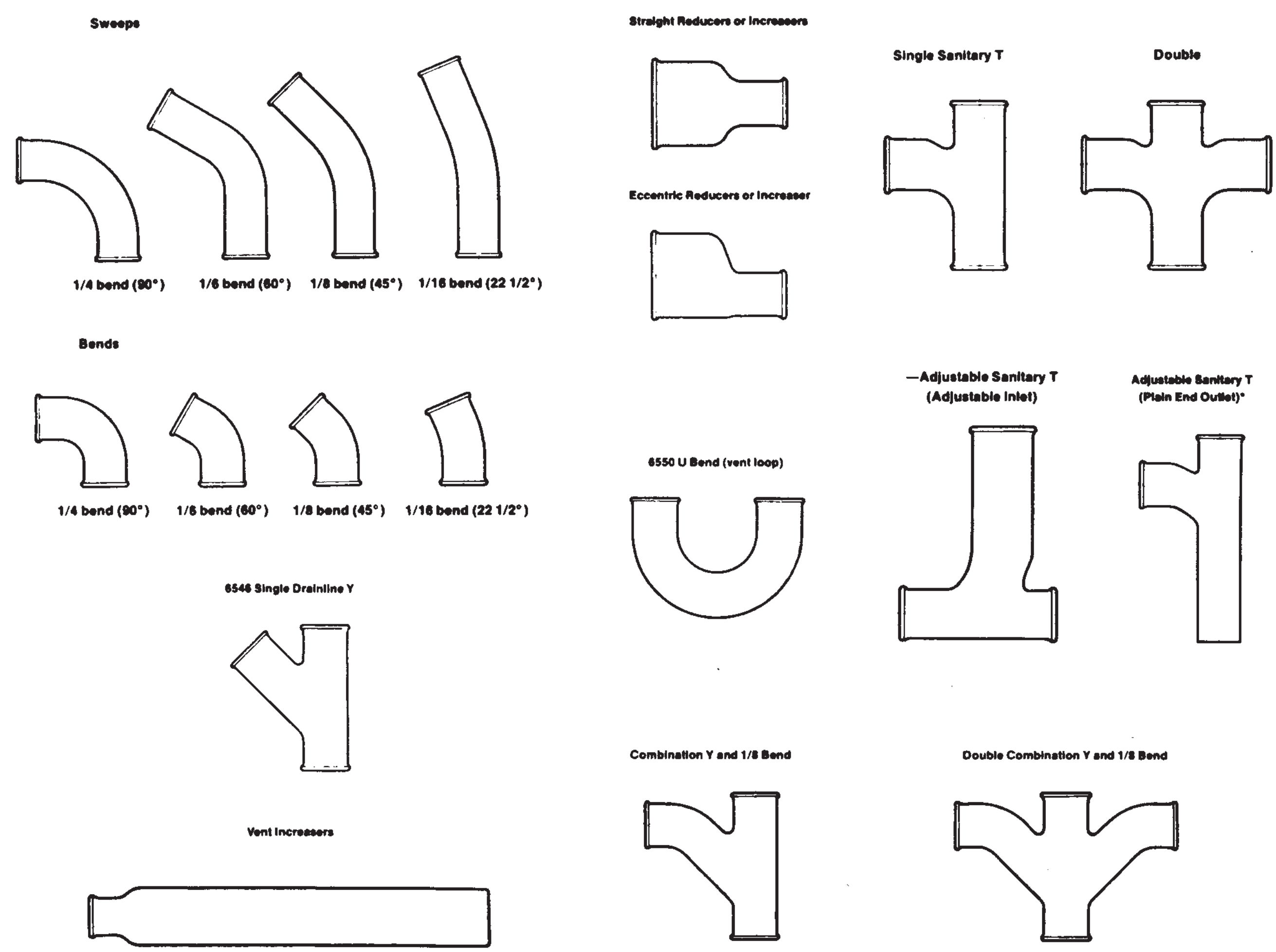


Figure 2-11 Standard Glass Fittings

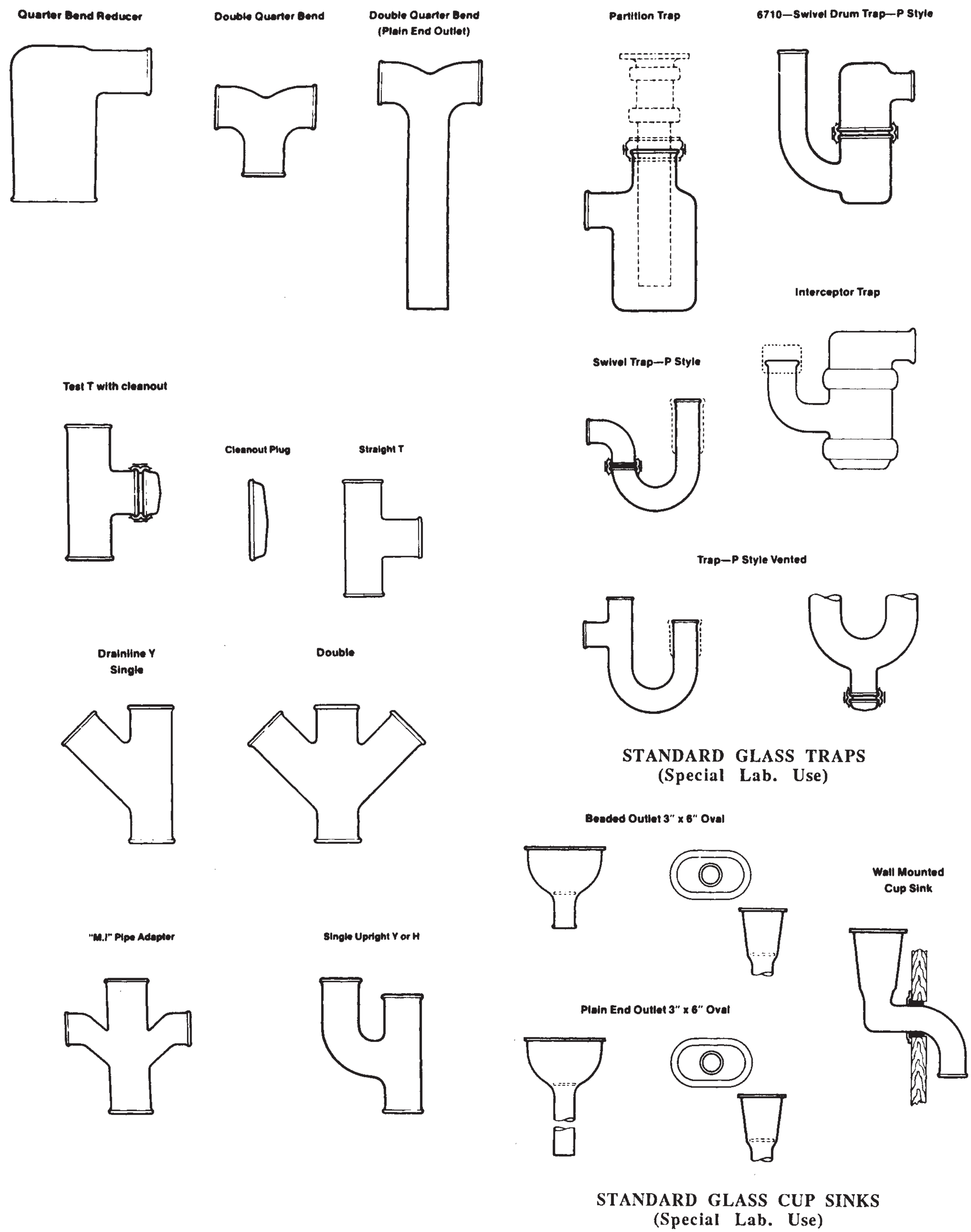


Figure 2-11 (continued)

Table 2-11 Dimensional and Capacity Data—Schedule 40 Steel Pipe

Diameter (in.)			Wall thickness (in.)	Cross-sectional area (sq. in.)			Weight per foot (lb)		
Nominal (in.)	Actual inside	Actual outside		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
⅛	0.269	0.405	0.068	0.129	0.057	0.072	0.25	0.028	0.278
¼	0.364	0.540	0.088	0.229	0.104	0.125	0.43	0.045	0.475
⅜	0.493	0.675	0.091	0.358	0.191	0.167	0.57	0.083	0.653
½	0.622	0.840	0.109	0.554	0.304	0.250	0.86	0.132	0.992
¾	0.824	1.050	0.113	0.866	0.533	0.333	1.14	0.232	1.372
1	1.049	1.315	0.133	1.358	0.864	0.494	1.68	0.375	2.055
1¼	1.380	1.660	0.140	2.164	1.495	0.669	2.28	0.649	2.929
1½	1.610	1.900	0.145	2.835	2.036	0.799	2.72	0.882	3.602
2	2.067	2.375	0.154	4.431	3.356	1.075	3.66	1.454	5.114
2½	2.469	2.875	0.203	6.492	4.788	1.704	5.80	2.073	7.873
3	3.068	3.500	0.216	9.621	7.393	2.228	7.58	3.201	0.781
3½	3.548	4.000	0.226	12.568	9.888	2.680	9.11	4.287	3.397
4	4.026	4.500	0.237	15.903	12.730	3.173	10.80	5.516	6.316
5	5.047	5.563	0.258	24.308	20.004	4.304	14.70	8.674	3.374
6	6.065	6.625	0.280	34.474	28.890	5.584	19.00	12.52	31.52
8	7.981	8.625	0.322	58.426	50.030	8.396	28.60	21.68	50.28
10	10.020	10.750	0.365	90.79	78.85	11.90	40.50	34.16	74.66
12	11.938	12.750	0.406	127.67	113.09	15.77	53.60	48.50	02.10
14	13.126	14.000	0.437	153.94	135.33	18.61	63.30	58.64	21.94
16	15.000	16.000	0.500	201.06	176.71	24.35	82.80	76.58	59.38
18	16.876	18.000	0.562	254.47	223.68	30.79	105.00	96.93	201.93
20	18.814	20.000	0.593	314.16	278.01	36.15	123.00	120.46	243.46

Nominal Diam. (in.)	Circumference (in.)		Ft^2 of Surface per Lineal Foot		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	Ft^3	Gal	1 Ft^3	1 Gal	1 Lb of Water
⅛	1.27	0.84	0.106	0.070	0.0004	0.003	2533.775	338.74	35.714
¼	1.69	1.14	0.141	0.095	0.0007	0.005	1383.789	185.00	22.222
⅜	2.12	1.55	0.177	0.129	0.0013	0.010	754.360	100.85	12.048
½	2.65	1.95	0.221	0.167	0.0021	0.016	473.906	63.36	7.576
¾	3.29	2.58	0.275	0.215	0.0037	0.028	270.034	36.10	4.310
1	4.13	3.29	0.344	0.274	0.0062	0.045	166.618	22.38	2.667
1¼	5.21	4.33	0.435	0.361	0.0104	0.077	96.275	12.87	1.541
1½	5.96	5.06	0.497	0.422	0.0141	0.106	70.733	9.46	1.134
2	7.46	6.49	0.622	0.540	0.0233	0.174	42.913	5.74	0.688
2½	9.03	7.75	0.753	0.654	0.0332	0.248	30.077	4.02	0.482
3	10.96	9.63	0.916	0.803	0.0514	0.383	19.479	2.60	0.312
3½	12.56	11.14	1.047	0.928	0.0682	0. 513	14.565	1.95	0.233
4	14.13	12.64	1.178	1.052	0.0884	0.660	11.312	1.51	0.181
5	17.47	15.84	1.456	1.319	0.1390	1.040	7.198	0.96	0.115
6	20.81	19.05	1.734	1.585	0.2010	1.500	4.984	0.67	0.080
8	27.90	25.07	2.258	2.090	0.3480	2.600	2.878	0.38	0.046
10	33.77	31.47	2.814	2.622	0.5470	4.100	1.826	0.24	0.029
12	40.05	37.70	3.370	3.140	0.7850	5.870	1.273	0.17	0.021
14	47.12	44.76	3.930	3.722	1.0690	7.030	1.067	0.14	0.017
16	53.41	51.52	4.440	4.310	1.3920	9.180	0.814	0.11	0.013
18	56.55	53.00	4.712	4.420	1.5530	11.120	0.644	0.09	0.010
20	62.83	59.09	5.236	4.920	1.9250	14.400	0.517	0.07	0.008

Table 2-11(M) Dimensional and Capacity Data—Schedule 40 Steel Pipe

Diameter			Wall thickness (mm)	Cross-sectional area (10^3 mm^2)			Weight per foot (kg)		
Nominal (in.)	Actual inside (mm)	Actual outside (mm)		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
⅛	6.8	10.3	1.7	0.083	0.037	0.047	0.37	0.04	0.41
¼	9.3	13.7	2.2	0.148	0.067	0.081	0.64	0.07	0.71
⅜	12.5	17.2	2.3	0.231	0.123	0.108	0.85	0.12	0.97
½	15.8	21.3	2.8	0.357	0.196	0.161	1.28	0.20	1.48
¾	20.9	26.7	2.9	0.559	0.344	0.215	1.7	0.35	2.05
1	26.7	33.4	3.4	0.876	0.557	0.319	2.5	0.56	3.06
1¼	35.1	42.2	3.6	1.396	0.965	0.432	3.4	0.97	4.37
1½	40.9	48.3	3.7	1.829	1.314	0.516	4.05	1. 31	5.36
2	52.5	60.3	3.9	2.859	2.165	0.694	5.45	2.17	7.62
2½	62.7	73.0	5.2	4.188	3.089	1.099	8.64	3.09	11.73
3	77.9	88.9	5.5	6.207	4.77	1.437	11.29	4.77	16.06
3½	90.1	101.6	5.7	8.108	6.379	1.729	13.57	6.39	19.96
4	102.3	114.3	6.0	10.26	8.213	2.047	16.09	8.22	24.31
5	128.2	141.3	6.6	15.68	12.91	2.777	21.9	12.92	34.82
6	154.1	168.3	7.1	22.24	18.64	3.603	28.3	18.65	46.95
8	202.7	219.1	8.2	37.69	32.28	5.417	42.6	32.29	74.89
10	254.5	273.1	9.3	58.57	50.87	7.677	60.33	50.88	111.21
12	303.2	323.9	10.3	82.37	72.96	10.17	79.84	72.24	152.08
14	333.4	355.6	11.1	99.32	87.31	12.01	94.29	87.34	181.63
16	381.0	406.4	12.7	129.72	114.01	15.71	123.33	114.07	237.4
18	428.7	457.2	14.3	164.17	144.31	19.87	156.4	144.38	300.78
20	477.9	508.0	15.1	202.68	179.36	23.32	183.21	179.43	362.64

Nominal Diam. (in.)	Circumference (mm)		M^2 of surface per Meter		Contents of Tube per Lineal Meter		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	(L)	(L)	1 L	1 L	1 kg of Water
⅛	32.26	21.34	0.032	0.021	0.037	0.037	27.27	27.28	23.98
¼	42.93	28.96	0.043	0.029	0.065	0.062	14.9	14.9	14.92
⅜	53.85	39.37	0.054	0.039	0.121	0.124	8.12	8.12	8.09
½	67.31	49.53	0.067	0.051	0.195	1.199	5.1	5.1	5.09
¾	83.57	65.53	0.084	0.066	0.344	0.348	2.91	2.91	2.89
1	104.9	83.57	0.105	0.084	0.576	0.559	1.79	1.79	1.79
1¼	132.33	109.98	0.133	0.11	0.966	0.956	1.04	1.04	1.03
1½	151.38	128.52	0.152	0.129	1.31	1.316	0.76	0.76	0.76
2	189.48	164.85	0.19	0.165	2.165	2.161	0.46	0.46	0.46
2½	229.36	196.85	0.23	0.199	3.084	3.08	0.32	0.32	0.32
3	278.38	244.6	0.279	0.245	4.775	4.756	0.21	0.21	0.21
3½	319.02	282.96	0.319	0.283	6.336	6.37	0.16	0.16	0.16
4	358.9	321.06	0.359	0.321	8.213	8.196	0.12	0.12	0.12
5	443.74	402.34	0.444	0.402	12.91	12.92	0.08	0.08	0.08
6	528.57	483.87	0.529	0.483	18.67	18.63	0.05	0.05	0.05
8	688.09	636.78	0.688	0.637	32.33	32.29	0.03	0.03	0.03
10	857.76	799.34	0.858	0.799	50.82	50.91	0.02	0.02	0.02
12	1017.27	957.58	1.027	0.957	72.93	72.89	0.013	0.014	0.014
14	1196. 85	1136.9	1.198	1.135	99.31	87.3	0.011	0.011	0.011
16	1356.61	1308.61	1.353	1.314	129.32	114.0	0.009	0.009	0.009
18	1436.37	1346.2	1.436	1.347	144.28	138.09	0.007	0.007	0.007
20	1595.88	1500.89	1.596	1.5	178.84	178.82	0.006	0.006	0.006

Table 2-12 Dimensional and Capacity Data—Schedule 80 Steel Pipe

Diameter (in.)			Wall thickness (in.)	Cross-sectional area (sq. in.)			Weight per foot (lb)		
Nominal (in.)	Actual inside	Actual outside		Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
⅛	0.215	0.405	0.091	0.129	0.036	0.093	0.314	0.016	0.330
¼	0.302	0.540	0.119	0.229	0.072	0.157	0.535	0.031	0.566
⅜	0.423	0.675	0.126	0.358	0.141	0.217	0.738	0.061	0.799
½	0.546	0.840	0.147	0.554	0.234	0.320	1.087	0.102	1.189
¾	0.742	1.050	0.154	0.866	0.433	0.433	1.473	0.213	1.686
1	0.957	1.315	0.179	1.358	0.719	0.639	2.171	0.312	2.483
1¼	1.278	1.660	0.191	2.164	1.283	0.881	2.996	0.555	3.551
1½	1.500	1.900	0.200	2.835	1.767	1.068	3.631	0.765	4.396
2	1.939	2.375	0.218	4.431	2.954	1.477	5.022	1.280	6.302
2½	2.323	2.875	0.276	6.492	4.238	2.254	7.661	1.830	9.491
3	2.900	3.500	0.300	9.621	6.605	3.016	10.252	2.870	13.122
3½	3.364	4.000	0.318	12.568	8.890	3.678	12.505	3.720	16.225
4	3.826	4.500	0.337	15.903	11.496	4.407	14.983	4.970	19.953
5	4.813	5.563	0.375	24.308	18.196	6.112	20.778	7.940	28.718
6	5.761	6.625	0.432	34.474	26.069	8.405	28.573	11.300	39.873
8	7.625	8.625	0.500	58.426	45.666	12.750	43.388	19.800	63.188
10	9.564	10.750	0.593	90.79	71.87	18.92	64.400	31.130	95.530
12	11.376	12.750	0.687	127.67	101.64	26.03	88.600	44.040	132.640
14	12.500	14.000	0.750	153.94	122.72	31.22	107.000	53.180	160.180
16	14.314	16.000	0.843	201.06	160.92	40.14	137.000	69.730	206.730
18	16.126	18.000	0.937	254.47	204.24	50.23	171.000	88.500	259.500
20	17.938	20.000	1.031	314.16	252.72	61.44	209.000	109.510	318.510

Nominal Diam. (in.)	Circumference (in.)		Ft^2 of Surface per Lineal Foot		Contents of Tube per Lineal Foot		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	Ft^3	Gal	1 Ft^3	1 Gal	1 Lb of Water
⅛	1.27	0.675	0.106	0.056	0.00033	0.0019	3070	527	101.01
¼	1.69	0.943	0.141	0.079	0.00052	0.0037	1920	271	32.26
⅜	2.12	1.328	0.177	0.111	0.00098	0.0073	1370	137	16.39
½	2.65	1.715	0.221	0.143	0.00162	0.0122	616	82	9.80
¾	3.29	2.330	0.275	0.194	0.00300	0.0255	334	39.2	4.69
1	4.13	3.010	0.344	0.251	0.00500	0.0374	200	26.8	3.21
I¼	5.21	4.010	0.435	0.334	0.00880	0.0666	114	15.0	1.80
1½	5.96	4.720	0.497	0.393	0.01230	0.0918	81.50	10.90	1.31
2	7.46	6.090	0.622	0.507	0.02060	0.1535	49.80	6.52	0.78
2½	9.03	7.320	0.753	0.610	0.02940	0.220	34.00	4.55	0.55
3	10.96	9.120	0.916	0.760	0.0460	0.344	21.70	2.91	0.35
3½	12.56	10.580	1.047	0.882	0.0617	0.458	16.25	2.18	0.27
4	14.13	12.020	1.178	1.002	0.0800	0.597	12.50	1.675	0.20
5	17.47	15.150	1.456	1.262	0.1260	0.947	7.95	1.055	0.13
6	20.81	18.100	1.734	1.510	0.1820	1.355	5.50	0.738	0.09
8	27.09	24.000	2.258	2.000	0.3180	2.380	3.14	0.420	0.05
10	33.77	30.050	2.814	2.503	0.5560	4.165	1.80	0.241	0.03
12	40.05	35.720	3.370	2.975	0.7060	5.280	1.42	0.189	0.02
14	47.12	39.270	3.930	3.271	0.8520	6.380	1.18	0.157	0.019
16	53.41	44.970	4.440	3.746	1.1170	8.360	0.895	0.119	0.014
18	56.55	50.660	4.712	4.220	1.4180	10.610	0.705	0.094	0.011
20	62.83	56.350	5.236	4.694	1.7550	13.130	0.570	0.076	0.009

Table 2-12(M) Dimensional and Capacity Data—Schedule 80 Steel Pipe

Diameter				Cross-sectional area (10^3 mm^2)			Weight per foot (kg)		
Nominal (in.)	Actual inside (mm)	Actual outside (mm)	Wall thickness (mm)	Outside	Inside	Metal	of tube alone	of water in tube	of tube and water
⅛	5.46	10.29	2.41	0.083	0.023	0.06	0.468	0.024	0.492
¼	7.67	13.72	3.02	0.148	0.047	0.101	0.797	0.046	0.843
⅜	10.74	17.15	3.2	0.231	0.091	0.14	1.099	0.091	1.19
½	13.87	21.34	3.73	0.357	0.151	0.207	1.619	0.152	1.771
¾	18.85	26.67	3.91	0.559	0.279	0.279	2.194	0.317	2.511
1	24.31	33.4	4.55	0.876	0.464	0.412	3.234	0.465	3.698
1¼	32.46	42.16	4.85	1.396	0.828	0.569	4.463	0.827	5.289
1½	38.1	48.26	5.08	1.829	1.14	0.689	5.408	1.14	6.548
2	49.25	60.33	5.54	2.859	1.906	0.953	7.48	1.907	9.386
2½	59	73.03	7.01	4.188	2.734	1.454	11.411	2.726	14.137
3	73.66	88.9	7.62	6.207	4.261	1.946	15.27	4.275	19.545
3½	85.45	101.6	8.08	8.108	5.736	2.373	18.626	5.541	24.167
4	97.18	114.3	8.56	10.26	7.417	2.843	22.317	7.403	29.72
5	122.25	141.3	9.53	15.683	11.739	3.943	30.949	11.827	42.776
6	146.33	168.28	10.97	22.241	16.819	5.423	42.56	16.831	59.391
8	193.68	219.08	12.7	37.694	29.462	8.232	64.627	29.492	94.119
10	242.93	273.05	15.06	58.574	46.368	12.206	95.924	46.368	142.292
12	288.95	323.85	17.45	82.368	65.574	16.794	131.97	65.598	197.568
14	317.5	355.6	19.05	99.316	79.174	20.142	159.377	79.212	238.588
16	363.58	406.4	21.41	129.716	103.819	25.897	204.062	103.863	307.925
18	409.6	457.2	23.8	164.174	131.768	32.406	254.705	131.821	386.526
20	455.63	508	26.19	202.684	163.045	39.639	311.306	163.115	474.421

Nominal Diam. (in.)	Circumference (mm)		M^2 of surface per Meter		Contents of Tube per Lineal Meter		Lineal Feet to Contain		
	Outside	Inside	Outside	Inside	(L)	(L)	1 L	1 L	1 kg of Water
⅛	32.26	17.15	0.032	0.017	0.031	0.024	33.05	42.44	67.82
¼	42.93	23.95	0.043	0.024	0.048	0.046	20.67	21.82	21.66
⅜	53.85	33.73	0.054	0.034	0.091	0.091	14.75	11.03	11
½	67.31	43.56	0.067	0.044	0.151	0.152	6.63	6.6	6.58
¾	83.57	59.18	0.084	0.059	0.279	0.317	3.6	3.16	3.15
1	104.9	76.45	0.105	0.077	0.465	0.464	2.15	2.16	2.16
1¼	132.33	101.85	0.133	0.102	0.818	0.827	1.23	1.21	1.21
1½	151.38	119.89	0.152	0.12	1.143	1.14	0.88	0.88	0.88
2	189.48	154.69	0.19	0.155	1.914	1.906	0.54	0.53	0.52
2½	229.36	185.93	0.23	0.186	2.731	2.732	0.37	0.37	0.37
3	278.38	231.65	0.279	0.232	4.274	4.272	0.23	0.23	0.24
3½	319.02	268.73	0.319	0.269	5.732	5.687	0.18	0.18	0.18
4	358.9	305.31	0.359	0.305	7.432	7.414	0.14	0.14	0.13
5	443.74	384.81	0.444	0.385	11.706	11.76	0.09	0.09	0.09
6	528.57	459.74	0.529	0.46	16.909	16.826	0.06	0.06	0.06
8	688.09	609.6	0.688	0.61	29.543	29.555	0.03	0.03	0.03
10	857.76	763.27	0.858	0.763	51.654	51.721	0.02	0.02	0.02
12	1017.27	907.29	1.027	0.907	65.59	65.567	0.015	0.015	0.014
14	1196.85	997.46	1.198	0.997	79.154	79.227	0.013	0.013	0.013
16	1356.61	1142.24	1.353	1.142	103.773	103.814	0.01	0.01	0.009
18	1436.37	1286.76	1.436	1.286	131.737	131.755	0.008	0.008	0.007
20	1595.88	1431.29	1.596	1.431	163.046	163.048	0.006	0.006	0.006

GLASS PIPE

Glass pipe is used in the mechanical industry in two ways: as pressure ½-inch to 8-inch (13-mm to 203-mm) pipe and as drainage 1½-inch to 6-inch (38-mm to 153-mm) pipe. It is available in standard 5-foot and 10-foot (1.5-m and 3.1-m) lengths.

Glass is unique for several reasons. First, it is clear, allowing the contents to be visible. Second, it is the piping system that is least susceptible to fire. Glass does not burn. With enough heat, it can melt. This is why in buildings with a return air plenum for heating, ventilation, and air-conditioning (HVAC), most plastics are not acceptable by fire codes, and glass is a solution for meeting this building code requirement.

Glass pipe (see Figure 2-8) is made of low-expansion borosilicate glass with a low alkali content. It most commonly is used for chemical waste drainlines, vent piping, and purified water piping. Nonstandard lengths are available, or it can be field cut or fabricated to special lengths. Glass can be installed aboveground (padded or with coated hangers) or buried (with Styrofoam blocking around the pipe). Glass is fragile, so care must be taken to prevent scratches or impact by sharp objects. Glass is used for chemical waste DWV systems in high schools, colleges, laboratories, industrial plants, and hospitals when hot fluids are put down the systems constantly. (Hot fluids are those at 200°F with no dilution.)

Glass is installed by cutting the pipe to the exact fixed length. It is held together with either of two types of coupling, depending on whether it is a "bead to bead" or "bead to cut glass end" application. (See Figures 2-9 and 2-10.)

Joints are made by using compression-type couplings consisting of 300 series stainless steel outer bands, electrometric compression liners, and sealing members of chemically inert tetrafluoroethylene (TFE). The coefficient of glass expansion is 0.2 inch/100 feet/100°F (5 mm/30.4 m/37.8°C), and glass is very stable and can operate up to 300°F (148.9°C).

Fittings are made of borosilicate glass and include a full range of sanitary and plumbing fittings (see Figure 2-11).

The referenced standard for glass pipe is ASTM C599: *Standard Specification for Conical Process Glass Pipe and Fittings.*

STEEL PIPE

Steel pipe specified for heating, air-conditioning, plumbing, gas, and air lines conforms to ASTM A53: *Standard Specification for Pipe, Steel, Black and Hot-Dipped, Zinc-Coated, Welded and Seamless.* Steel pipe conforming to ASTM A53 is intended for coiling, bending, forming, or other special purposes. Steel pipe that meets the requirements of ASTM A106: *Standard Specification for Seamless Carbon Steel Pipe for High-Temperature Service* is used for high-temperature service and is suitable for coiling, bending, and forming.

Other reference standards for steel pipe are:

- ASTM A135: *Standard Specification For Electric-Resistance-Welded Steel Pipe*
- ASME B16.9: *Factory-made Wrought Steel Buttwelding Fittings*
- ASME B16.11: *Forged Fittings, Socket-Welding and Threaded*
- ASME B16.28: *Wrought Steel Buttwelding Short Radius Elbows and Returns*

Steel pipe may be either seamless (extruded) or welded. The welding of steel piping is accomplished by two methods: continuous or electric-resistance welding (ERW). Continuous welded pipe is heated and formed. Electric-resistance welding is cold rolled and then welded. Steel pipe also may be black iron or galvanized (zinc coated). Galvanized steel pipe is dipped and zinc coated to produce a galvanized protective coating both inside and out.

Steel pipe is produced in three basic weight classifications: standard, extra strong, and double extra strong. Steel pipe in standard weight and various weights or "schedules"—ranging from Schedule 10, also known as "light wall pipe," to Schedule 160—is normally supplied in random lengths of 6 feet to 22 feet (1.8 m to 6.7 m) and is available in ⅛-inch to 24-inch (3.2-mm to 660-mm) diameters. Exceptions to this are butt-welded standard weight and extra strong, which are not available in diameters larger than 4 inches, and butt-welded double extra-strong steel pipe, which is not made in diameters larger than 2½ inches.

Steel pipe conforming to ASTM A135 is made in sizes through 12 inches by the electric-resistance welding method only. Grade A is suitable for flanging or binding. Pipe meeting ASTM A135 is used extensively for light-wall pipe in fire sprinkler systems. See Tables 2-11 and 2-12 for dimensional and capacity data for Schedule 40 and Schedule 80 steel pipe respectively.

The methods of joining are:

- Welding
- Threading
- Grooved

PLASTIC PIPE

Plastic pipe is available in compositions designed for various applications, including DWV, water supply, gas service and transmission lines, and laboratory and other chemical drainage and piping systems.

Fuel double-containment systems; high-purity pharmaceutical or electronic grade water; and R-13, R-13A, R-13D fire protection sprinkler systems are additional uses.

There are two basic types of plastic pipe: thermoset and thermoplastic. A thermoset plastic has the property of being permanently rigid. Epoxy and phenolics are examples of thermosets. A thermoplastic is a material having the property of softening when heated and hardening when cooled. Acrylonitrile butadiene styrene (ABS), polyvinyl chloride (PVC), polybutylene (PB), polyethylene (PE), polypropylene (PP), cross-linked polyethylene (PEX), and chlorinated polyvinyl chloride (CPVC) are thermoplastics. With thermoplastics, consideration must be given to the temperature/pressure relationship when selecting the support spacing and method of installation. Some common plastic pipe materials are discussed below. (See Figure 2-12 and Tables 2-13 and 2-14.)

Polybutylene

Polybutylene is a flexible thermoplastic that was manufactured to pipe and tubing specifications. PB tubing is no longer manufactured but is listed here in the event that repairs or modifications are made to existing systems.

Polybutylene is an inert polyolefin material, meaning that it is chemically resistant. That is why PB pipe cannot be solvent cemented like other plastic piping systems. PB pipe was one of the most flexible piping materials acceptable for potable water. It is typically blue or gray in color.

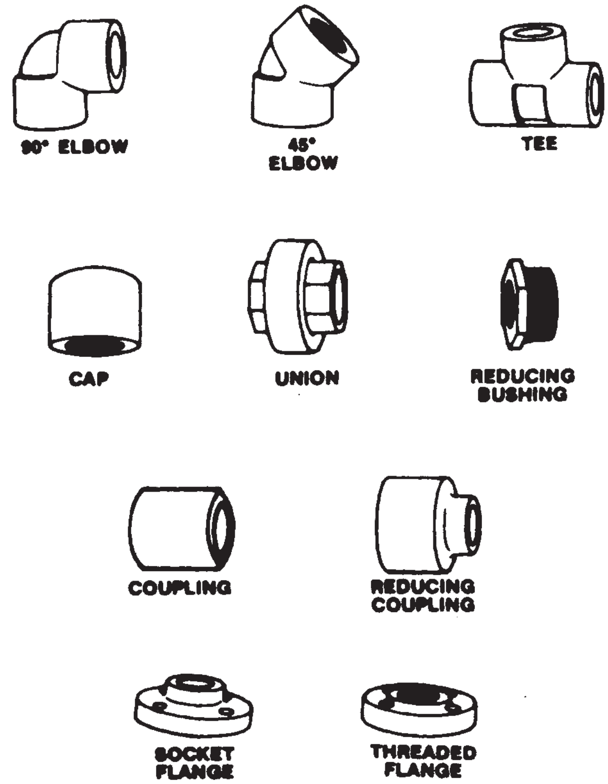


Figure 2-12 Plastic Pipe Fittings

Table 2-13 Plastic Pipe Data

Material	Schedule Numbers	Pipe Sizes (in.)	Fitting Sizes (in.)	Temperature Limit (°F)	Joining Methods
PVC I	40, 80, 120 SDR	¼–20	¼–8	150	Solvent weld, thread, flange, thermal weld
PVC II [a]	40, 80, 120 SDR	¼–20	¼–8	130	Solvent weld, thread, flange, thermal weld
Polypropylene	40–80	½–8	½–8	150	Thermal fusion, flange, thread, compression
CPVC	40–80	½–8	½–8	210	Solvent weld, thread, flange
Poyethylene	40, 80 SDR	½–6	½–6	120–140	Thermal fusion, compression
ABS	40, 80 SDR	⅛–12	½–6	160	Solvent weld, thread, flange
Polybutylene	SDR	¼–6	¼–6	210	Thermal fusion, flare, compression, insert

[a] The usage of PVC II is limited to electrical conduit.

Table 2-13(M) Plastic Pipe Data

Material	Schedule Numbers	Pipe Sizes (in.)	Fitting Sizes (mm)	Temperature Limit (°C)	Joining Methods
PVC I	40, 80, 120 SDR	¼–20	6.4 to 203.2	65.6	Solvent weld, thread, flange,
PVC II [a]	40, 80, 120 SDR	¼–20	6.4 to 203.2	54.4	Solvent weld, thread, flange,
Polypropylene	40–80	½–8	12.7 to 203.2	65.6	Thermal fusion, flange, thread,
CPVC	40–80	½–8	12.7 to 203.2	98.9	Solvent weld, thread, flange
Poyethylene	40, 80 SDR	½–6	12.7 to 152.4	48.9 to 60	Thermal fusion, compression
ABS	40, 80 SDR	⅛–12	3.2 to 152.4	71.1	Solvent weld, thread, flange
Polybutylene	SDR	¼–6	6.4 to 152.4	98.9	Thermal fusion, flare,

[a] The usage of PVC II is limited to electrical conduit.

Table 2-14 Physical Properties of Plastic Piping Materials

Material		Specific Gravity	Tensile Strength (psi at 73°F)	Modulus of Elasticity in Tension (psi at 73°F×105)	Compressive Strength (psi)	Strength Flexural (psi)	Resistance to Heat (continuous) (°F)	Coefficient of Expansion (in./in./°F×10^{-6})	Thermal Conductivity (Btuh ft²/°F/in.)	Burning Rate	Heat Distortion Temp (°F at 264 psi)	Water Absorption at (%/24 hr73°F)	Izod Impact (73°F ft lb/in. notch)
PVC	Type I	1.38	7,940	4.15	9,600	14,500	140	3.0	1.2	Self Extinguishing	160	.05	.65
	Type II [a]	1.35	6,000	3.5	8,800	11,500	140	5.55	1.35	Self Extinguishing	155	.07	2-15
CPVC	Type IV	1.55	8,400	4.2		15,600	210	3.8	.95	Self Extinguishing	221	.05	—
Polyethylene	Type I	.92	1,750	1.9–.35		1,700	120	10.0	2.3	Slow	NA	.01	16
	Type III	.95	2,800	1.5		2,000	120	7.3	3.5	Slow	NA	0.0	3.0
Polypropylene		.91	4,900	1.5	8,500		160–212	3.8	1.3	Slow	150	0.03	2.1
ABS	Type I	1.03	5,300	3.0	7,000	8,000	160	6.0	1.9	Slow	197	.20	5-9
	Type II	1.08	8,000		10,000	12,000	170	3.8	2.5	Slow	225	.20	4
Polyvinylidene	Floride (PDVF)	1.76	7,000	1.2	10,000		200–250	8.5	1.05	Self Extinguishing	195	.04	3.0
	Polybutylene	.93	4,800	.38	—	—	—	7.1	1.5	Slow	NA	< .01	no break

Notes: 1. Above data compiled in accordance with ASTM test requirements.

2. NA = Not Applicable.

a The usage of PVC II is limited to electrical conduit.

Table 2-14(M) Physical Properties of Plastic Piping Materials

Material		Specific Gravity	Tensile Strength (MPa at 22.8°C)	Modulus of Elasticity in Tension (10^5 kPa at 22.8°C×10^5)	Compressive Strength (MPa)	Strength Flexural (MPa)	Resistance to Heat (continuous) (°C)	Coefficient of Expansion (10^{-5} mm/mm/°C)	Thermal Conductivity (W/m²°K)	Burning Rate	Heat Distortion Temp (°C at 1.82 MPa)	Water Absorption at (%/24h at 22.8°C)	Izod Impact (J/mm notch at 22.8°C)
PVC	Type I	1.38	48.26	28.61	66.19	99.98	65.6	127.0	5.96	Self Extinguishing	73.9	0.07	0.04
	Type II [a]	1.25	41.37	24.13	60.67	79.29	60.0	251.73	7.56	Self Extinguishing	68.3	0.07	0.53–0.80
CPVC	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA
Polyethylene	Type I	0.92	12.07	131.0–2.41	—	11.72	48.9	453.57	13.06	Slow	—	–0.01	0.85
	Type III	0.95	13.79	10.34	—	13.79	48.9	331.11	19.87	Slow	—	0	0.16
Polypropylene		0.91	33.79	10.34	58.61	—	71.1–100	172.36	7.38	Slow	65.6	0.03	0.11
ABS	Type I	1.03	36.54	20.68	48.26	55.16	71.1	272.14	10.79	Slow	91.7	0.20	0.27–0.48
	Type II	1.08	55.16	—	68.95	82.74	76.7	172.36	14.20	Slow	107.2	0.20	0.21
Polyvinylidene Floride (PDVF)		1.76	48.26	8.27	68.95	—	93.3–121.1	385.54	5.96	Self Extinguishing	90.6	0.04	0.16
Polybutylene		0.93	33.10	2.62	—	—	—	180.34	8.51	Slow	NA	< .01	no break

Notes: 1. Above data compiled in accordance with ASTM test requirements.

2. NA = Not applicable.

[a] The usage of PVC II is limited to electrical conduit.

Its applications included hydronic slab heating systems, fire sprinklers systems, hot and cold water distribution, and plumbing and water supply.

Joints were made by mechanical, flared, and heat fusion methods.

Applicable standards and specifications include ASTM D3309: *Standard Specification for Polybutylene (PB) Plastic Hot- and Cold-water Distribution Systems* and Canadian Standards Association (CSA) B137.8: *Polybutylene (PB) Piping for Pressure Applications*.

Polyethylene

Polyethylene is an inert polyolefin material, meaning that it is chemically resistant. Polyethylene pipe cannot be solvent cemented like other plastic piping systems. This type of piping typically is supplied in blue or black for water applications. Orange-colored polyethylene piping is typically used for gas pipe installations. Joints are made with inserts and clamps and by heat fusion. PE cannot be threaded or solvent welded. Sizes range from ½ inch to 63 inches (12.7 mm to 1,600.2 mm) in diameter in both iron pipe size (IPS) and copper tube size (CTS). Pressures range from 50 psi to 250 psi depending on wall thickness.

PE is available in two basic resins: 2406 MDPE (medium density) or 3408 HDPE (high density). (An ultra-high molecular weight product also is available.) The two basic types of resin have been used extensively for several decades in low-pressure street main distribution networks for natural and propane gas. MDPE presently is used only in the buried gas transmission industry, in sizes ranging from ½ inch to 16 inches (12.7 mm to 406.4 mm) and is joined by butt and socket fusion.

HDPE comprises 90 percent of the polyethylene piping industry. It has a wide variety of belowground and aboveground applications, including domestic water supply, well water systems, lawn sprinkler systems, irrigation systems, skating rinks, buried chilled water pipe, underground Factory Mutual (FM) approved fire mains, chemical lines, snow-making lines at ski slopes, pressurized chilled water piping underground between buildings and a central heating or cooling plant, methane gas collection piping, leachate collection lines at landfills, relining water and sewer mains to save redigging streets, water transmission mains over highway bridges (it absorbs vibration), brine at skating rinks, and residential swimming pools.

Typically, HDPE is installed with mechanical barbed joints or compression fittings through 2 inches (50.8 mm), and the pipe comes in coils. It is also available heat socket fused from ½ inch to 40 inches (12.7 mm to 1,016 mm), butt fused from 2 inches to 63 inches (50.8 mm to 1,600.2 mm), and electro-fused from 1½ inches to 30 inches (38.1 mm to 762 mm) in diameter.

HDPE comes in a wide variety of fittings and pipe. Depending on the diameter, ½ inch to 2 inches (12.7 mm to 50.8 mm) comes in rolled coils, which can be 100 feet to 5,000 feet (30.5 m to 1,542 m) on special reels, and 2-inch to 63-inch (50.8-mm to 1,600.2-mm) diameter generally comes as 40-foot (12.2-m) pipe lengths.

The designer should not consider HDPE a fixed, rigid, perfectly straight pipe—it bends. When designing systems with HDPE, expansion must be preplanned and best efforts should be made to determine what direction it will take (i.e., bury the pipe in an S or snake pattern to let it try to expand or contract.)

Both pipe and tubing (IPS and CTS) are manufactured using a standard dimension ratio (SDR) series.

The upper operating maximum temperature limit is 160°F, but as always, the manufacturer of the product should be consulted on temperature versus pressure.

The color is typically black for HDPE, which according to ASTM means that 2 percent carbon black has been blended with the resin to give the minimum 50-year life span at full pressure in direct sunlight. Two unique properties of HDPE pipe are that it swells and does not break if it freezes and it floats in water since its specific gravity is 0.95. This is why HDPE pipe can be preassembled, and thousands of feet can be floated to a certain position and then sunk with concrete collars.

The reference standards for polyethylene pipe are:

- ASTM D2239: *Standard Specification for Polyethylene (PE) Plastic Pipe (SIDR-PR) Based on Controlled Inside Diameter*
- ASTM D2609: *Standard Specification for Plastic Insert Fittings for Polyethylene (PE) Plastic Pipe*
- ASTM D2737: *Standard Specification for Polyethylene (PE) Plastic Tubing*
- ASTM D3035: *Standard Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter*
- ASTM F771: *Standard Specification for Polyethylene (PE) Thermoplastic High-pressure Irrigation Pipeline Systems*
- ASTM F810: *Standard Specification for Smoothwall Polyethylene (PE) Pipe for Use in Drainage and Waste Disposal Absorption Fields*
- ASTM F894: *Standard Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe*
- CSA B137.1: *Polyethylene Pipe, Tubing, and Fittings for Cold Water Pressure Services*

The methods of joining are:

- Mechanical joints (barbed joints and compression fittings)
- Heat fusion

Crossed-linked Polyethylene

Crossed-linked polyethylene tubing has been used extensively in Europe for many years for hot and cold potable water distribution systems.

A specially controlled chemical reaction takes place during the manufacturing of the polyethylene pipe to form PEX. Cross-linked molecular structuring gives the pipe greater resistance to rupture over a wider range of temperatures and pressures than other polyolefin piping (PB, PE, and PP).

Because of the unique molecular structure and heat resistance of PEX pipe, heat fusion is not permitted as a joining method. Being a member of the polyolefin plastic family, PEX is resistant to solvents and cannot be joined by solvent cementing. Mechanical connectors and fittings for PEX piping systems are proprietary in nature and must be used only with the pipe for which they have been designed. A number of mechanical fastening techniques have been developed for joining PEX pipe. Manufacturer's installation instructions should be consulted for properly identifying the authorized fittings for the intended system use.

PEX pipe is flexible, allowing it to be bent. It is bent by two methods: hot and cold bending. See manufacturer's instructions for the exact requirements for bending. The tubing can be bent to a minimum radius of six times the outside diameter for cold bending and a minimum of 2½ times the outside diameter for hot bending.

The reference standards for PEX are:

- ASTM F876: *Standard Specification for Crosslinked Polyethylene (PEX) Tubing*
- ASTM F877: *Standard Specification for Crosslinked Polyethylene (PEX) Plastic Hot- and Cold-water Distribution Systems*
- CSA B137.1

PEX is available in nominal pipe size (NPS) ¼ inch through 2 inches (6.4 mm through 51 mm).

The method of joining is mechanical joints (barbed joints and compression fittings).

Crossed-linked Polyethylene, Aluminum, Crossed-linked Polyethylene

PEX-AL-PEX is a composite pipe made of an aluminum tube laminated with interior and exterior layers of cross-linked polyethylene. The layers are bonded with an adhesive.

The cross-linked molecular structuring described above and the addition of the aluminum core makes the pipe resistant to rupture. Therefore, along with other system usages, the pipe is suitable for hot and cold water distribution. The pipe is rated for 125 psi at 180°F (862 kPa at 82°C).

Mechanical joints are the only methods currently available to join PEX-AL-PEX pipe. A number of mechanical compression-type connectors have been developed for joining this type of pipe material to permit transition to other types of pipe and fittings. The installation of any fitting is to be in accordance with the manufacturer's installation instructions.

Although it is partially plastic, PEX-AL-PEX pipe resembles metal tubing in that it can be bent by hand or with a suitable bending device while maintaining its shape without fittings or supports. The minimum radius is five times the outside diameter.

The reference standard for PEX-AL-PEX is ASTM F1281: *Standard Specification for Crosslinked Polyethylene/Aluminum/Crosslinked Polyethylene (PEX-AL-PEX) Pressure Pipe*. It is available in nominal pipe size (NPS) ¼ inch through 1 inch (6.4 mm through 25 mm). The method of joining is mechanical joints (barbed joints and compression fittings).

Polyethylene/Aluminum/Polyethylene

PE-AL-PE is identical to the PEX-AL-PEX composite pipe except for the physical properties of the polyethylene.

Polyethylene does not display the same resistance to temperature and pressure as the cross-linked polyethylene. Therefore, this type of pipe is limited to cold water applications or applications with other suitable fluids up to 110°F at 150 psi (43°C at 1,034 kPa) of pressure.

The reference standards for PE-AL-PE are:

- ASTM F1282: *Standard Specification for Polyethylene/Aluminum/Polyethylene (PE-AL-PE) Composite Pressure Pipe*
- CSA B137.1

It is available in nominal pipe size (NPS) ¼ inch through 1 inch (6.4 mm through 25 mm). The method of joining is mechanical joints (barbed joints and compression fittings).

Polyvinyl Chloride

Polyvinyl chloride is rigid, pressure- or drainage-type pipe that resists chemicals and corrosion. Two types are available: Schedule 40 and Schedule 80. PVC water service piping is a different material than PVC drainage pipe, although both pipe materials are white in color. For pressure, SDR 21 (200 psi) or SDR 26 (160 psi) is used. PVC is used for water distribution, irrigation, storm drainage, sewage, laboratory and hospital wastes, chemical lines, chilled water lines, heat pumps, underground FM-approved fire mains, animal rearing facilities, hatcheries, graywater piping, and ultra-pure water.

The working pressure varies with the temperature. As the temperature increases, tensile strength decreases. The maximum working pressure is to be continuously marked on the pipe along with the manufacturer's name, ASTM or CSA standard, and the grade of PVC material. Temperature should be limited to 140°F to 150°F (60°C to 65.6°C). The joints are solvent welded or threaded. Schedule 40 PVC cannot be threaded, and it can be used only with socket fittings. Schedule 80 can be threaded through the 4-inch (101.6-mm) size and used with either socket or threaded fittings. However, it also can be installed with mechanical-grooved couplings or bell and gasket (underground only and thrust blocked).

The reference standards for PVC are:

- ASTM D1785: *Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe, Schedules 40, 80, and 120*
- ASTM D2241: *Standard Specification for Poly(Vinyl Chloride) (PVC) Pressure-rated Pipe (SDR Series)*
- ASTM D2464: *Standard Specification for Threaded Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80*
- ASTM D2466: *Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 40*
- ASTM D2467: *Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Pipe Fittings, Schedule 80*
- ASTM D2564: *Standard Specification for Solvent Cements for Poly(Vinyl Chloride) (PVC) Plastic Piping Systems*
- ASTM D2665: *Standard Specification for Poly(Vinyl Chloride) (PVC) Plastic Drain, Waste, and Vent Pipe and Fittings*
- ASTM D2672: *Standard Specification for Joints for IPS PVC Pipe Using Solvent Cement*
- ASTM D2729: *Standard Specification for Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings*
- ASTM F477: *Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe*
- CSA B137.1

The pipe classifications and dimensional information are as follows:

- DWV: 1¼ inches to 24 inches (31.75 mm to 609.6 mm)
- Schedule 40: ⅛ inch to 30 inches (3.2 mm to 762 mm)
- Schedule 80: ⅛ inch 30 inches (3.2 mm to 762 mm)
- SDR 21: ¾ inch to 24 inches (22 mm to 609.6 mm), except ½-inch SDR (13.5 mm)
- SDR 26: 1¼ inches to 24 inches (32 mm to 609.6 mm)

The maximum temperature rating for PVC is 140°F (60°C). The coefficient of linear expansion is 2.9×10^{-5} inch/inch/°F. The specific gravity of PVC is 1.40 ± 0.02.

The method of joining is solvent welding.

Chlorinated Polyvinyl Chloride

CPVC finds application in hot and cold water distribution and chemical process piping.

The higher-temperature version of PVC is CPVC pipe. This piping network comes in a variety of pressure applications of CTS or IPS of Schedule 40 or Schedule 80. CPVC has an upper maximum temperature limit of 220°F. It is commonly used and is code accepted where residential water would quickly deteriorate copper pipe. Because of its size ranges—CTS: ½ inch to 2 inches (12.7 mm to 50.8 mm), Schedule 80: ¼ inch 18 inches (6.3 mm to 406.4 mm)—it can be used in a wide variety of hot or cold water systems. CPVC also has been used extensively in wet fire protection systems in hotels, motels, residences, office buildings, and dormitories (all applications that fall in the categories of 13, 13D, and 13R of NFPA). Pipe sizes for fire protection systems are ¾ inch to 3 inches (19 mm to 76.2 mm) and are ideally suited for the retrofit market.

Joining methods are solvent welding, threads, flanges, compression fittings, O-rings, transition fittings, bell rings, and rubber gaskets.

In the last several years, CPVC acid waste (AW) systems have been manufactured and have gained acceptance as a viable replacement for the traditional PP systems. Some of these systems now meet the CSA plenum rating and are working to pass ASTM E84: *Standard Test Method for Surface Burning Characteristics of Building Materials* as well.

The reference standards for CPVC are:

- ASTM D2846/D2846M: *Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Hot- and Cold-water Distribution Systems*
- ASTM F437: *Standard Specification for Threaded Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80*
- ASTM F438: *Standard Specification for Socket-type Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 40*
- ASTM F439: *Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe Fittings, Schedule 80*
- ASTM F441/F441M: *Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe, Schedules 40 and 80*

- ASTM F442/F442M: *Standard Specification for Chlorinated Poly(Vinyl Chloride) (CPVC) Plastic Pipe (SDR-PR)*
- CSA B137.1

The pipe classifications and dimensional information are as follows:

- CTS: ½ inch to 2 inches (12.7 mm to 50.8 mm)
- Schedule 80: ¼ inch to 18 inches (6.3 mm to 406.4 mm)
- Fire protection systems: ¾ inch to 3 inches (19 mm to 76.2 mm)

Note: PVC and CPVC piping systems are not recommended for compressed air or compressed gas lines. Compensation for both thermal expansion and contraction must be taken into account.

Acrylonitrile-butadiene-styrene

ABS is manufactured in Schedules 40 and 80 and in special dimensions for main sewers and utility conduits and in SDR for compressed air. It is commonly used for DWV plumbing (in the color black), main sanitary and storm sewers, underground electrical conduits, and applications in the chemical and petroleum industries. The joints are solvent welded for Schedule 40 and welded or threaded for Schedule 80.

For industrial applications, ABS piping is gray for low temperatures (-40°F to 176°F [-72°C to 80°C]) and pressure up to 230 psi in sizes ½ inch to 8 inches (12.7 mm to 203.2 mm). It is joined only by solvent cementing. The coefficient of linear expansion is 5.6×2^{-5} inch/inch/°F. Fittings are available for pressure only. The outside diameter of the pipe is nominal IPS, and a second product in the industrial area is "airline," which is designed to be used in delivering compressed air for machine tools from 0.63 inch to 4 inches (16 mm to 101 mm).

The reference standards are:

- ASTM D1527: *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe, Schedules 40 and 80*
- ASTM D2235: *Standard Specification for Solvent Cement for Acrylonitrile-Butadiene-Styrene (ABS) Plastic Pipe and Fittings*
- ASTM D2661: *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe and Fittings*
- ASTM D2680: *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) and Poly(Vinyl Chloride) (PVC) Composite Sewer Piping*
- ASTM D2751: *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Sewer Pipe and Fittings*
- ASTM F628: *Standard Specification for Acrylonitrile-Butadiene-Styrene (ABS) Schedule 40 Plastic Drain, Waste, and Vent Pipe With a Cellular Core*
- CSA B137.1

The pipe classifications and dimensional information are as follows:

- Schedule 40: 1½, 2, 3, 4, and 6 inches (38.1, 50, 63, 90, 110, and 160 mm), with the appropriate fittings
- Schedule 80: 1½, 2, 3, 4, and 6 inches (38.1, 50, 63, 90, 110, and 160 mm), with the appropriate fittings

Polypropylene

PP is manufactured for a wide variety of systems. The DWV systems are for chemical, special waste, or acid waste systems, in both buried and aboveground applications. Pipe is available in Schedule 40 or Schedule 80 black (underground) or flame retardant (FR) for aboveground installation. Polypropylene acid waste (AW) pipe systems come with either mechanical joints—sizes 1½, 2, 3, 4, and 6 inches (50, 63, 90, 110, and 160 mm)—or with an internal wire heat fused—sizes 1½, 2, 3, 4, 6, 8, 10, 12, 14, 16, and 18 inches (50, 63, 90, 110, 160, 200, 250, 300, 315, and 350 mm)—molded—sizes 1½ inches to 6 inches (50 mm to 160 mm)—and fabricated—sizes 8 inches to 18 inches (200 mm to 450 mm).

Fittings are made in both pressure-type and DWV configurations. PP is used for a wide range of industrial liquids, salt water disposal, and corrosive waste systems. It is available in sizes of ½ inch to 24 inches (50 mm to 630 mm). Pipe is available in 10-foot and 20-foot (3.05-m and 6.1-m) lengths. The joints cannot be solvent welded. Joints are made mechanically or by heat fusion (electric coil socket fusion, butt fusion, IR welding). (See Figure 2-13.)

Polypropylene systems for acid waste installed aboveground must utilize FR pipe and fittings.

Polypropylene comes in a variety of pressure systems. It can be natural in color for high-purity systems, or it may be black or beige with the added color pigment. Polypropylene pipe is available in both metric and IPS sizes.

Typically, polypropylene is joined by heat fusion, whether small diameter—½ inch to 4 inches (12.7 mm to 101.6 mm)—by socket fusion, or larger diameter—2 inches to 24 inches (50.8 mm to 609.6 mm)—by butt fusion.

Smaller diameter—½ inch to 2 inches (12.7 mm to 50.8 mm)—polypropylene may be joined by threading with a greatly reduced pressure rating, or certain manufacturers have molded fittings with stainless steel rings to restrain or help strengthen the threads for full pressure ratings.

Note: Glue cannot be used to join any polypropylene, polyethylene pipe, or polyvinylidene fluoride.

The reference standards are:

- ASTM F2389: *Standard Specification for Pressure-rated Polypropylene (PP) Piping Systems*
- ASTM F1412: *Standard Specification for Polyolefin Pipe and Fittings for Corrosive Waste Drainage Systems*
- ASTM F1055: *Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene Pipe and Tubing*
- ASTM F1056: *Standard Specification for Socket Fusion Tools for Use in Socket Fusion Joining Polyethylene Pipe or Tubing and Fittings*
- ASTM F1290: *Standard Practice for Electrofusion Joining Polyolefin Pipe and Fittings*

The methods of joining are:

- Mechanical joints
- Heat fusion
- Threaded joints

Double containment of polypropylene systems is a greatly expanded area of the DWV acid waste market. Double-containment polypropylene systems are typically nonflame pipe (NFPP) for underground and flame-retardant pipe (FRPP) for aboveground applications. Double-containment polypropylene can be installed with or without leak-detection systems.

Figure 2-13 Fusion Lock Process in Operation

(See the discussion in the "Double Containment" section below.)

Polyvinylidene Fluoride

PVDF is manufactured in Schedules 40 and 80, as well as SDR for the deionized water market. Polyvinylidene fluoride is a strong, tough, abrasion-resistant fluorocarbon material. It is used widely in high-purity electronic or medical-grade water or chemical piping systems that need to remain pure but function at high temperatures. Other uses include a wide range of industrial liquids, saltwater disposal, and corrosive waste systems, again where high-temperature performance is required. It also is often used for corrosive waste applications in return air plenum spaces. PVDF offers excellent flame- and smoke-resistant characteristics.

The coefficient of thermal expansion is 7.9×2^{-5} inch/inch/°F. It is available in metric and IPS sizes ranging from 0.37 inch to 12 inches (9.5 mm to 304.8 mm). Pipe is available in 10-foot (3.04-m) lengths.

The color is normally natural, and the resin is not affected by ultraviolet (UV) light. However, if the media it is transporting is affected, a red coloring is added to the resin, resulting in a red-colored piping system. Normally, PVDF is available in a pressure system pattern of fittings. What makes PVDF a piping system of choice is its ability to withstand high temperatures for elevated-temperature cleaning.

Fittings are made in both pressure and DWV configurations. It must be noted that a special flame and smoke package is added to the straight PVDF resin when used to manufacture DWV pipe and fittings used in return and supply plenum acid waste applications. (Only these special PVDF pipe and fittings meet the necessary ASTM E84 and the CSA equivalent requirement for plenum installations.) The joints cannot be solvent welded. Joints are made mechanically or by heat fusion (electric coil or socket fusion).

The reference standards are:

- ASTM F1673: *Standard Specification for Polyvinylidene Fluoride (PVDF) Corrosive Waste Drainage Systems*
- ASTM D3222: *Specification for Unmodified Poly(Vinylidene Fluoride) (PVDF) Molding Extrusion and Coating Materials*

Teflon (PTFE)

Teflon, or polytetrafluoroethylene (PTFE), has outstanding resistance to chemical attack by most chemicals and solvents. It has a temperature range of -200°F to 500°F (-128.9°C to 260°C). Teflon typically is considered tubing; however, it can be joined by threading in pipe sizes 0.13 inch to 4 inches (3.2 mm to 101.6 mm). Teflon piping is well suited for low-pressure—not to exceed 15 psi—laboratory or process industry applications. If higher pressure or hotter temperatures are needed, Teflon-lined steel pipe generally is used. Lined steel pipe is 1 inch to 12 inches (25.4 mm to 304.8 mm) and can handle corrosive chemicals as well as high-pressure applications.

Low-extractable PVC

Rather recent to the expensive high-purity piping market is the less expensive low-extractable PVC material that is used in pressure piping loops for the conveyance of ultra-pure water. Pipe and fittings with valves are joined by a special low-extractable solvent cement. Fluids being conveyed cannot exceed 140°F (60°C). Pipe is in Schedule 80 wall thickness and sizes of ½ inch to 6 inches (20 mm to 160 mm).

This piping network provides a very economical solution compared to stainless steel, PVDF, or PP for the engineering of ultra-pure water loops for use in healthcare, laboratory, micro-electronics, pharmaceutical, and various other industrial applications. Tests performed validate that resistivity can be maintained at levels greater than 18 megaohms and online total oxidizable carbon can average less than 5 parts per billion on properly designed and maintained systems.

The reference standards are ASTM D1785 and ASTM D2467. The method of joining is solvent welding.

The pipe classifications and dimensional information are as follows:

- Schedule 40: ⅛ inch to 30 inches (3.2 mm to 762 mm)
- Schedule 80: ⅛ inch to 30 inches (3.2 mm to 762 mm)

Fiberglass and Reinforced Thermosetting Resin Pipe

Fiberglass piping systems are manufactured and joined using epoxy, vinylester, or polyester resins. These three resins offer a very distinct price/performance choice varying from strongest/most expensive to weakest/least expensive. It normally is used in a pressure pattern mode and has good chemical resistance as well as excellent stability in its upper temperature limit of 275°F (135°C). However, it should be noted that the chemical resistance of such systems is provided exclusively by the resin-rich liner on the inside diameter of the system. If worn down, cracked, or compromised in any way, putting the process in direct contact with the glass fibers, leaks will result. Many systems are joined with epoxy resins and heating blankets; however, depending on the manufacturer, they also can be joined mechanically with bell and spigot, plain, or butt and wrap methods. It is manufactured in sizes of 1 inch to 48 inches (25.4 mm to 1,219 mm) and can be custom made in much larger diameters. It is especially helpful in resisting attacks from the various oils used in the petroleum industry.

Different products require different approvals. Some must meet American Petroleum Institute (API), Underwriters Laboratories (UL), or military (MIL) specifications. For potable water, they must meet National Sanitation Foundation (NSF) 14: *Plastics Piping System Components and Related Materials* per ASTM D2996: *Standard Specification for Filament-wound Fiberglass (Glass Fiber-reinforced Thermosetting Resin) Pipe* or ANSI/NSF 61: *Drinking Water System Components* for drinking water.

The coefficient of linear thermal expansion is 1.57×2^{-5} inch/inch/°F.

As with all plastics, certain considerations must be reviewed before installation. These include code compliance, chemical compatibility, correct maximum temperature, and allowance for proper expansion and contraction movement. Certain plastics are installed with solvent cements; others require heating to join piping networks along with mechanical joints. The designer should consult the manufacturer's recommendations for the proper connection of all piping systems.

VITRIFIED CLAY PIPE

Vitrified clay pipe is used in a building sewer starting outside of the building and connecting to the main sewer. It also is used for industrial waste because of its outstanding corrosion and abrasion resistance.

The reference standards are:

- ASTM C12: *Standard Practice for Installing Vitrified Clay Pipe Lines*
- ASTM C425: *Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings*
- ASTM C700: *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated*
- ASTM C1208: *Standard Specification for Vitrified Clay Pipe and Joints for Use in Microtunneling, Sliplining, Pipe Bursting, and Tunnels*
- ASTM C301: *Standard Test Methods for Vitrified Clay Pipe*
- ASTM C828: *Standard Test Method for Low-pressure Air Test of Vitrified Clay Pipe Lines*
- ASTM C1091: *Standard Test Method for Hydrostatic Infiltration and Exfiltration Testing of Vitrified Clay Pipe Lines*
- ASTM C896: *Standard Terminology Relating to Clay Products*

Vitrified clay pipe is extruded from a suitable grade of shale or clay and fired in kilns at approximately 2,000°F (1,100°C). Vitrification takes place at this temperature, producing an extremely hard and dense, corrosion-resistant material. Clay pipe is suitable for most gravity-flow systems and is not intended for pressure service. Available sizes include 3-inch to 48-inch (75-mm to 1,220-mm) diameters and lengths up to 10 feet (3.05 m) in standard or extra-strength grades as well as perforated. See Tables 2-15 and 2-16.

Pipe and fittings are joined with prefabricated compression seals.

DURIRON PIPE

Duriron is a 14.5 percent silicon iron that possesses nearly universal corrosion resistance. For nearly a century, duriron pipe and fittings have provided a durable and reliable means of transporting corrosive waste safely. Over the last few decades, however, thermoplastics (such as PVC, PP, and PVDF) have replaced duriron in most laboratory, school, and hospitals applications because of their even greater inertness to many chemicals, light weight, and ease of installation.

Duriron hub-and-spigot pipe and fittings are available in sizes from 2 inches to 15 inches and are

Table 2-15 Dimensions of Class 1 Standard Strength Perforated Clay Pipe

Size (in.)	Laying length		Maximum difference in length of two opposite sides (in.)	Outside diameter of barrel (in.)		Inside diameter of socket at 1/2 in. above base, (in.) Min.	Rows of perfora-tions	Perforations per row				Depth of socket (in.)		Thickness of barrel (in.)		Thickness of socket at 1/2 in. from outer end (in.)	
	Min.	Limit of minus variation (in. per ft. of length		Min.	Max.			2 ft.	3 ft.	4 ft.	5 ft.	Nominal	Min.	Nominal	Min.	Nominal	Min.
4	2	1/4	5/16	4 7/8	5 1/8	5 3/4	4	7	9	11	13	1 3/4	1 1/2	1/2	7/16	7/16	3/8
6	2	1/4	3/8	7 1/16	7 7/16	8 3/16	4	7	9	11	13	2 1/4	2	5/8	9/16	1/2	7/16
8	2	1/4	7/16	9 1/4	9 3/4	10 1/2	4	7	9	11	13	2 1/2	2 1/4	3/4	11/16	9/16	1/2
10	2	1/4	7/16	11 1/2	12	12 3/4	6	7	9	11	13	2 5/8	2 3/8	7/8	13/16	5/8	9/16
12	2	1/4	7/16	13 3/4	14 5/16	15 1/8	6	—	—	—	—	2 3/4	2 1/2	1	15/16	3/4	11/16
15	3	1/4	1/2	17 3/16	17 13/16	18 5/8	6	—	10	14	17	2 7/8	2 5/8	1 1/4	1 1/8	15/16	7/8
18	3	1/4	1/2	20 5/8	21 7/16	22 1/4	8	—	10	14	17	3	2 3/4	1 1/2	1 3/8	1 1/8	1 1/16
21	3	1/4	9/16	24 1/8	25	25 7/8	8	—	10	14	17	3 1/4	3	1 3/4	1 5/8	1 5/16	1 3/16
24	3	3/8	9/16	27 1/2	28 1/2	29 3/8	8	—	10	14	17	3 3/8	3 1/8	2	1 7/8	1 1/2	1 3/8

Source: Table from ASTM Specification C700.

Table 2-15(M) Dimensions of Class 1 Standard Strength Perforated Clay Pipe

Size (in.)	Laying Length		Maximum Difference in Length of 2 Opposite Sides (mm)	Outside Diameter of Barrel (mm)		Inside Diameter of Socket at 12.7 mm Above Base (mm)
	Minimum (m)	Limit of Minus Variation (mm/m)		Minimum	Maximum	
4	0.61	20.8	7.94	123.83	130.18	146.05
6	0.61	20.8	9.53	179.39	188.91	207.96
8	0.61	20.8	11.11	234.95	247.65	266.70
10	0.61	20.8	11.11	292.10	304.80	323.85
12	0.61	20.8	11.11	349.25	363.54	348.18
15	0.94	20.8	12.70	436.56	452.44	473.08
18	0.94	20.8	12.70	523.88	544.51	565.15
21	0.94	20.8	14.29	612.78	635.00	657.23
24	0.94	31.3	14.29	698.50	723.90	746.13

Size (in.)	Rows of Perfora-tions	Perforations per Row				Depth of Socket (mm)		Thickness of Barrel (mm)		Thickness of Socket at 12.7 mm from Outer End (mm)	
		0.61 m	0.91 m	1.22 m	1.52 m	Nominal	Minimum	Nominal	Minimum	Nominal	Minimum
4	4	7	9	11	13	44.45	38.10	12.70	11.11	11.11	9.53
6	4	7	9	11	13	57.15	50.80	15.88	14.29	12.70	11.11
8	4	7	9	11	13	63.50	57.15	19.05	17.46	14.29	12.70
10	6	7	9	11	13	66.68	60.33	22.23	20.64	15.88	14.29
12	6	—	—	—	—	69.85	63.50	25.40	23.81	19.05	17.46
15	6	—	10	14	17	73.03	66.68	31.75	28.58	23.81	22.23
18	8	—	10	14	17	76.20	69.85	38.10	34.93	28.58	26.99
21	8	—	10	14	17	82.55	76.20	44.45	41.28	33.34	30.16
24	8	—	10	14	17	85.73	79.38	50.80	48.63	38.10	34.93

Source: Table from ASTM Specification C700.

Table 2-16 Dimensions of Class 1 Extra Strength Clay Pipe

Size (in.)	Laying length		Maximum difference in length of two opposite sides (in.)	Outside diameter of barrel (in.)		Inside diameter of socket at ½ in. above base, (in.)	Depth of socket (in.)		Thickness of barrel (in.)		Thickness of socket at ½ in. fromouter end (in.)	
	Min.	Limit of minus variation (in. per ft. of length		Min.	Max.	Min.	Nominal	Min.	Nominal	Min.	Nominal	Min.
4	2	¼	5⁄16	4⅞	5⅛	5¾	1¾	1½	⅝	9⁄16	7⁄16	⅜
6	2	¼	⅜	7 1⁄16	7 7⁄16	8 3⁄16	2¼	2	11⁄16	9⁄16	½	7⁄16
8	2	¼	7⁄16	9¼	9¾	10½	2½	2¼	⅞	¾	9⁄16	½
10	2	¼	7⁄16	11½	12	12¾	2⅝	2⅜	1	⅞	⅝	9⁄16
12	2	¼	7⁄16	13¾	14 5⁄16	15⅛	2¾	2½	1 3⁄16	1 1⁄16	¾	11⁄16
15	3	¼	½	17 3⁄16	17 13⁄16	18⅝	2⅞	2⅝	1½	1⅜	15⁄16	⅞
18	3	¼	½	20⅝	21 7⁄16	22¼	3	2¾	1⅞	1¾	1⅛	1 1⁄16
21	3	¼	9⁄16	24⅛	25	25⅞	3¼	3	2¼	2	1 5⁄16	1 3⁄16
24	3	⅜	9⁄16	27½	28½	29⅜	3⅜	3⅛	2½	2¼	1½	1⅜
27	3	⅜	⅝	31	32½	33	3½	3¼	2¾	2½	1 11⁄16	1 9⁄16
30	3	⅜	⅝	34⅜	35⅝	36½	3⅝	3⅜	3	2¾	1⅞	1¾
33	3	⅜	⅝	37⅝	38 15⁄16	39⅞	3¾	3¼	3¼	3	2	1¾
36	3	⅜	11⁄16	40¾	42¼	43¼	4	3¾	3½	3¼	2 1⁄16	1⅞

Source: Table from ASTM Specification C700.

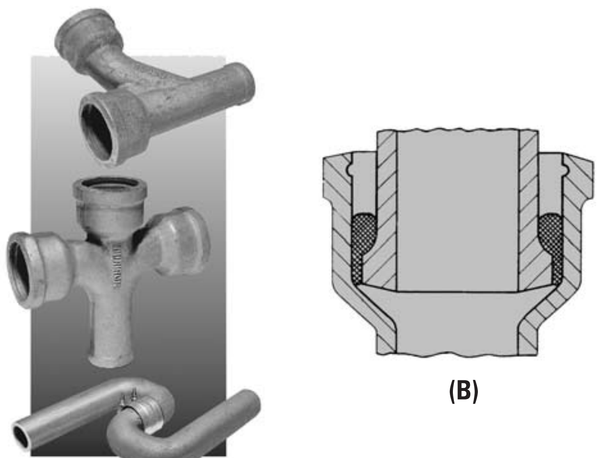
Table 2-16(M) Dimensions of Class 1 Extra Strength Clay Pipe

Size (in.)	Laying Length		Maximum Difference in Length of 2 Opposite Sides (mm)	Outside Diameter of Barrel (mm)		Inside Diameter of Socket at 12.7 mm Above Base (mm)
	Minimum (m)	Limit of Minus Variation (mm/m)		Minimum	Maximum	
4	0.61	20.8	7.94	123.83	130.18	146.05
6	0.61	20.8	9.53	179.39	188.91	207.96
8	0.61	20.8	11.11	234.95	247.65	266.70
10	0.61	20.8	11.11	292.10	304.80	323.85
12	0.61	20.8	11.11	349.25	363.54	384.18
15	0.91	20.8	12.70	436.56	452.44	473.08
18	0.91	20.8	12.70	523.88	544.51	565.15
21	0.91	20.8	14.29	612.78	635.00	657.23
24	0.91	31.3	14.29	698.50	723.90	746.13
27	0.91	31.3	15.88	787.40	815.98	838.20
30	0.91	31.3	15.88	873.13	904.88	927.10
33	0.91	31.3	15.88	955.68	989.01	1012.83
36	0.91	31.3	17.46	1035.05	1073.15	1098.55

Size (in.)	Depth of Socket (mm)		Thickness of Barrel (mm)		Thickness of Socket at 12.7 mm from Outer End (mm)	
	Nominal	Minimum	Nominal	Minimum	Nominal	Minimum
4	44.45	38.10	15.88	14.29	11.11	9.53
6	57.15	50.80	17.46	14.29	12.70	11.11
8	63.50	57.15	22.23	19.05	14.29	12.70
10	66.68	60.33	25.40	22.23	15.88	14.29
12	69.85	63.50	30.16	26.99	19.05	17.46
15	73.03	66.68	38.10	34.93	23.81	22.23
18	76.20	69.85	47.63	44.45	28.58	26.99
21	82.55	76.20	57.15	50.80	33.34	30.16
24	85.73	79.38	63.50	57.15	38.10	34.93
27	88.90	82.55	69.85	63.50	42.86	39.69
30	92.08	85.73	76.20	69.85	47.63	44.45
33	95.25	88.90	82.55	76.20	50.80	44.45
36	101.60	95.25	88.90	82.55	52.39	47.63

Source: Table from ASTM Specification C700.

Note: There is no limit for plus variation.



(B)

(A)

Figure 2-14 Duriron Pipe (A) Duriron Joint (B)

Source: Courtesy of Duriron.

installed using traditional plumbing techniques. (See Figure 2-14.) Duriron mechanical joint pipe and fittings are available from 1½ inches to 4 inches and offer ease of installation through the use of couplings.

The duriron bell-and-spigot joint is made using conventional plumbing tools, virgin lead, and a special acid-resistant caulking yarn. The caulking yarn is packed into the bell of the duriron joint, and a small amount of lead is poured over the yarn to fill the hub. It is the caulking yarn, not the lead, that seals the joint.

Duriron mechanical joints are designed for fast and easy assembly through the use of the two-bolt mechanical coupling. A calibrated ratchet is necessary to complete the joint. The nuts are tightened to 10 feet per pound 24 hours prior to testing.

The reference standards for duriron pipe are:

- ASTM A861: *Standard Specification for High-silicon Iron Pipe and Fittings*
- ASTM A518/A518M: *Standard Specification for Corrosion-resistant High-silicon Iron Castings*

Duriron is similar to cast iron hub-and-spigot pipe and fittings. It has a hub into which the spigot (plain end) of the pipe or fitting is inserted. Hub-and-spigot pipe and fitting sizes include 2-inch to 15-inch diameters and 5-foot or 10-foot (1.5-m or 3.1-m) lengths.

SPECIAL-PURPOSE PIPING MATERIALS

Stainless steel and aluminum are the most common special-purpose piping materials used for a wide range of applications where performance requirements outweigh costs. Stainless steel and aluminum require specialized skills in design and fabrication. Many alloys are available for specific applications.

Aluminum

Aluminum is extruded or drawn in a variety of alloys. Its uses include cryogenic systems with temperatures as low as -423°F (-252.8°C), process systems, heat transfer, and pressure lines. The joints can be brazed or welded. It should be noted that special techniques often are required, depending on the type of alloy. Aluminum is available in 8-inch through 48-inch diameters, depending on the type.

Stainless Steel

The designation “stainless steel” applies to a number of alloys with different properties. Common to all stainless steels is the fact that they contain at least 12 percent chromium. Stainless steel is manufactured in three basic types: martensitic (hardenable, straight chromium alloy), ferritic (straight chromium, for corrosive service where nickel steel is undesirable), and austenitic (18 percent chromium and 8 percent nickel, for general corrosive service). The joints can be butt welded, socket welded, screwed, or flanged. Pipe and fittings are available in ⅛-inch through 48-inch diameters.

Stainless steel is a clean, durable, corrosion-resistant, and long-lasting material. Products are chemically descaled (acid pickled) to enhance the natural corrosion resistance and to provide a uniform, aesthetically pleasing matte-silver finish.

Stainless steel is used where sanitation and product contamination resistance are critical (dairies, food processing, etc.). In processing systems, stainless steel is used to resist corrosion. All stainless steels have inherent corrosion resistance, but the austenitic group of stainless steels has the greatest resistance to many different chemical products and most detergents. Austenitic steels also have an excellent ability to resist impacts and shocks at all temperatures. Hard blows to the material may cause dents in certain cases, but it is very difficult to actually damage the steel.

Other uses include applications in the food industry, shipbuilding, pharmaceutical industry, breweries and dairies, industrial kitchens, and institutions. When increased acid resistance is required and spot and crevice corrosion may occur, molybdenum-alloyed chromium-nickel steels may be used. These acid-resistant steels resist a number of organic and inorganic acids. However, acid-proof steels are only partially resistant to solutions containing chlorides.

Stainless steel cannot burn and consequently is classified as nonflammable. This means that pipes and drains made of stainless steel may penetrate floor partitions without the need for special fire insulation. Likewise, no harmful fumes or substances are released from the steel in the event of fire.

Due to their very low heat expansion coefficient, drain products in stainless steel are not in any way influenced by temperatures occurring in drain installations. Furthermore, drain products need not be stored or installed at specific temperatures. Neither heat nor cold affects stainless steel.

Stainless steel piping is manufactured in two different grades: 304, which is suitable for most environments, and 316, which is suitable for corrosive environments. Piping is available in single hub. Pipes are available in eight lengths: 0.5, 0.8, 1.6, 3.3, 4.9, 6.6, 9.8, and 16.4 feet (150, 250, 500, 1,000, 1,500, 2,000, 3,000, and 5,000 mm) and 2 inches to 6 inches (50.8 mm to 152.4 mm). It is necessary to determine the lengths required between fitting location points and to select the pipe lengths that best minimize waste and eliminate field cuts when possible. A stainless steel piping system is lightweight and easy to install. A pipe joint can be made in a few seconds.

Corrugated Stainless Steel Tubing

Corrugated stainless steel tubing (CSST) is a flexible gas piping system made from 300 series stainless steel. The tubing is suitable for natural gas and propane. It can be used for both aboveground and underground installations. See specific manufacturer's recommendations for underground use and installation. The tubing is protected with a fire-retardant polyethylene jacket. It is manufactured in ⅜-inch to 2-inch (9.52-mm to 50.8-mm) sizes and in coils of up to 1,000 feet (304.8 m) based on pipe sizes.

Mechanical joints are the only methods currently available to join CSST tubing. A number of mechanical compression-type connectors have been developed for joining this type of pipe material to permit transition to other types of pipe and fittings. The installation of any fitting is to be in accordance with the manufacturer's installation instructions.

Manufacturers have specific protective devices and termination fittings for their products. The designer should consult with the manufacturer for all required accessories.

DOUBLE CONTAINMENT

Double containment (DC) has proven to be needed both underground and aboveground for a multitude of purposes. Typically, to avoid a failed single-wall chemical pipe, a second walled enclosure pipe is added. DC is marketed for preventing corrosive chemicals from getting into soils or spilling from a single-wall overhead pipe to people or objects below. Now DC is available in both drainage and pressure systems.

Double containment is most commonly available in PVC DWV × PVC DWV, PVC Schedule 40/80 × PVC DWV; PVC 40/80 × PVC 40/80 CPVC 80 × PVC 80; DWV PP × DWV PP; FRP × FRP. However, DC system are also available with materials such as PVDF as well as any metals and a limitless combination of dissimilar materials (both plastics and metals mixed together). It can be ordered with or without a leak detection, which can be a continuous cable (single use or re-usable), point of collections, or non-wetted sensors.

DC currently is not governed by ASTM standards, but an attempt is being made to eliminate as many fabricated inner fittings as possible, especially for drainage.

When planning for DC, the designer should leave plenty of space. Labor costs are five to seven times those for installing single-wall pipe. When testing DC, the designer should double-check manufacturer's requirements for procedures to test inner and outer pipe. A simple DC size variation is 6 inches inner diameter and 10 inches outer diameter, so a great difference in size exists. A typical 6-inch trap may take up 15 inches to 18 inches, and a 6-inch by 10-inch trap may take up 48 inches of space. Thus, maintaining pitch requires a very different site plan and pitch elevation plan.

JOINING PRACTICES

Mechanical Joints

Mechanical joints include transition (flanged), compression, and threaded joints. Mechanical joints shall incorporate a positive mechanical system for axial restraint in addition to any restraint provided by friction. All internal grab rings shall be manufactured from corrosion-resistant steel. Polyethylene sealing rings shall be Type 1 (LDPE) compound.

Compression Joints

Compression-type gaskets have been used in pressure pipe joints for years. The compression joint uses hub-and-spigot pipe and fittings (as does the lead and oakum joint). The major difference is the one-piece neoprene rubber gasket. When the spigot end of the pipe or fitting is pulled or drawn into the gasketed hub, the joint is sealed by displacement and compression of the neoprene gasket. The resulting joint is leak free, and it absorbs vibration and can be deflected up to 5 degrees without leaking or failing.

Gaskets are precision molded of durable neoprene. Service gaskets must be used with service weight pipe and fittings. Extra-heavy gaskets must be used with extra-heavy pipe and fittings. The standard specification for rubber gaskets for joining cast iron soil pipe and fittings is ASTM C564: *Standard Specification for Rubber Gaskets for Cast Iron Soil Pipe and Fittings*.

Neoprene does not support combustion, and gasket materials can be used safely up to 212°F. Maximum deflection should not exceed ½ inch per foot of pipe. This allows 5 inches of deflection for a 10-foot piece of pipe and 2½ inches for 5 feet of pipe. For more than 5 degrees of deflection, fittings should be used.

Lead and Oakum Joints (Caulked Joints)

Hub-and-spigot cast iron soil pipe and fitting joints can be made with oakum fiber and molten lead, which provides a leak-free, strong, flexible, and root-proof joint. The waterproofing characteristics of oakum fiber have long been recognized by the plumbing trades, and when molten lead is poured over the oakum in a cast iron soil pipe joint, it completely seals and locks the joint. This is because the hot lead fills a groove in the bell end of the pipe or fitting, firmly anchoring the lead in place after cooling.

To make a caulked joint, the spigot end of a pipe or fitting is placed inside the hub of another pipe or fitting. Oakum is placed around the spigot in the hub using a yarning tool, and then the oakum is packed to the proper depth using a packing tool. Molten lead is then poured into the joint, ensuring that the lead is brought up near the top of the hub.

After the lead has cooled sufficiently, it is caulked with a caulking tool to form a solid lead insert. The result is a lock-tight soil pipe joint with excellent flexural characteristics. If horizontal joints are to be made, a joint runner must be used to retain the molten lead. Customary safety precautions should be taken when handling molten lead.

Shielded Hubless Coupling

The shielded coupling for hubless cast iron soil pipe and fittings is a plumbing concept that provides a more compact arrangement without sacrificing the quality and performance of cast iron. The hubless coupling system typically uses a one-piece neoprene gasket, a shield of stainless steel retaining clamps. The hubless coupling is manufactured in accordance with CISPI 310 and ASTM C1277: *Standard Specification for Shielded Couplings Joining Hubless Cast Iron Soil Pipe and Fittings.*

The great advantage of the system is that it permits joints to be made in limited-access areas. 300 series stainless steel is always used with hubless couplings because of its superior corrosion resistance. It is resistant to oxidation, warping and deformation, offers rigidity under tension with substantial tension strength, and provides sufficient flexibility. The shield is corrugated in order to grip the gasket sleeve and to give maximum compression distribution to the joint.

The stainless steel worm gear clamps compress the neoprene gasket to seal the joint. The neoprene gasket absorbs shock and vibration and completely eliminates galvanic action between the cast iron and the stainless steel shield. Neoprene does not support combustion and can be used safely up to 212°F. The neoprene sleeve is completely protected by a nonflammable stainless steel shield, and as a result, a fire rating is not required. Joint deflection using a shielded hubless coupling has a maximum limit of up to 5 degrees. Maximum deflection should not exceed ½ inch per foot of pipe. This allows 5 inches of deflection for a 10-foot piece of pipe. For more than 5 degrees of deflection, fittings should be used.

Mechanically Formed Tee Fittings for Copper Tube

Mechanically formed tee fittings shall be formed in a continuous operation consisting of drilling a pilot hole and drawing out the tube surface to form a tee having a height of not less than three times the thickness of the branch tube wall so as to comply with the American Welding Society's lap joint weld. The device shall be fully adjustable to ensure proper tolerance and complete uniformity of the joint. (See Figure 2-15.)

The branch tube shall be notched to conform to the inner curve of the run tube and have two dimple/depth stops pressed into the branch tube, one ¼ inch (6.4 mm) atop the other so as to serve as a visual point of inspection. The bottom dimple ensures that penetration of the branch tube into the tee is of sufficient depth for brazing and that the branch tube does not obstruct the flow in the main line tube. Dimple/depth stops shall be in line with the run of the tube.

Mechanically formed tee fittings shall be brazed in accordance with the Copper Development Association's *Copper Tube Handbook* using BCuP series filler metal.

Note that soldered joints are not permitted. Mechanically formed tee fittings shall conform to ASTM F2014: *Standard Specification for Non-Reinforced Extruded Tee Connections for Piping Applications,* ANSI B31.9: *Building Services Piping*, and ASME B31: *Standards of Pressure Piping*.

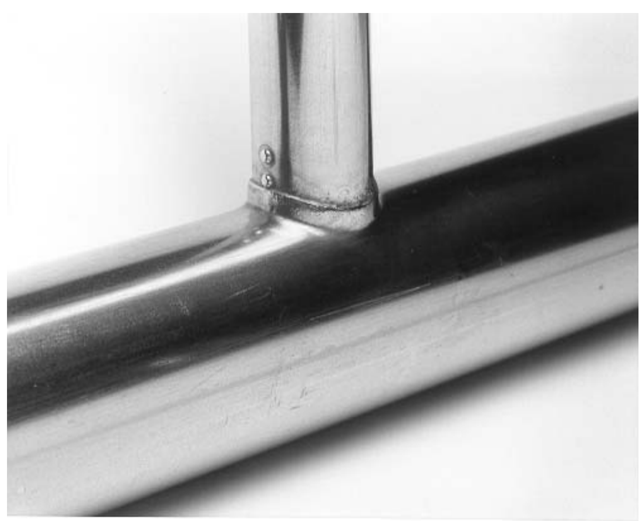


Figure 2-15 Copper Pipe Mechanical T-joint

Source: Courtesy of T-Drill.

Mechanical Joining of Copper Tube

Press Connect and Push Connect

Press-connect and push-connect copper joining systems provide fast and clean installations for both aboveground and belowground applications. The systems do not require heat, which offers faster and safer installation. Joints made using these systems are capable of withstanding pressure and temperature ranges common to residential and commercial plumbing systems.

Roll Groove

Roll groove is another form of mechanical joining that does not require heat. Many manufacturers provide pipe and fittings already roll grooved for faster installation.

Brazing

"Brazing" is defined as a process where the filler metals (alloys) melt at a temperature greater than 840°F, and the base metals (tube and fittings) are not melted. The most commonly used brazing filler metals melt at temperatures from 1,150°F to 1,550°F.

Soldering

"Soldering" is defined as a process wherein the filler metal (solder) melts at a temperature of less than 840°F, and the base metals (tube and fittings) are not melted. The most commonly used leak-free solders melt at temperatures from 350°F to 600°F. Lead-free solders must contain less than 0.2 percent lead (Pb) to be classified as "no lead."

Soldered joints should be installed in accordance with the requirements, steps, and procedures outlined in ASTM B828: *Standard Practice for Making Capillary Joints by Soldering of Copper and Copper Alloy Tube and Fittings* and the procedures found in the *Copper Tube Handbook*.

Fluxes used for the soldering of copper and copper alloys should be those meeting the requirements of ASTM B813: *Standard Specification for Liquid and Paste Fluxes for Soldering Applications of Copper and Copper Alloy Tube.*

Joining Plastic Pipe

PEX

PEX connections are made using PEX press stainless steel sleeves or PEX crimp rings. The connection must meet or exceed the requirement of ASTM F877 or the appropriate fitting standard.

Vinyls and ABS

Schedule 80 plastic piping systems can be solvent welded or threaded. Schedule 40 can only be solvent welded.

The use of cleaners is not always a must. However if dirt, grease, oil, or surface impurities are present on the areas to be jointed, a cleaner must be used. Cleaners must be allowed to evaporate completely before proceeding.

Primers are used to prepare (soften) the surfaces of the pipe and fitting so that the fusion process can occur. Unlike with the cleaner, the primer must be wet when proceeding to the cement. Specially formulated one-step cements (no primer required) are available.

Cements must be material specific and must be selected based on the application (pressure, nonpressure, chemicals, sizes, temperatures, etc.).

Assembling Flanged Joints

The face of the flange should be cleaned with a solvent-soaked rag to remove any rust-preventive grease. Any dirt should be cleaned from the gasket. The pipe and the flanges should be aligned to eliminate any strain on the coupling. The gasket should be coated with graphite and oil or some other recommended lubricant, inserted, and then bolted. Thread lubricant should be applied to the bolts. The bolts should be evenly tightened with a wrench. The nuts should be hand tightened. When tightening the bolts, care should be exercised that they are diametrically opposed; adjacent bolts never should be tightened.

Making Up Threaded Pipe

Male and female threads should be cleaned with a wire brush. Pipe dope should be applied only to the male thread. (If dope is applied to the female thread, it will enter the system). The pipe and coupling should be aligned and hand tightened and then finished by turning with a wrench. A few imperfect threads should be left exposed. Sections of the assembled piping should be blown out with compressed air before being placed in the system.

Thread Cutting

The pipe should be cut with a pipe cutter. It should be clamped in a vise and the pipe stock and die engaged with short jerks. When the cutter catches, it should be pulled slowly with a steady movement using both hands. Enough cutting oil should be used during the cutting process to keep the die cool and the edges clean. The die should be backed off frequently to free the cutters, and the follower should be watched when reversing the dies against the jumping threads, cross-threading, or the stripping of threads. Leaky threaded joints are usually caused by faulty or improper lubricants.

Welding

Basic welding processes include electric arc, oxyacetylene, and gas shielded. Commercial welding fittings are available with ends designed for butt welding or for socket-joint welding. The type of joint used depends on the type of liquid, pressure in the system, pipe size and material, and applicable codes. The butt

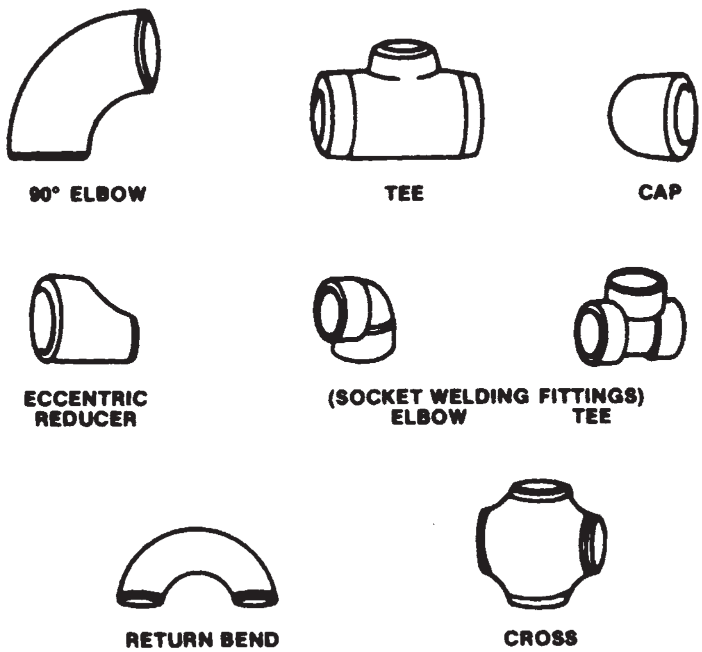


Figure 2-16 Typical Welding Fittings

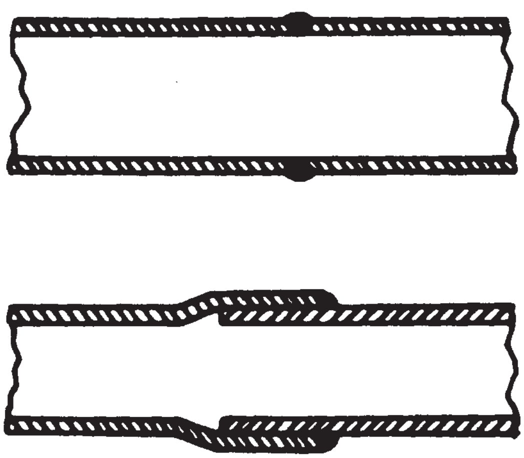


Figure 2-17 Types of Welded Joints

joint frequently is used with a liner (backing ring). (See Figures 2-16 and 2-17.)

Electric Arc Welding

Electric arc welding is used for standard, extra-heavy, or double extra-heavy commercial steel pipe. ASTM A53 grades of low-carbon steel butt-welded pipe are the most weldable.

Oxyacetylene Welding

In this welding process, the flame develops a temperature to 6,300°F (3,482.2°C), completely melting commercial metals to form a bond. The use of a rod increases strength and adds extra metal to the seam. This process is used with many metals (iron, steel, stainless steel, cast iron, copper, brass, aluminum, bronze, and other alloys) and can be used to join dissimilar metals. When cut on site, the pipe ends must be beveled for welding. This can be accomplished with an oxyacetylene torch.

Gas-shielded Arcs

This process is good for nonferrous metals since flux is not required, producing an extremely clean joint. The two types of gas-shielded arc are tungsten inert gas (TIG) and metallic inert gas (MIG). Gas-shielded arcs are used for aluminum, magnesium, low-alloy steel, carbon steel, stainless steel, copper nickel, titanium, and others.

Joining Glass Pipe

The joints are either bead to bead or bead to plain end. The bead-to-bead coupling is used for joining factory-beaded or field-beaded end pipe and fittings. The bead-to-plain-end coupling is used to join a pipe section or fitting that has a beaded end to a pipe section that has been field cut to length and is not beaded.

Bending Pipe and Tubing

Pipe bending (cold or hot method) typically is done with a hydraulic pipe bender. The radius of the bend should be large enough to free the surface of cracks or buckles (see ANSI B31.1). Some bends are designed specifically to be creased or corrugated. Corrugated bends are more flexible than conventional types and may have smaller radii. Straight sections of pipe sometimes are corrugated to provide flexibility. Copper tube typically is bent with a spring tube bender, grooved wheel and bar, bending press, or machine. Sharp bends are made by filling the pipe with sand or other material to prevent flattening or collapsing. Bending pipe or tubing is easier and more economical than installing fittings. Bends reduce the number of joints (which could leak) and also minimize friction loss through the pipe.

Electrofusion Joining

Electrofusion is a heat-fusion joining process wherein a heat source is an integral part of the fitting. Where electric current is applied, heat is produced, melting and joining the components. Fusion occurs when the joint cools below the melting temperature of the material. The applicable standard is ASTM F1290.

ACCESSORIES AND JOINTS

Anchors

Anchors are installed to secure piping systems against expansion or contraction and to eliminate pipe variation. During the installation of anchors, damage to building walls or steel must be prevented. Common anchor materials are strap steel, cast iron, angles, steel plate, channels, and steel clamps. (See Figure 2-18.)

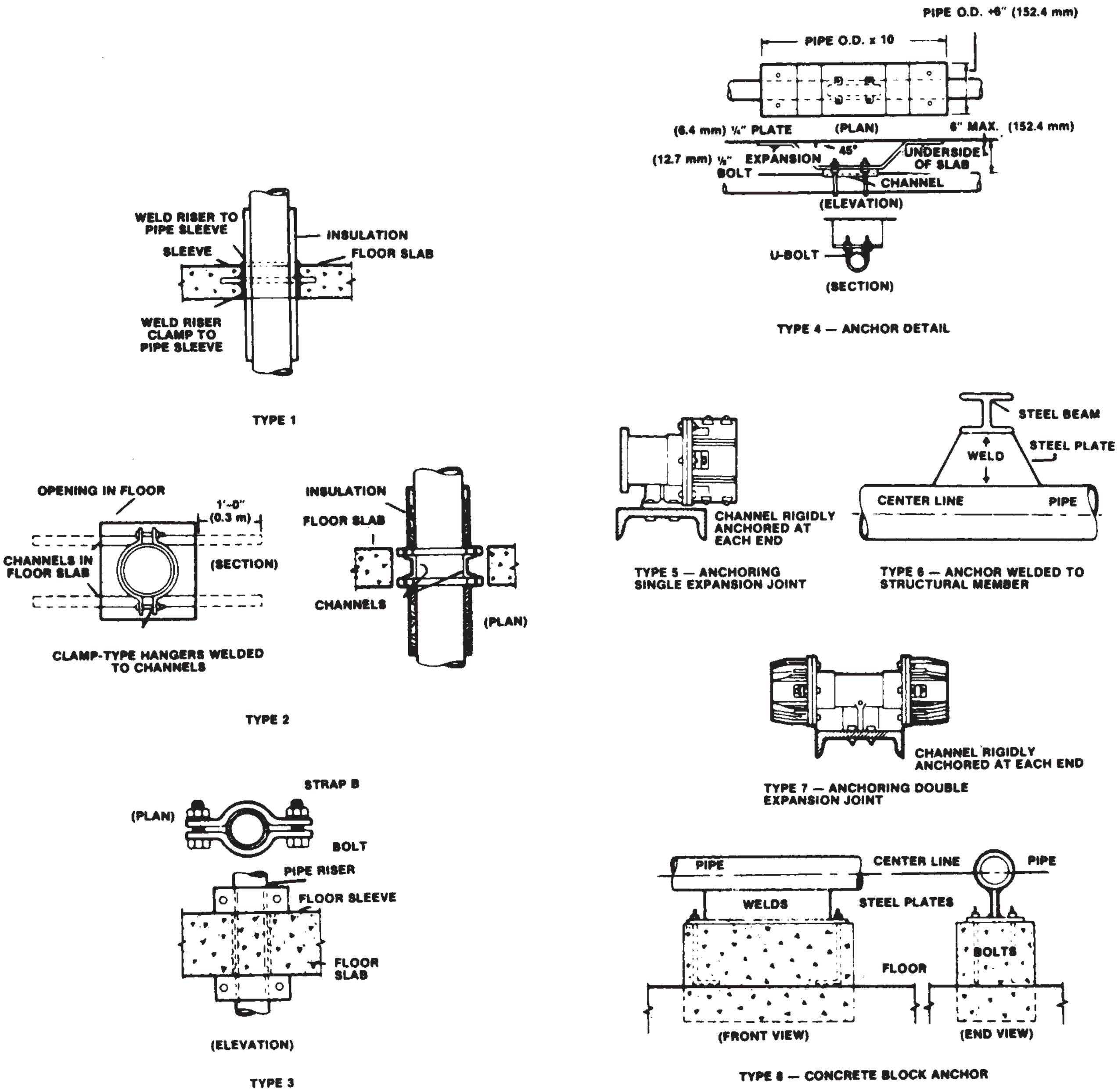


Figure 2-18 Anchors and Inserts

Dielectric Unions or Flanges

Dielectric unions or flanges are installed between ferrous and nonferrous piping to resist corrosion. Dielectric fittings prevent electric current from flowing from one part of the pipe to another. The spacer should be suitable for the system pressure and temperature. (See Figure 2-19.)

Expansion Joints and Guides

Expansion joints and guides are designed to permit free expansion and contraction and to prevent excessive bending at joints, hangers, and connections to the equipment caused by heat expansion or vibration. Expansion guides should be used where the direction of the expansion is critical. (See Figure 2-20.)

Ball Joints

Ball joints are used in hydronic systems, where pipe flexibility is desired, for positioning pipe, and where rotary or reciprocal movement is required. Ball joints are available with threaded, flanged, or welded ends of stainless steel, carbon steel, bronze, or malleable iron.

Flexible Couplings (Compression or Slip)

Flexible couplings do not require the same degree of piping alignment as flanges and threaded couplings. They provide ¼ inch to ⅜ inch (6 mm to 9.5 mm) of axial movement because of the elasticity in the gaskets. These couplings should not be used as slip-

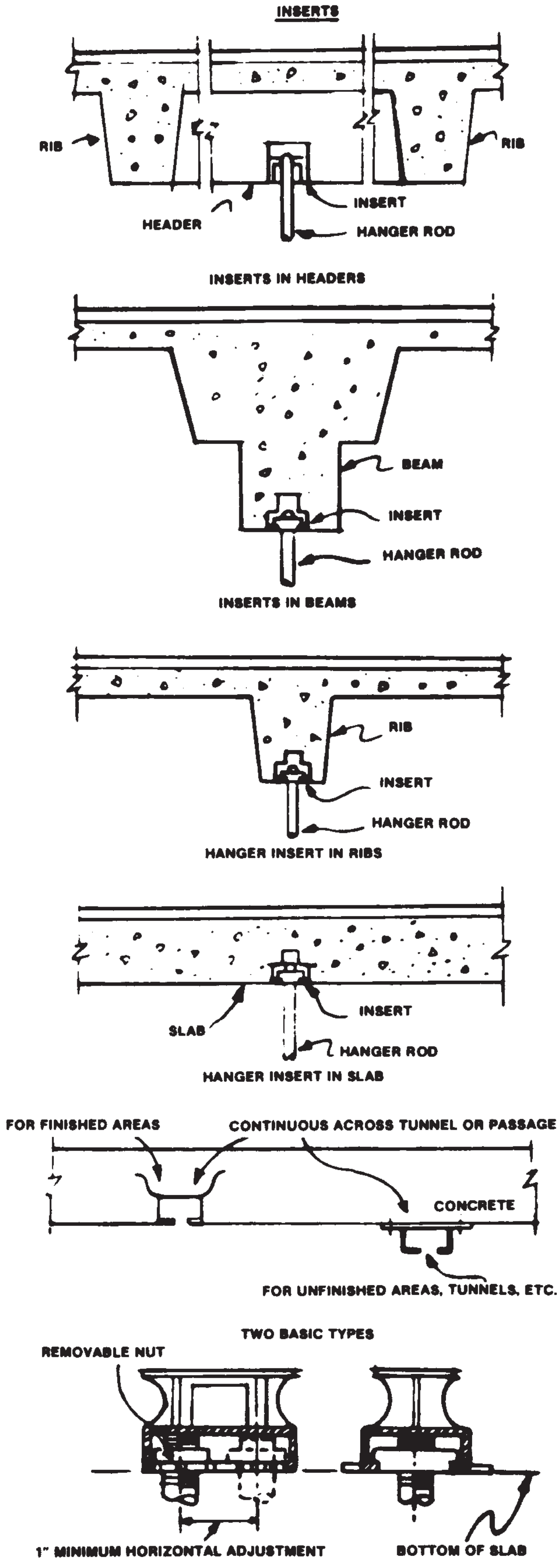


Figure 2-18 Anchors and Inserts (continued)

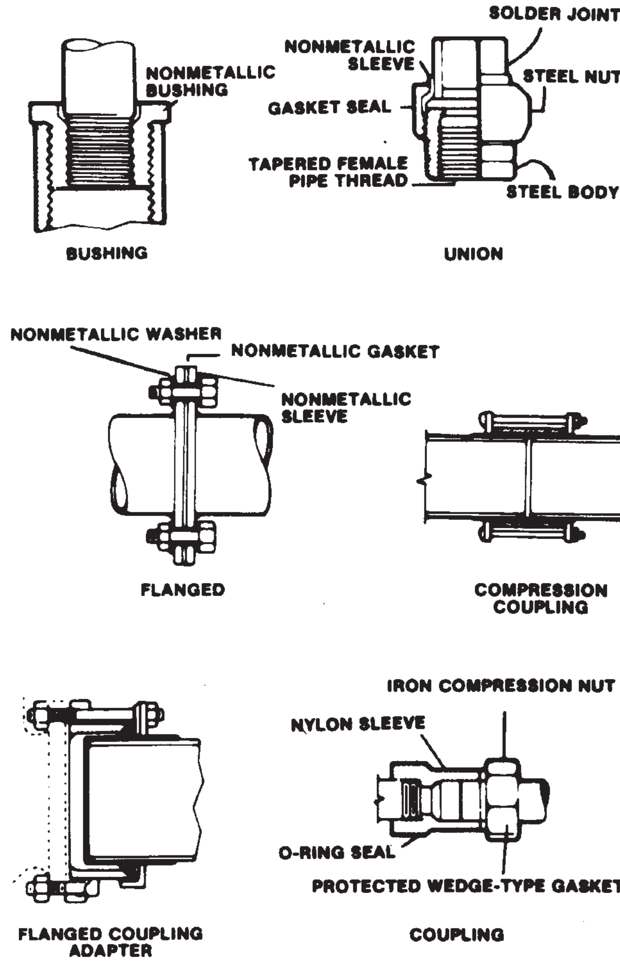


Figure 2-19 Dielectric Fittings

type expansion joints or as replacements for flexible expansion joints. (See Figure 2-21.)

Gaskets (Flanged Pipe)

Gaskets must withstand pressure, temperature, and attack from the fluid in the pipe. Gaskets normally should be as thin as possible. ANSI B16.21: *Nonmetallic Flat Gaskets for Pipe Flanges* designates the dimensions for nonmetallic gaskets.

Mechanical Couplings

Mechanical couplings are self-centering, lock-in-place grooves or shouldered pipe and pipe fitting ends. The fittings provide some angular pipe deflection, contraction, and expansion. Mechanical couplings often are used instead of unions, welded flanges, screwed pipe connections, or soldered tubing connections. Mechanical couplings are available for a variety of piping materials, including steel and galvanized steel, cast iron, copper tubing, and plastics. Bolting methods are standard and vandal resistant. The gasketing material varies based on the fluid in the piping system. (See Figure 2-22.)

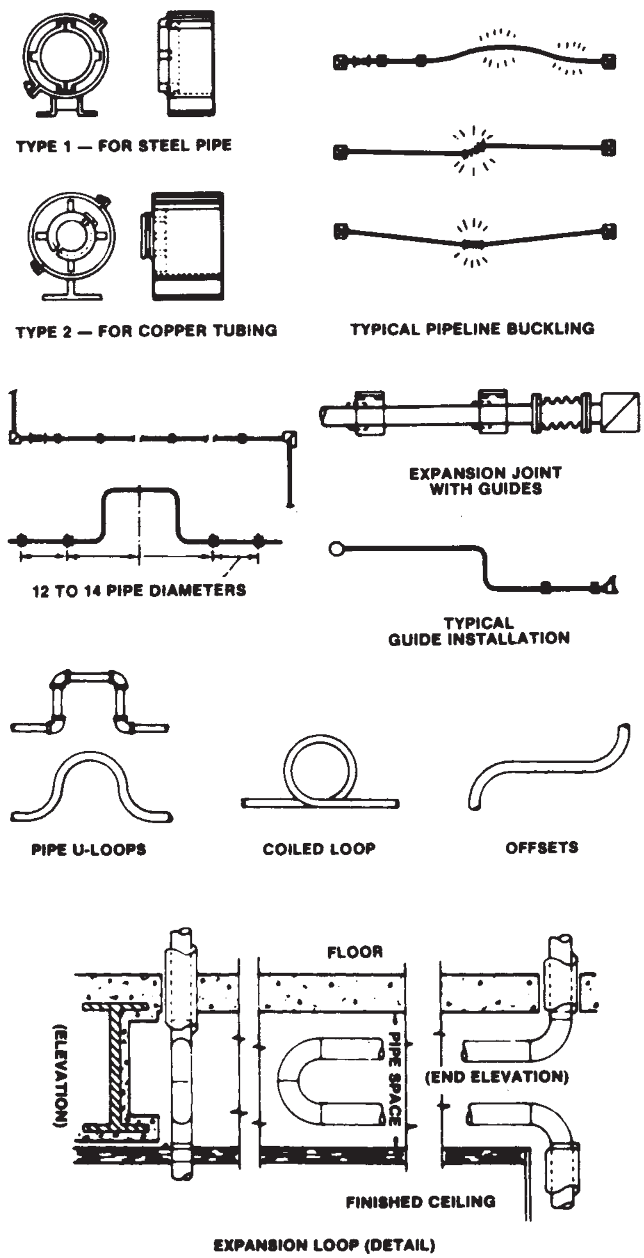


Figure 2-20 Expansion Joints and Guides

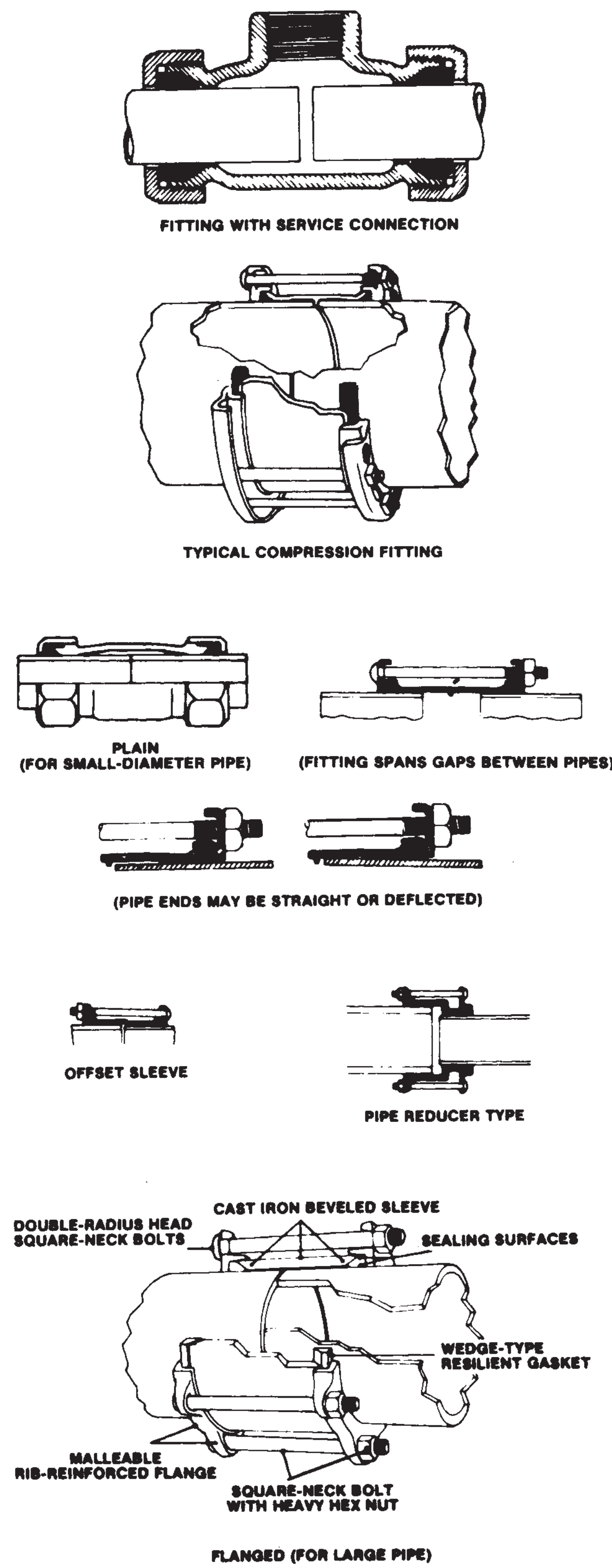


Figure 2-21 Compression Fittings

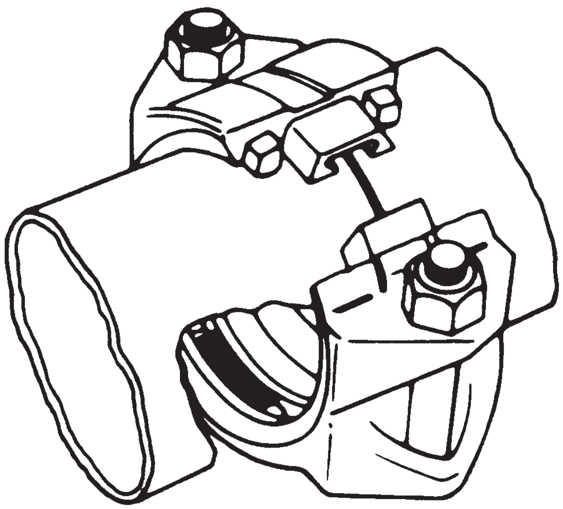


Figure 2-22 Mechanical Joint

Hangers and Supports

Pipe should be securely supported with an ample safety factor. Horizontal suspended pipe should be hung using adjustable pipe hangers with bolted, hinged loops or turnbuckles. Chains, perforated strap irons, or flat steel strap hangers are not acceptable. Pipes 2 inches in diameter and smaller (supported from the side wall) should have an expansion hook plate. Pipes 2½ inches in diameter and larger (supported from the side wall) should have brackets and clevis hangers. Rollers should be provided wherever necessary. Trapeze hangers, holding several pipes, may be preferred over individual pipeline hangers. For individual hangers of pipes 2 inches in diameter and smaller, clevis hangers should be used. Where hangers are attached to concrete slabs, the slabs should have more concrete-reinforcing rods at the point of support. The risers can be supported vertically using approved methods such as resting on the floor slab with an elbow support, resting on the floor sleeve with a clamp, or anchoring to the wall.

Consideration also must be given to seismic conditions in pipe hanging. The designer should consult with local, state, and all other governing agencies for specific requirements.

Pipe supports should be spaced according to the following:

- Less than ¾-inch pipe: On 5-foot (1.5-m) centers
- 1-inch and 1¼-inch pipe: On 6-foot (1.8-m) centers
- 1½-inch to 2½-inch pipe: On 10-foot (3.1-m) centers
- 3-inch and 4-inch pipe: On 12-foot (3.7-m) centers
- 6-inch and larger pipe: On 15-foot (4.6-m) centers

Pipes installed in finished trenches or tunnels should rest on a suitable sidewall or floor supports. (See Figure 2-23.)

Hanger and Support Installation for Copper Piping

The hanger spacing and rod size requirements given are from MSS SP-69: *Pipe Hangers and Supports—Selection and Application*. Designers should consult the local plumbing, mechanical, or building code for required hanger spacing requirements.

First, install hangers for horizontal piping with the maximum spacing and minimum rod sizes as shown in Table 2-17. Then, support vertical copper tube, copper pipe, or brass pipe at each floor. Finally, in areas where excessive moisture is anticipated, either the piping or the support shall be wrapped with an approved tape or otherwise isolated to prevent contact between dissimilar metals and inhibit galvanic corrosion of the supporting member.

Table 2-17 Maximum and Minimum Rod Sizes for Copper Piping

Nominal Tube Size, in.	Copper Tube Maximum Span, ft	Minimum Rod Diameter, in.
Up to ¾	5	⅜
1	6	⅜
1¼	7	⅜
1½	8	⅜
2	8	⅜
2½	9	½
3	10	½
3½	11	½
4	12	½
5	13	½
6	14	⅝
8	16	¾
10	18	¾
12	19	¾

Pipe Unions (Flanged Connections)

Pipe unions are installed at several locations to facilitate dismantling. They typically are installed near the control valves, regulators, water heaters, meters, check valves, pumps, compressors, and boilers so that equipment can be readily disconnected for repair or replacement. (See Figure 2-24 and Table 2-18.)

Pipe Sleeves

For pipes passing through walls, sleeves should extend completely through the construction, flush with each

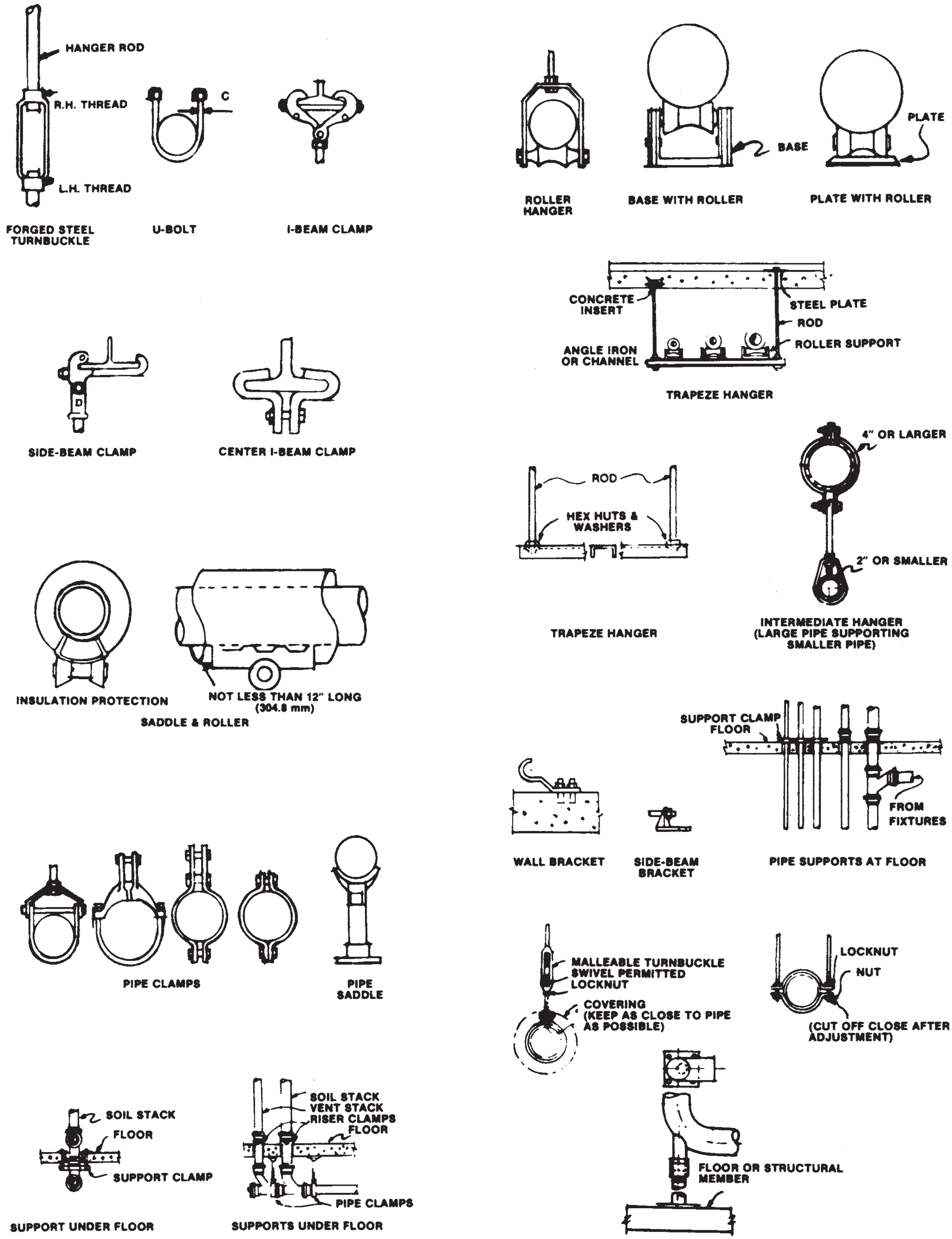


Figure 2-23 Hangers, Clamps, and Supports

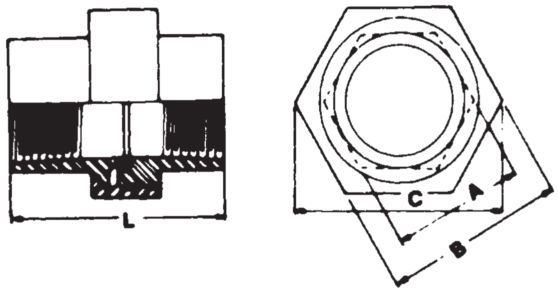


Figure 2-24 Pipe Union

surface. The sleeves should be caulked with graphite packing and a suitable plastic waterproof caulking compound. Pipe sleeves in rated walls are to be installed to suit the specific manufacturer's hourly fire rating. Packing and sealing compounds are to be the required thickness to meet the specific hourly ratings assembly.

Sleeves in bearing walls should be of steel, cast iron, or terra-cotta pipe. Sleeves in other masonry structures may be of sheet metal, fiber, or other suitable material. Sleeves for 4-inch pipe and smaller should be at least two pipe sizes larger than the pipe passing through. For larger pipes, sleeves should be at least one pipe size larger than the enclosed pipe. The inside diameter of pipe sleeves should be at least ½ inch (12.7 mm) larger than the outside diameter of the pipe or covering. (See Figure 2-25.)

Service Connections (Water Piping)

Hand-drilled, self-tapping saddle, or cut-in sleeves should be used. Two types of cut-in sleeves are available: for pressures to 50 psi (344.7 kPa) and for pressures to 250 psi (1,727.7 kPa). Tapping valves are for working pressures of 175 psi (1,206.6 kPa) for 2-inch to 12-inch (50.8-mm to 304.8-mm) pipe and 150 psi (1,034.2 kPa) for 16-inch pipe.

PIPING EXPANSION AND CONTRACTION

Piping, subject to changes in temperature, expands (increases in length) and contracts (decreases in length), and each material has its own characteristics. Piping expands as the temperature increases and contracts as the temperature decreases. The coefficient of expansion (CE) of a material is the material's characteristic unit increase in length per 1°F (0.56°C) temperature increase. Values for CE of various materials are given in *Marks' Standard Handbook for Mechanical Engineers* and manufacturer literature.

Provisions must be made for the expansion and contraction of piping. If the piping is restrained, it will be subject to compressive (as the temperature increases) and tensile (as the temperature decreases) stresses. The piping usually withstands the stresses; however, failures may occur at the joints and fittings.

Common methods to absorb piping expansion and contraction are the use of expansion joints, expansion loops, and offsets.

Table 2-18 Pipe Union Dimensions

	Standard								Normal Engagement	
	A		B		C		L			
Pipe Size (in.)	(250 lb) (in.)	(113.5 kg) (mm)	(250 lb) (in.)	(113.5 kg) (mm)	(250 lb) (in.)	(113.5 kg) (mm)	(250 lb) (in.)	(113.5 kg) (mm)	(in.)	(mm)
⅛	0.505	12.8	0.935	23.8	1.080	27.4	1.484	37.7	¼	6.4
¼	0.638	16.2	1.113	28.3	1.285	32.6	1.641	41.7	⅜	9.5
⅜	0.787	20.0	1.264	32.1	1.460	37.1	1.766	44.9	⅜	9.5
½	0.950	24.1	1.456	37.0	1.681	42.7	2.000	50.8	½	12.7
¾	1.173	29.8	1.718	43.6	1.985	50.4	2.141	54.4	9⁄16	14.3
1	1.440	36.6	2.078	52.8	2.400	61.0	2.500	63.5	11⁄16	17.5
1¼	1.811	46.0	2.578	65.5	2.978	75.6	2.703	68.7	11⁄16	17.5
1½	2.049	52.1	2.890	73.4	3.338	84.8	2.875	73.0	11⁄16	17.5
2	2.563	65.1	3.484	88.5	4.025	102.2	3.234	82.1	¾	19.1
2½	3.109	79.0	4.156	105.6	4.810	122.2	3.578	90.9	15⁄16	23.8
3	3.781	96.0	4.969	126.2	5.740	145.8	3.938	100.0	1	25.4

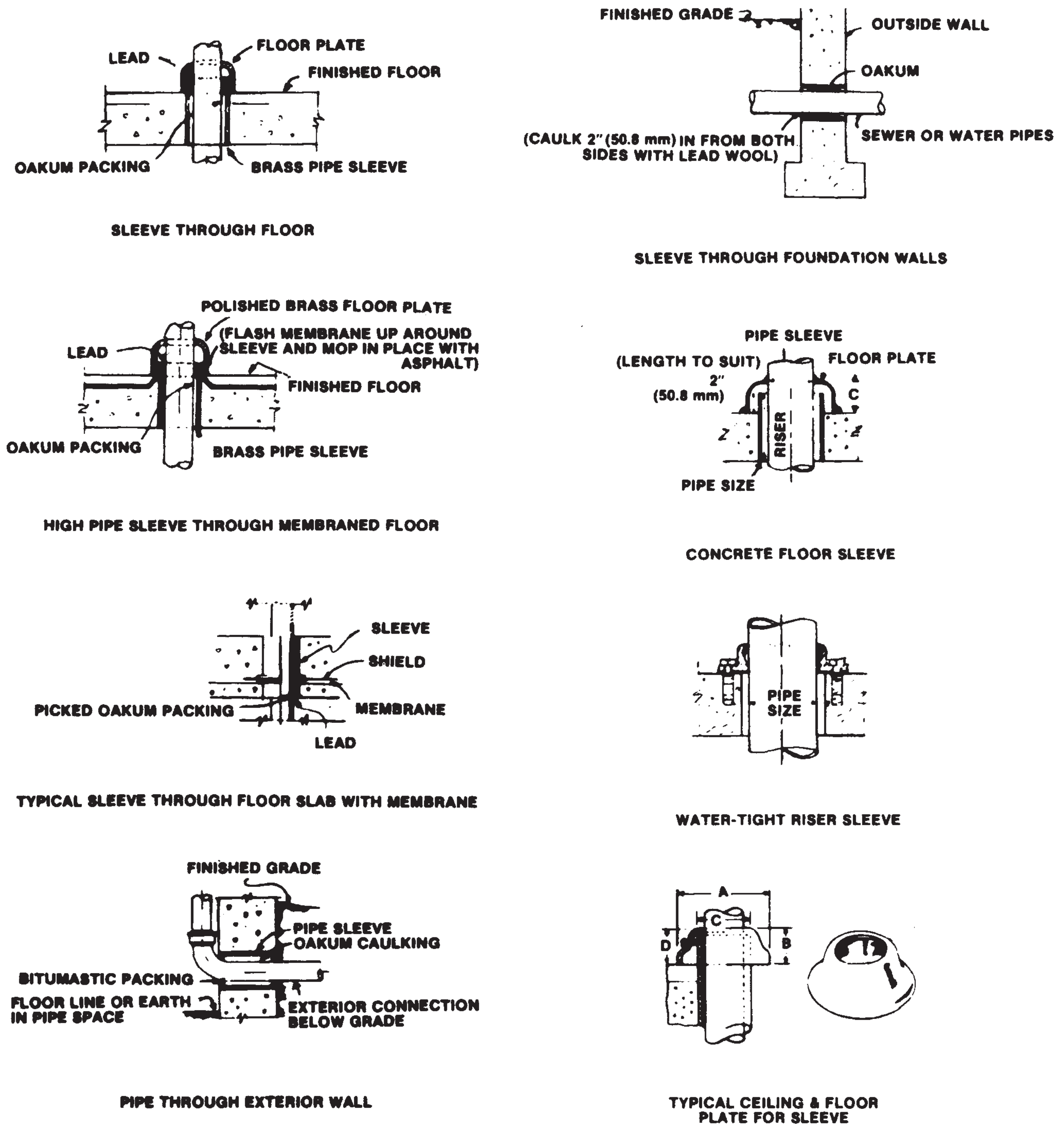


Figure 2-25 Sleeves

3 Valves

Valves serve the purpose of controlling the fluids in building service piping. They come in many shapes, sizes, design types, and materials to accommodate different fluids, piping, pressure ranges, and types of service. Proper selection is important to ensure the most efficient, cost-effective, and long-lasting systems. No single valve is best for all services. This chapter is limited to manually operated valves that start, stop, and regulate flow and prevent its reversal.

APPROVAL ORGANIZATIONS AND STANDARD PRACTICES

The following organizations publish standards and guidelines governing the use of valves:

- Manufacturers Standardization Society (MSS)
- Underwriters Laboratories (UL)
- Factory Mutual (FM)
- American Petroleum Industries (API)

MSS standard practices regarding valves are as follows:

- SP-25: *Standard Marking System for Valves, Fittings, Flanges, and Unions*
- SP-42: *Class 150 Corrosion-resistant Gate, Globe, Angle, and Check Valves with Flanged and Butt-weld Ends*
- SP-67: *Butterfly Valves*
- SP-70: *Gray Iron Gate Valves, Flanged and Threaded Ends*
- SP-71: *Gray Iron Swing Check Valves, Flanged and Threaded Ends*
- SP-72: *Ball Valves with Flanged or Butt-welding Ends for General Service*
- SP-78: *Cast Iron Plug Valves, Flanged and Threaded Ends*
- SP-80: *Bronze Gate, Globe, Angle, and Check Valves*
- SP-81: *Stainless Steel, Bonnetless, Flanged Knife Gate Valves*
- SP-85: *Cast Iron Globe and Angle Valves, Flanged and Threaded Ends*
- SP-110: *Ball Valves Threaded, Socket-Welding, Solder Joint, Grooved and Flared Ends*

A large number of former MSS standard practices have been approved by the American National Standards Institute (ANSI) as ANSI standards. To maintain a single source of authoritative information, MSS withdraws its standard practices when they are approved as ANSI Standards.

GLOSSARY

Ball valve A valve consisting of a single drilled ball that is operated by a handle attached to the vertical axis of the ball, which permits fluid flow in a straight-through direction. The ball within the valve body may be rotated fully opened or fully closed by a one-quarter turn of the handle.

Body That part of the valve that attaches to the pipeline or equipment—with screwed ends, flanged ends, or soldered/welded joint ends—and encloses the working parts of the valve.

Bonnet The part of the valve housing through which the stem extends. It provides support and protection to the stem and houses the stem packing. It may be screwed or bolted to the body.

Butterfly valve A type of valve consisting of a single disc that is operated by a handle attached to the disc, which permits fluid flow in a straight-through direction. The valve is bidirectional. The disc within the valve body may be rotated fully open or fully closed by a one-quarter turn of the handle.

Cap The top part of the housing of a check valve (equivalent to the bonnet of a gate or globe valve), which may be either screwed or bolted onto the main body.

Check valve An automatic, self-closing valve that permits flow in only one direction. It automatically closes by gravity when liquid ceases to flow in that direction.

Clapper A common term that is used to describe the disc of a swing-type check valve.

Disc The disc-shaped device that is attached to the bottom of the stem and is brought into contact with or lifted off the seating surfaces to close or open a globe valve or butterfly valve.

Flanged bonnet A type of bonnet so constructed that it attaches to the body by means of a flanged, bolted connection. The whole bonnet assembly, including the hand wheel, stem, and disc, may be quickly removed by unscrewing the nuts from the bonnet stud bolts.

Full port A term meaning that the area through the valve is equal to or greater than the area of standard pipe.

Gate valve A valve that is used to open or close off the flow of fluid through a pipe. It is so named because of the wedge (gate) that is either raised out of or lowered into a double-seated sluice to permit full flow or completely shut off flow. The passageway through a gate valve is straight through, uninterrupted, and the full size of the pipeline into which the valve is installed.

Gland bushing A metal bushing installed between the packing nut and the packing to transmit the force exerted by the packing nut against the packing.

Globe valve A valve that is used for throttling or regulating the flow through a pipe. It is so named because of the globular shape of the body. The disc is raised off a horizontal seating surface to permit flow or lowered against the horizontal seating surface to shut off flow. The disc may be lifted completely to permit full flow or lifted only slightly to throttle or regulate flow. The flow through a globe valve has to make two 90-degree turns.

Hand wheel The wheel-shaped turning device by which the stem is rotated, thus lifting or lowering the disc or wedge.

Hinge pin The valve part that the disc or clapper of a check valve swings.

Lift check valve A check valve using a disc that lifts off the seat to allow flow. When flow decreases, the disc starts closing and seals before reverse flow occurs.

Outside screw and yoke (OS&Y) A type of bonnet so constructed that the operating threads of the stem are outside the valve housing, where they may be lubricated easily and do not come into contact with the fluid flowing through the valve.

Packing A general term describing any yielding material used to affect a tight joint. Valve packing is generally "jam packing." It is pushed into a stuffing box and adjusted from time to time by tightening down a packing gland or packing nut.

Packing gland A device that holds and compresses the packing and provides for additional compression by manual adjustment of the gland as wear of the packing occurs. A packing gland may be screwed or bolted in place.

Packing nut A nut that is screwed into place and presses down upon a gland bushing, which transmits the force exerted by the packing nut to the packing. It serves the same purpose as the packing gland.

Rising stem A threaded component that is unscrewed or screwed through the bonnet to open or close the valve. The hand wheel may rise with the stem, or the stem may rise through the hand wheel.

Screwed bonnet A type of bonnet so constructed that it attaches to the body by means of a screwed joint. A bonnet may be attached to the body by screwing over the body or inside the body or by means of a union-type screwed connection.

Solid wedge A wedge consisting of one solid piece into which the valve stem is attached, so it seals against the valve seating surfaces to ensure a tight seal when the valve is closed.

Split wedge A wedge consisting of two pieces into which the valve stem is screwed, so it expands the two pieces against the valve seating surfaces to ensure a tight seal when the valve is closed.

Standard port A term meaning that the area through the valve is less than the area of standard pipe.

Stem The usually threaded shaft to which the hand wheel is attached at the top and the disc or wedge at the lower end. The stem also may be called the "spindle."

Stop plug An adjusting screw that extends through the body of a check valve. It adjusts and controls the extent of movement of the disc or clapper.

Swing check valve A check valve that uses a hinged disc or clapper to limit the direction of flow. The pressure exerted by the fluid flowing through the valve forces the disc away from the seating surface. When the flow ceases, the clapper falls to its original position, preventing flow in the opposite direction.

Union A coupling fitting consisting of three parts (a shoulder piece, thread piece, and ring) that is used for coupling the ends of pipe sections. Adjoining faces of shoulder and thread pieces are lapped together to form a tight joint. Unions permit easy disconnection for repair and replacement of piping and fittings.

Union bonnet A type of bonnet that is so constructed that the whole bonnet assembly, including the hand wheel, stem, and disc assembly, may be removed quickly by unscrewing the bonnet union ring from the valve body.

Union ring A large nut-like component that secures the union thread and the union shoulder together. It slips over and against the shoulder piece and screws onto the union thread piece.

Union shoulder piece A part of the union fastened to the pipe that retains the union ring.

Union threaded piece The part of the union that is fastened to the pipe and has external threads over which the union ring is screwed to effect a coupling.

Wedge The wedge-shaped device that fits into the seating surfaces of a gate valve and is drawn out of contact with the seating surfaces to permit flow or is pushed down into contact with the seating surfaces to close off flow with the valve. (See also disc.)

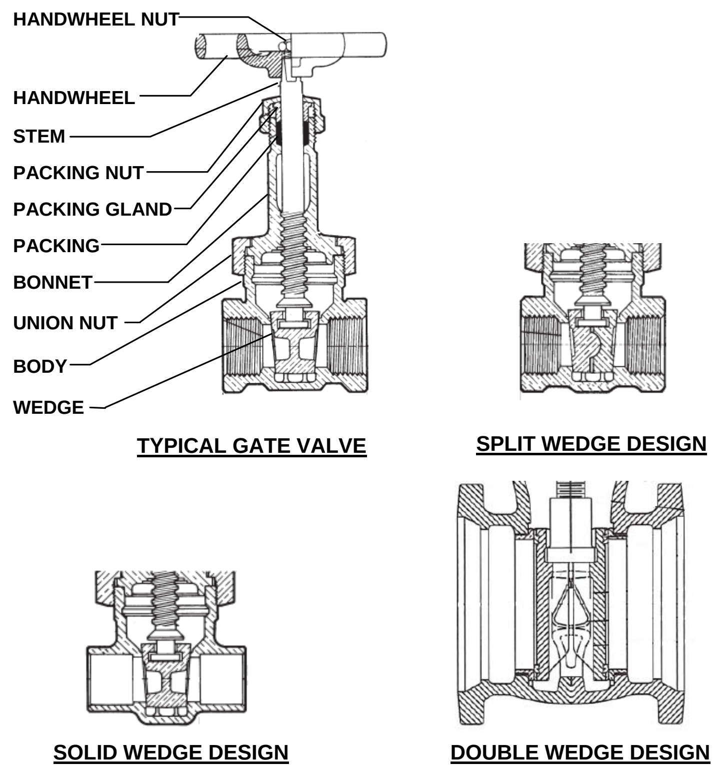


Figure 3-1 Gate Valve

TYPES OF VALVES

Gate Valve

With starting and stopping flow as its prime function, the gate valve is intended to operate either fully open or fully closed. The components of a gate valve are shown in Figure 3-1.

The gate valve uses a gate-like disc, actuated by a stem screw and hand wheel that moves up and down at right angles to the path of flow and seats against two faces to shut off flow. As the disc of the gate valve presents a flat surface to the oncoming flow, this valve should never be used for regulating or throttling flow. Flow through a partially open gate valve creates vibration and chattering and subjects the disc and seat to inordinate wear.

A wide variety of seats and discs suit the conditions under which the valve is to operate. For relatively low pressures and temperatures and for ordinary fluids, seating materials are not a particularly difficult problem. Bronze and iron valves usually have bronze or bronze-faced seating surfaces; iron valves may be all iron. Nonmetallic composition discs are available for tight seating or hard-to-hold fluids, such as air and gasoline.

Gate discs can be classified as solid-wedge discs, double discs, or split-wedge discs. In the solid-wedge design, a single tapered disc, thin at the bottom and thicker at the top, is forced into a similarly shaped seat. In the double and split-wedge disc designs, two discs are employed back to back, with a spreading device between them. As the valve wheel is turned, the gate drops into its seat (as with any other gate valve), but on the final turns of the wheel, the spreader forces the discs outward against the seats, effecting tight closure.

Bypass valves should be provided where the differential pressure exceeds 200 pounds per square inch (psi) (1,378 kilopascals [kPa]) on valves sized 4 inches to 6 inches (101.6 millimeters to 152.4 mm), and 100 psi (689 kPa) on valves 8 inches (203.2 mm) or larger. Bypass valves should be ½ inches (12.7 mm) for 4-inch (101.6-mm) valves and ¾ inch (19.1 mm) for 5-inch (127-mm) valves or larger.

Globe Valve

The globe valve (see Figure 3-2), which is named for the shape of its body, is much more resistant to flow than the gate valve, as can be seen by examining the path of flow through it. Its main advantages over the gate valve are its use as a throttling valve to regulate flow and its ease of repair.

Because all contact between the seat and disc ends when flow begins, the effects of wire drawing (seat erosion) are minimized. The valve can operate just

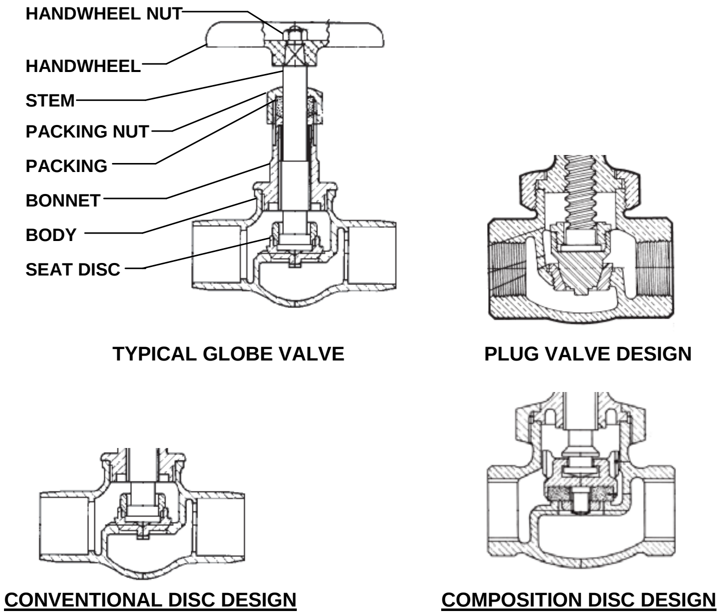


Figure 3-2 Globe Valve

barely open or fully open with little change in wear. Also, because the disc of the globe valve travels a relatively short distance between fully open and fully closed, with fewer turns of the wheel required, an operator can gauge the rate of flow by the number of turns of the wheel.

As with the gate valve, a number of disc and seat arrangements are available. These are classified as conventional disc, plug type, and composition disc. The conventional disc is relatively flat, with beveled edges. On closure, it is pushed down into a beveled, circular seat. Plug-type discs differ only in that they are far more tapered, thereby increasing the contact surface between disc and seat. This characteristic has the effect of increasing their resistance to the cutting effects of dirt, scale, and other foreign matter. The composition disc differs from the others in that it does not fit into the seat opening, but over it, much as a bottlecap fits over the bottle opening. This seat adapts the valve to many services, including use with hard-to-hold substances such as compressed air, and makes it easy to repair.

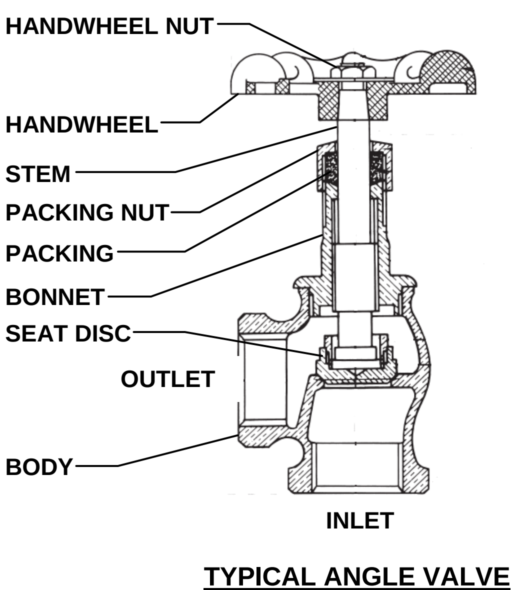


Figure 3-3 Angle Valve

Angle Valve

Very much akin to the globe valve, the angle valve (see Figure 3-3) can decrease piping installation time, labor, and materials by serving as both valve and 90-degree elbow. It is less resistant to flow than the globe valve, as flow must change direction twice instead of three times. It is also available with conventional, plug type, or composition discs.

Ball Valve

The ball valve derives its name from the drilled ball that swivels on its vertical axis and is operated by a handle. Its advantages are its straight-through flow, minimum turbulence, low torque, tight closure, and compactness. Also, a quarter turn of the handle makes it a quick-closing or quick-opening valve. Reliability, ease of maintenance, and durability have made the ball valve popular in industrial, chemical, and gas transmission applications.

Ball valves are available in one-, two-, and three-piece body types, as shown in Figure 3-4. The one-piece body is machined from a solid bar of stock material or is a one-piece casing. The ball is inserted in the end for assembly, and the body insert that acts as the seat ring is threaded in against the ball. The two-piece body is the same as the one-piece valve, except that the body insert is larger and acts as an end bushing. The three-piece body consists of a center body section containing the ball that fits between two body end pieces. Two or more bolts hold the assembly together.

Butterfly Valve

The butterfly valve (see Figure 3-5) is the valve most commonly used in place of a gate valve in cases where absolute, bubble-free shutoff is required.

In addition to its tight closing, one of the valve's advantages is that it can be placed into a very small space between pipe flanges. It is available with several types of motorized and manual operators and a variety of component material combinations.

The two most common body types are the wafer body and lug body. The wafer body is placed between pipe flanges, and the flange bolts surround the valve body. The lug body has protruding lugs that provide

TYPICAL ONE-PIECE TYPE

TYPICAL TWO-PIECE TYPE

TYPICAL THREE-PIECE TYPE

Figure 3-4 Ball Valve

bolt holes matching those in the flanges. Screwed-lug valves can be provided so that equipment may be removed without draining down the system.

Check Valve

Swing checks and lift checks (see Figure 3-6) are the most common forms of check valve. Both are designed to prevent reversal of flow in a pipe. The swing check permits straight-through flow when open and is, therefore, less resistant to flow than the lift check.

To ensure immediate closure upon reversal of flow and when installed in vertical installations, the check valve should be of the spring-loaded (non-slamming) type. If reverse flow is not stopped immediately, the velocity of backflow could rise to such a point that when closure does occur, the resulting shock could cause serious damage to the valve and system.

The lift check is primarily for use with gases or compressed air or in fluid systems where pressure drop is not critical.

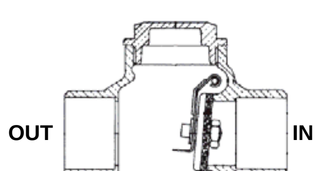
Plug Valve

The plug valve has a quarter-turn design similar to a ball valve, with the ball replaced by a plug. The plug valve typically requires a higher operating torque for closure, meaning specialized wrenches or expensive automation packages are required. Plug valves are available in lubricated, non-lubricated, or eccentric types. The non-lubricating type eliminates periodic lubrication and ensures that the valve's lubrication does not contaminate the process media or affect any downstream instrumentation. The eccentric type is basically a valve with the plug cut in half. The eccentric design allows a high achieved seating force with minimal friction encountered from the open to closed positions.

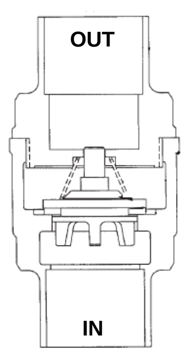
WAFER STYLE

LUG STYLE

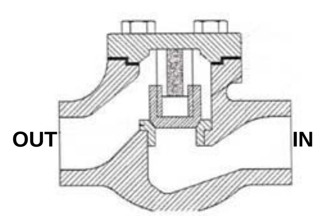
Figure 3-5 Butterfly Valve



SWING TYPE

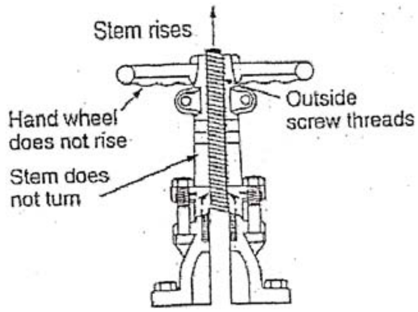


SPRING-LOADED NON-SLAMMING TYPE

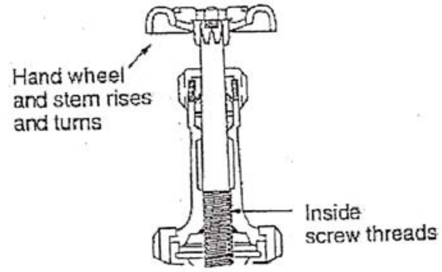


LIFT TYPE

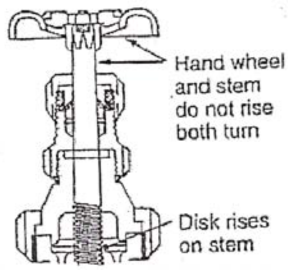
Figure 3-6 Check Valve



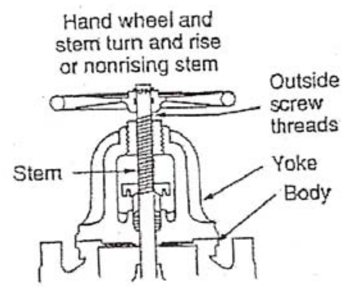
RISING STEM WITH OUTSIDE SCREW



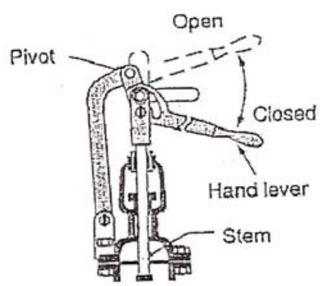
RISING STEM WITH INSIDE SCREW



NON-RISING STEM WITH INSIDE SCREW



RISING STEM WITH OUTSIDE SCREW AND YOKE



SLIDING STEM

Figure 3-7 Valve Stems

VALVE MATERIALS

A valve may be constructed of several materials. For example, it may have a bronze body, monel seat, and an aluminum wheel. Metallic materials include brass, bronze, cast iron, malleable iron, ductile iron, steel, and stainless steel. Non-metallic materials are typically thermoplastics. Material specifications depend on the operating conditions.

Brass and Bronze

Brass usually consists of 85 percent copper, 5 percent lead, 5 percent tin, and 5 percent zinc. Bronze has a higher copper content, ranging from 86 percent to 90 percent, with the remaining percentage divided among lead, tin, and zinc.

Under certain circumstances, a phenomenon known as "dezincification" occurs in valves or pipes containing zinc. The action is a result of electrolysis; in effect, the zinc is actually drawn out and removed from the brass or bronze, leaving a porous, brittle, and weakened material. The higher the zinc content, the greater the susceptibility to dezincification. To slow or prevent the process, tin, phosphorus antimony, and other inhibitors are added. Brass valves should not be used for operating temperatures above 450°F (232.2°C). The maximum operating temperature for bronze is 550°F (287.8°C).

Iron

Iron used in valves usually conforms to American Society for Testing and Materials (ASTM) A126: *Standard Specification for Gray Iron Castings for Valves, Flanges, and Pipe Fittings*. Although iron-bodied valves are manufactured in sizes as small as ¼-inch (6.4-mm) nominal diameter, they most commonly are stocked in sizes of 2 inches (50.8 mm) and above. In these larger sizes, they are considerably less expensive than bronze.

The higher weight of iron valves, as compared to bronze valves, should be considered when determining hanger spacing and loads. A typical 2-inch (50.8-mm) bronze screwed globe valve rated at 125 psi (861.3 kPa) weighs about 13 pounds (5.9 kilograms [kg]). The same valve in iron weighs 15 pounds (6.8 kg) and, if specified with a yoke bonnet, about 22 pounds (10 kg).

Malleable Iron

Malleable iron valves are stronger, stiffer, and tougher than iron-bodied valves and hold tighter pressures. Toughness is most valuable for piping subjected to stresses and shocks.

Stainless Steel

For highly corrosive fluids, stainless steel valves provide the maximum corrosion resistance, high strength, and good wearing properties. Seating surfaces, stems, and discs of stainless steel are suitable where foreign materials in the fluids handled could have adverse effects.

Thermoplastic

Many different types of thermoplastic materials are used for valve construction. Plastic valves generally are limited to a maximum temperature of 250°F (121.1°C) and a maximum pressure of 150 psi (1,035 kPa).

VALVE RATINGS

Most valve manufacturers rate their products in terms of saturated steam pressure; pressure of non-shock cold water, oil, or gas (WOG); or both. These ratings usually appear on the body of the valve. For instance, a valve with the markings “125” with “200 WOG” will operate safely at 125 psi (861.3 kPa) of saturated steam or 200 psi (1,378 kPa) cold water, oil, or gas.

The engineer should be familiar with the markings on the valves specified and should keep them in mind during construction inspection. A ruptured valve can do much damage.

VALVE COMPONENTS

Stems

Stem designs fall into four basic categories: rising stem with outside screw, rising stem with inside screw, nonrising stem with inside screw, and sliding stem. (See Figure 3-7.)

Rising Stem with Outside Screw

This design is ideal where the valve is used infrequently and the possibility of sticking constitutes a hazard, such as in a fire protection system. In this arrangement, the screws are not subject to corrosion or elements in the line fluid that might cause damage because they are outside the valve body. Also, being outside, they can be lubricated easily.

As with any other rising stem valve, sufficient clearance must be allowed to enable a full opening.

Rising Stem with Inside Screw

This design is the simplest and most common stem design for gate, globe, and angle valves. The position of the hand wheel indicates the position of the disc, opened or closed.

Nonrising Stem

These are ideal where headroom is limited. They generally are limited to use with gate valves. In this type, the screw does not raise the stem, but rather raises and lowers the disc. As the stem only rotates and does not rise, wear on packings is lessened slightly.

Sliding Stem

These are applied where quick opening and closing are required. A lever replaces the hand wheel, and stem threads are eliminated.

Bonnets

In choosing valves, the service characteristics of the bonnet joint should not be overlooked. Bonnets and bonnet joints must provide a leak-proof closure for the body. There are many modifications, but the three most common types are screwed-in bonnet, screwed union-ring bonnet, and bolted bonnet.

Screwed-in Bonnet

This is the simplest and least expensive construction, frequently used on bronze gate, globe, and angle valves and recommended where frequent dismantling is not needed. When properly designed with running threads and carefully assembled, the screwed-in bonnet makes a durable, pressure-tight seal that is suited for many services.

Screwed Union-ring Bonnet

This construction is convenient where valves need frequent inspection or cleaning—also for quick renewal or changeover of the disc in composition disc valves. A separate union ring applies a direct load on the bonnet to hold the pressure-tight joint with the body. The turning motion used to tighten the ring is split between the shoulders of the ring and bonnet. Hence, the point-of-seal contact between the bonnet and the body is less subject to wear from frequent opening of the joint.

Contact faces are less likely to be damaged in handling. The union ring gives the body added strength and rigidity against internal pressure and distortion.

While ideal on small valves, the screwed union-ring bonnet is impractical on large sizes.

Bolted Bonnet Joint

A practical and commonly used joint for large valves or for high-pressure applications, the bolted bonnet joint has multiple boltings with small-diameter bolts that permit equalized sealing pressure without the excessive torque needed to make large threaded joints. Only small wrenches are needed.

End Connections

Valves are available with screwed, welded, brazed, soldered, flared, flanged, hub, and press-fitted ends.

Screwed End

This is by far the most widely used type of end connection. It is found in brass, iron, steel, and alloy piping materials. It is suited for all pressures but usually is confined to small pipe sizes. The larger the pipe size, the more difficult it is to make up the screwed joint.

Welded End

This type of end is available only in steel valves and fittings and is mainly for high-pressure and high-temperature services. It is recommended for lines not requiring frequent dismantling. There are two types of welded-end materials: butt and socket welding. Butt-welding valves and fittings come in all sizes; socket-welding ends are limited to small sizes.

Brazed End

This is available in brass materials. The ends of such materials are specially designed for the use of brazing alloys to make the joint. When the equipment and brazing material are heated with a welding torch to the temperature required by the alloy, a tight seal is formed between the pipe and valve or fitting. While made in a manner similar to a solder joint, a brazed joint can withstand higher temperatures due to the brazing materials used.

Soldered Joint

This is used with copper tubing for plumbing and heating lines and for many low-pressure industrial services. The joint is soldered by applying heat. Because of the close clearance between the tubing and the socket of the fitting or valve, the solder flows into the joint by capillary action. The use of soldered joints under high temperatures is limited because of the low melting point of the solder. Silver solder or Sil-Fos are used for high pressures and temperatures.

Flared End

This is commonly used on valves and fittings for metal and plastic tubing up to 2 inches (50.8 mm) in diameter. The end of the tubing is skirted or flared, and a ring nut is used to make a union-type joint.

Flanged End

This is generally used when screwed or soldered ends become impractical because of cost, size, or strength of joint. Flanged ends generally are used for large-diameter lines due to ease of assembly and dismantling. Flanged facings are available in various designs depending on service requirements. One important rule is to match facings. When bolting iron valves to forged steel flanges, the facing should be of the flat face design on both surfaces.

Hub End

This generally is limited to valves for water-supply and sewage piping. The joint is assembled on the socket principle, with the pipe inserted in the hub end of the valve or fitting.

Press-fitted End

This method involves crimping the ends with a crimping tool around an ethylene propylene diene monomer (EPDM) seal to form a water-tight connection.

WATER-PRESSURE REGULATORS

A pressure regulator is an automatic valve controlled by an inner valve connected to a diaphragm or piston or both. The diaphragm, held in the extreme travel, or open, position by a preloaded spring, is positioned in the downstream portion of the valve and closes the valve when the desired pressure has been reached.

The effectiveness of the diaphragm and the amount of preloading must be related to allow the diaphragm to move the inner valve to the extreme opposite travel, or closed, position immediately after the pressure on the diaphragm passes the desired operating pressure.

To change the operating pressure, tension on the diaphragm is increased or decreased by turning the adjusting screw.

Normally, a regulator does not go from closed to fully open or from open to fully closed immediately, but moves between these extreme positions in response to system requirements. The regulator adjusts to a fully open position instantaneously only if maximum system demand is imposed quickly, which is not a common occurrence, unless the regulator is undersized. The degree of valve opening, therefore, depends entirely on the regulator's ability to sense and respond to pressure changes.

A reducing pressure change that causes a valve to open is known as a "reduced pressure fall-off," or "droop," and is an inherent characteristic of all self-operated or pilot-operated regulators. Technically, fall-off is expressed as the deviation in pressure from the set value that occurs when a regulator strokes from the minimum flow position to a desired flow position. The amount of fall-off necessary to open a valve to its rated capacity varies with different types of valves.

It is important to realize that the installation of a regulator sets up a closed system; therefore, it is necessary to install a relief valve and expansion tank to eliminate excessive pressure caused by the thermal expansion of water in the water heater or hot water storage tank.

Every manufacturer makes regulators with an integral bypass to eliminate relief valve dripping caused by thermal expansion. During normal operation, the bypass is held closed by high initial pressure. However, when thermal expansion pressure equals initial pressure, the bypass opens, passing the expanded water back into the supply line. The effectiveness of this feature is limited to systems where initial pressure is less than the pressure setting of the relief valve.

The integral bypass is not a replacement for the relief valve. It is used only to eliminate excessive drip from the relief valve.

Regulator Selection and Sizing

Selection of the correct type of regulator depends entirely on the accuracy of regulation required. The valve plug in oversized valves tends to remain close to the seat, causing rapid wire drawing and excessive wear. Unfortunately, no set standard for rating a pressure-regulating valve or for capacity sizing it to the system exists. The many methods proposed for selecting the proper valve are often a cause of confusion to the engineer.

The capacity rating of a pressure-regulating valve usually is expressed in terms of some single value. This value, to be useful, must specify all the conditions under which the rating was established. Otherwise, it is impossible to adapt it to different system conditions.

Manufacturers attempt to recognize the inherent characteristics of their own design and to stipulate those factors that, in their opinion, must be considered in sizing the valve to the system. Some stress the importance of the difference between initial and reduced pressure-differential pressure. Set pressure and allowable reduced pressure fall-off are very important factors in sizing a valve. A fall-off of 15 psi to 17 psi (103.4 kPa to 117.1 kPa) is considered reasonable for the average residential installation and, in well-designed valves, produces a good rating.

Another procedure for establishing valve performance is on the basis of flow rate, with a reduced pressure fall-off of 15 psi to 17 psi (103.4 kPa to 117.1 kPa) below reduced lockup or no-flow pressure. For general use, this approach provides an adequate means of valve selection. However, it is not specific enough to enable the selection of the valve best suited to particular conditions.

Other manufacturers rate their valves on the basis of a stipulated flow rate at a specific pressure differential, with the valve open to the atmosphere, without regard to change in pressure drop when the system demand is zero. This method does not provide ample information for proper judgment of valve behavior and capability, which could result in the selection of a valve that, under no-demand conditions, permits a reduction in pressure great enough to damage equipment in the system.

The maximum pressure permitted on a system under no-flow conditions is a most important factor, for both physical and economic reasons, and should be stipulated in the specification.

The rule of thumb frequently employed is a size-to-size selection—that is, using a valve having the same connection sizes as the pipeline in which it is to be installed. This is a gamble inasmuch as the actual capacities of many valves are inadequate to satisfy the service load specified for a pipeline of corresponding size. Consequently, the system may be starved, and the equipment may operate in an inconsistent manner.

The only sound valve selection procedure to follow is to capacity size a valve on the basis of known performance data related to system requirements.

Common Regulating Valves

Direct-acting, Diaphragm-actuated Valve

This valve is simple in construction and operation, requiring minimum attention after installation. This type of pressure regulator does not regulate the delivery pressure with extreme accuracy.

Pilot-operated Valve

The pilot-controlled valve operates efficiently because the pilot magnifies the control valve travel for a given change in control pressure.

The pilot-type regulator consists of a small, direct-acting, spring-loaded valve and a main valve. The pilot valve opens just enough to supply the necessary pressure for operating the main valve. Extreme accuracy is effected as there is practically a constant load on the adjusting spring, and variations in initial pressure have little effect.

Direct-acting, Balanced-piston Valve

This valve is a combination piston and diaphragm and requires little attention after installation. With the dependability of the diaphragm and the simplicity of direct action, this valve is only slightly affected by variations in initial pressure.

Booster Pump Control Valve

This is a pilot-operated valve designed to eliminate pipeline surges caused by the starting and stopping of the booster pump. The pump starts against a closed valve. After the pump starts, a solenoid valve is energized, slowly opening the valve and allowing the line pressure to gradually increase to full pumping head. When the pump shuts off, the solenoid is de-energized, and the valve slowly closes as the pump continues to run. When the valve is fully closed, the pump stops.

Level Control Valve

This valve is a non-modulating valve used to accurately control the liquid level in a tank. The valve opens fully when a preset liquid low point is reached and closes drip tight when the preset high point is reached. This is a hydraulically operated diaphragm valve with the pilot control and float mechanism mounted on the cover of the valve.

Common Types of Regulator Installations

Single Regulator in Supply Line

This type of installation is most common in domestic service and is self-explanatory.

Two Regulators in Series in Supply Line

This type of installation provides extra protection when the main pressure is so excessive that it must be reduced to two stages to prevent high-velocity noise in the system.

Multiple Regulators Used as a Battery in Supply Line

In many instances, a battery installation is preferable to the use of a single valve, as it provides closer regulation over a wide demand variation.

This type of installation consists of a group of parallel regulators, all receiving water from a common manifold. After flowing through the battery of valves, water enters a common manifold of sufficient size to service the system at the reduced pressure. The battery installation is advantageous because it allows maintenance work to be performed without the necessity of turning off the entire system. It also provides better performance where demands vary from one extreme to the other.

For example, at a school with a 3-inch (76.2-mm) service, demand on drinking fountains during classes may be approximately 6 gallons per minute (gpm) to 7 gpm (22.7 liters per minute [lpm] to 26.5 lpm). However, between classes, when all services are in use, the demand may be at a maximum. With a single 3-inch (76.2-mm) regulator in the system, when the faucet is turned on, the regulator must open to allow a small draw. Each time this is done, it cuts down on the service life of the large regulator.

In comparison, with a battery installation of two or three regulators set at a graduated pressure, with the smallest valve set 2-psi to 3-psi (13.8-kPa to 20.7-kPa) higher than the larger ones, the system is more efficient. For a small demand, only the smallest valve opens. As the demand increases, the larger valves also open, providing the system with the capacity of all valves in the battery.

VALVE DESIGN CHOICES

Service Considerations

1. Pressure
2. Temperature
3. Type of fluid
   - Liquid
   - Gas (i.e., steam or air)
   - Dirty or abrasive (erosive)
   - Corrosive
4. Flow
   - On-off
   - Throttling
   - Need to prevent flow reversal
   - Concern for pressure drop
   - Velocity
5. Operating conditions
   - Frequency of operation
   - Accessibility
   - Overall space/size available
   - Manual or automated control
   - Need for bubble-tight shutoff
   - Concerns about body joint leaks
   - Fire-safe design
   - Speed of closure

Multi-turn Type

1. Gate
2. Globe and angle globe
3. End connection

Quarter-turn Type

1. Ball
2. Butterfly-resilient seated
3. Plug
4. End connection

Check Type

1. Swing
2. Lift
3. Silent or non-slam
4. End connection

DESIGN DETAIL: GATE VALVE

Advantages and Recommendations

1. Good choice for on/off service

2. Full flow, low pressure drop
3. Bidirectional

Disadvantages

1. Not for throttling. Use fully open or fully closed. Flow through a partially open gate valve causes vibration and chattering and subjects the disc and seat to inordinate wear.
2. Metal-to-metal seating is not the best choice for frequent operation. Bubble-tight seating should not be expected with metal-to-metal design.

Disc and Seat Designs

1. Bronze or bronze-faced seating surfaces are used with bronze and iron valves. Iron valves may use all-iron seating surfaces. These are preferred for low pressures and temperatures and for ordinary fluids. Stainless steel is used for high-pressure steam and erosive media.
2. Nonmetallic "composition" discs are available for tight seating or hard-to-hold fluids, such as air and gasoline.
3. Solid-wedge disc design is thinner at the bottom, thicker at the top, and forced into the seat of a similar shape.
4. Double-disc or split-wedge disc designs are two discs employed back to back with a spreading device between them. As the valve wheel is turned, the gate drops into its seat (as with any other gate valve), but on the final turns of the wheel, the spreader forces the discs outward against the seats, effecting tighter closure.
5. Resilient wedge is a rubber-encapsulated metal wedge that seals against an epoxy-coated body. Resilient wedge is limited to cold water applications.

DESIGN DETAIL: GLOBE AND ANGLE GLOBE VALVE

Advantages and Recommendations

1. Recommended for throttling applications
2. Positive bubble-tight shutoff when equipped with resilient seating
3. Good for frequent operation

Disadvantages

1. Flow path causes a significant pressure drop.
2. Globe valves are more costly than alternative valves.

Disc and Seat Designs

1. Resilient (soft) seat discs are preferred over metal to metal, except where temperature, very close throttling, or abrasive flow makes all-metal seating a better choice. Stainless steel trim is available for medium- to high-pressure steam and abrasive applications. Tetrafluoroethylene (TFE) is the most resilient disc material for most services, although rubber's softness provides good performance in cold water. TFE is good up to 400°F. Nitrile rubber (Buna-N) is good up to 200°F.
2. Automatic, steam, stop-check angle globe valves are best on medium-pressure steam service.
3. The sliding action of the semi-plug disc assembly permits the valve to serve as a shutoff valve, throttling valve, or check valve.

DESIGN DETAIL: CHECK VALVE

1. Swing-type check valves offer the least pressure drop and simple automatic closure. When fluid flow stops, gravity and flow reversal close the valve. Many bronze valves offer a Y-pattern body with an angle seat for improved performance. Resilient Teflon seating is preferred for tight shutoff.
2. Lift checks come in an inline or globe-style body pattern. Both cause greater pressure drop than the swing type, with the horizontal pattern similar in restriction to globe valves.
3. Some styles are spring actuated and center guided for immediate closure when flow stops. The inline, spring-actuated lift check is also referred to as the "silent check" because the spring closes the valve before gravity and fluid reversal can slam the valve closed. Resilient seating is recommended.
4. Double-disc check valves have twin discs on a spring-loaded center shaft. These valves have better flow characteristics than lift checks and most often use a wafer body for low cost and easy installation. Resilient seating is recommended.

DESIGN DETAIL: QUARTER-TURN BALL VALVE

Advantages and Recommendations

1. Bubble-tight shutoff from resilient (TFE) seats
2. Quick, 90-degree open/close; not torque dependent for seating
3. Straight-through, unobstructed flow, bidirectional
4. Easier to automate than multi-turn valves

5. More compact than multi-turn valves
6. Offer long cycle life

Disadvantages

1. Temperature and pressure range is limited by seat material.
2. Cavity around ball traps media and does not drain entrapped media. Susceptible to freezing, expansion, and increased pressure due to increased temperature.

Body Styles

1. One-piece valves have no potential body leak path but have a double-reduced port; thus, significant pressure drop occurs. Not repairable, they are used primarily by chemical and refining plants.
2. Two-piece end entries are used most commonly in building services. They are the best-value valves and are available in full- or standard-port balls. They are recommended for on/off or throttling service and not recommended to be repaired.
3. Three-piece valves are costly but are easier to disassemble and offer the possibility of inline repair. They are available in full- or standard-port balls.

Port Size

1. Full-port ball valves provide a pressure drop equal to the equivalent length of the pipe, slightly better than gate valves.
2. Standard-port (conventional) balls are up to one pipe size smaller than the nominal pipe size but still have significantly better flow characteristics than globe valves.
3. Reduced-port ball valves have greater than one pipe size flow restriction and are not recommended in building services piping, but rather are used for process piping for hazardous material transfer.

Handle Extensions

1. Insulated handle extensions or extended handles should be used to keep insulated piping systems intact.

DESIGN DETAIL: QUARTER-TURN BUTTERFLY VALVE

Advantages and Recommendations

1. Bubble-tight shutoff from resilient seats
2. Quick, 90-degree open/close; easier to automate than multi-turn valves
3. Very cost-effective compared to alternative valve choices
4. Broad selection of trim materials to match different fluid conditions
5. More compact than multi-turn valves
6. Offer long cycle life
7. Dead-end service

Disadvantages

1. They are not to be used with steam.
2. Gear operators are needed for 8-inch and larger valves to aid in operation and to protect against operating too quickly and causing destructive line shock.

Body Styles

1. Wafer-style valves are held in place between two pipe flanges. They are easy to install but cannot be used as isolation valves.
2. Lug-style valves have wafer bodies but tapped lugs matching up to bolt circles of class 125/150-pound flanges. They are easily installed with cap screws from either side. Lug style designs from some manufacturers permit dropping the pipe from one side while the valve holds full pressure if needed.
3. Groove butterfly valves directly connect to pipe using iron-pipe-size, grooved couplings. While more costly than wafer valves, grooved valves are easier to install.

DESIGN DETAIL: QUARTER-TURN VALVE, LUBRICATED PLUG COCK

Advantages and Recommendations

1. Bubble-tight shutoff from stem seal of reinforced Teflon. Leak-proof, spring-loaded ball and lubricated, sealed check valve and combination lubricant screw and button head fitting prevent foreign matter from being forced into the lubrication system.
2. Quick, 90-degree open/close; not dependent on torque for seating
3. Straight-through, unobstructed flow, bidirectional flow, three-way flow, or four-way flow
4. Offers long cycle life
5. Adjustable stop for balancing or throttling service
6. Can be supplied with round, diamond, or rectangular (standard) plug
7. Mechanism for power operation or remote control of any size and type to operate with air, oil, or water

Disadvantages

1. Temperature and pressure range is limited by type of lubricant sealant and ANSI standard rating (i.e., 150-psi steam working pressure [SWP], 200-psi nonshock cold working pressure [CWP], and water, oil, gas).

VALVE SIZING AND PRESSURE LOSSES

Valve size and valve pressure losses can be determined utilizing a flow coefficient called C_V. C_V is the number of gallons per minute that will pass through a valve with a pressure drop of 1 psi. C_V is determined by physically counting the number of gallons that pass through a valve with 1-psi applied pressure to the valve inlet and zero pressure at the outlet. The C_V coefficient for specific valves can be obtained from the valve manufacturer. Since the C_V factor varies in relation to valve size, the C_V can be used to determine the proper size valve for the amount of flow at a given pressure drop or conversely the pressure drop at a given flow. The formulas for this are as follows:

$$Q = C_V \sqrt{P/G}$$

$$C_V = \frac{Q}{\sqrt{\Delta P/G}}$$

$$\Delta P = [Q/C_V]^2\ G$$

where

G = Specific gravity of the fluid
ΔP = Pressure drop across the valve
Q = Flow through the valve in gpm
C_V = Valve flow coefficient

GENERAL VALVE SPECIFICATION BY SERVICE

Hot and Cold Domestic Water Service

Gate Valve

2 inches and smaller Valves 2 inches and smaller shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP, rising stem. Body, union bonnet, and solid wedge shall be of ASTM B62: *Standard Specification for Composition Bronze or Ounce Metal Castings* cast bronze with soldered ends. Stems shall be of dezincification-resistant silicon bronze (ASTM B371: *Standard Specification for Copper-Zinc-Silicon Alloy Rod)* or low-zinc alloy (ASTM B99: *Standard Specification for Copper-Silicon Alloy Wire for General Applications).* Packing glands shall be bronze (ASTM B62), with aramid fiber, nonasbestos packing, complete with malleable hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 100 psi SWP, 150 psi nonshock CWP and have an iron body and bronze-mounted OS&Y. Body and bolted bonnet shall conform to ASTM A126 class B cast iron, flanged ends, with aramid fiber, nonasbestos packing and two-piece packing gland assembly. Valves shall comply with MSS SP-70.

All domestic water valves 4 inches and larger that are buried in the ground shall be iron body and bronze fitted, with an O-ring stem seal. They shall have epoxy coating inside and outside and a resilient-seated gate valve with nonrising stem and mechanical joint or flanged ends as required. All valves furnished shall open left. All internal parts shall be accessible without removing the valve body from the line. Valves shall conform to ANSI/American Water Works Association (AWWA) C509: *Resilient-seated Gate Valves for Water-supply Service*. Epoxy coating shall conform to AWWA C550: *Protective Epoxy Interior Coating for Valves and Hydrants*.

Ball Valves

2 inches and smaller Valves 2 inches and smaller shall be rated 150 psi SWP, 600 psi nonshock CWP and have two-piece, cast brass bodies, replaceable reinforced Teflon seats, ¼-inch to 1-inch full port or 1¼-inch to 2-inch conventional port, blowout-proof stems, chrome-plated brass ball, and threaded, soldered, or press-fit ends. Valves shall comply with MSS SP-110. Provide extended stems for valves in insulated piping.

Globe Valves

2 inches and smaller Valves 2 inches and smaller shall be of class 125, rated 125 psi SWP, 200 psi nonshock CWP. Body and bonnet shall be of ASTM B62 cast bronze composition with threaded or soldered ends. Stems shall be of dezincification-resistant silicon bronze (ASTM B371) or low-zinc alloy (ASTM B99). Packing glands shall be bronze (ASTM B62), with aramid fiber, nonasbestos packing, complete with malleable hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have an iron body and bronze-mounted OS&Y, with body and bolted bonnet conforming to ASTM A126 class B cast iron, flanged ends, with aramid fiber, nonasbestos packing, and two-piece packing gland assembly. Valves shall comply with MSS SP-85.

Butterfly Valves

2½ inches and larger Valves 2½ inches and larger shall be rated 200 psi nonshock CWP and have a lug or IPS grooved-type body with a 2-inch extended neck for insulating. They shall be cast or ductile iron (ASTM A536: *Standard Specification for Ductile Iron Castings* or ASTM A126), with an aluminum bronze disc, 416 stainless steel stem, EPDM O-ring stem seals, and resilient, EPDM cartridge lined to seat. Sizes 2½ inches to 6 inches shall be lever operated with a 10-position throttling plate. Sizes 8 inches to 12 inches shall have gear operators. Sizes 14 inches and larger shall have worm gear operators only. They are suitable for use as bidirectional isolation valves and, as recommended by the manufacturer, on dead-end service at full pressure without the need for downstream flanges.

Valves shall comply with MSS SP-67.

Note: Butterfly valves in dead-end service require both upstream and downstream flanges for proper shutoff and retention or must be certified by the manufacturer for dead-end service without downstream flanges.

Check Valves

2 inches and smaller Valves 2 inches and smaller shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have threaded or soldered ends, with body and cap conforming to ASTM B62 cast bronze composition and a Y-pattern swing-type disc. Valves shall comply with MSS SP-80

Note: Class 150 valves meeting the above specifications may be used where system pressure requires. For class 125 seat disc, specify Buna-N for WOG service and TFE for steam service. For class 150 seat disc, specify TFE for steam service.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have an iron body, bronze mounted, with body and bolted bonnet conforming to ASTM A126 class B cast iron, flanged ends, swing-type disc, and nonasbestos gasket. Valves shall comply with MSS SP-71.

Alternative check valves (2½ inches and larger) shall be class 125/250 iron body, bronze mounted, wafer check valves, with ends designed for flanged-type connection, aluminum bronze disc, EPDM seats, 316 stainless steel torsion spring, and hinge pin.

A spring-actuated check valve is to be used on pump discharge. Swing check with outside lever and spring (not center guided) is to be used on sewage ejectors or storm water sump pumps.

Compressed Air Service

Ball Valves

2 inches and smaller Main line valves 2 inches and smaller shall be rated 150 psi SWP, 600 psi nonshock CWP. They shall have two-piece, cast bronze bodies; reinforced Teflon seats; full port; blowout-proof stems; chrome-plated brass ball; and threaded or soldered ends. Valves shall comply with MSS SP-110.

Branch line valves 2 inches and smaller shall be rated 150 psi SWP, 600 psi nonshock CWP and have two-piece, cast bronze (ASTM B584) bodies with reinforced Teflon seats. Full-port ¼-inch to 1-inch valves and conventional-port 1¼-inch to 2-inch valves require blowout-proof stems, chrome-plated brass ball with a safety vent hole on the downstream side with threaded or soldered ends and lockout/tagout handles. Lockout/tagout handles must meet the requirements of Occupational Safety and Health Administration (OSHA) 29 CFR Section 1910.147: The Control of Hazardous Energy (Lockout/Tagout). Valves shall comply with MSS SP-110.

Butterfly Valves

2½ inches and larger Valves 2½ inches and larger shall be rated 200 psi nonshock CWP. Valves shall be lug or IPS, grooved-type body and shall be cast or ductile iron (ASTM A536) with a Buna-N seat; ductile iron, aluminum bronze disc; ASTM A582: *Standard Specification for Free-Machining Stainless Steel Bars* Type 416 stainless steel stem; and Buna-N O-ring stem seals. Sizes 2½ inches to 6 inches shall be lever operated with a 10-position throttling plate. Sizes 8 inches to 12 inches shall have gear operators. Lever-operated valves shall be designed to be locked in the open or closed position. Butterfly valves on dead-end service or valves needing additional body strength shall be lug type conforming to ASTM A536, ductile iron, drilled and tapped, with other materials and features as specified above. Valves shall comply with MSS SP-67.

Note: Dead-end service requires lug-pattern or grooved-type bodies. For dead-end service, flanges are required upstream and downstream for proper shutoff and retention, or valves must be certified by the manufacturer for dead-end service without downstream flanges. Ductile iron bodies are preferred; however, cast iron may be acceptable.

Check Valves

2 inches and smaller Valves 2 inches and smaller shall be of class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have threaded ends, with body and cap conforming to ASTM B62, cast bronze composition, Y-pattern, swing-type with TFE seat disc, or spring-loaded lift type with resilient seating. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 200 psi nonshock CWP, and have a maximum temperature of 200°F. They shall have ASTM A126 class B cast iron body; wafer-check valve, with ends designed for flanged-type connections; Buna-N resilient seats, molded to body; bronze disc; 316 stainless steel torsion spring; and hinge pin. Valves shall conform to ANSI B16.10: *Gray Iron Pipe Flanges and Flanged Fittings: Classes 25, 125, and 250.*

Note: If the compressor is the reciprocating type, check valves shall be downstream of the receiver tank.

Vacuum Service

Ball Valves

2 inches and smaller Valves 2 inches and smaller shall be rated 150 psi SWP, 600 psi nonshock CWP. They shall have two-piece, cast brass bodies, reinforced Teflon seats, a full port, blowout-proof stems, a chrome-plated brass ball, and threaded or soldered ends. Valves shall comply with MSS SP-110.

Butterfly Valves

2½ inches and larger Valves 2½ inches and larger shall be rated 200 psi nonshock CWP. Valves shall be lug or IPS grooved-type body with a 2-inch extended neck for insulating and shall be cast or ductile iron (ASTM A536), with a Buna-N seat; ductile iron, aluminum bronze disc (ASTM A582); type 416 stainless steel stem; and Buna-N O-ring stem seals. Sizes 2½ inches to 6 inches shall be lever operated with a 10-position throttling plate. Sizes 8 inches to 12 inches shall have gear operators. Lever-operated valves shall be designed to be locked in the open or closed position.

For butterfly valves on dead-end service or requiring additional body strength, valves shall be lug type, conforming to ASTM A536, ductile iron, drilled and tapped, with other materials and features as specified above. Valves shall comply with MSS SP-67.

Note: Dead-end service requires lug-pattern or grooved-type bodies. For dead-end service, flanges are required upstream and downstream for proper shutoff and retention, or valves must be certified by the manufacturer for dead-end service without downstream flanges. Ductile iron bodies are preferred; however, cast iron may be acceptable.

Medical Gas Service

Ball Valves

2 inches and smaller Valves 2 inches and smaller shall be rated 600 psi nonshock CWP, 200 psi for medical gas. They shall have three-piece, cast bronze (ASTM B584) bodies, replaceable reinforced TFE seats, a full port, blowout-proof stems, a chrome-plated brass/bronze ball, and brazed ends. Valves shall be provided by the manufacturer cleaned and bagged for oxygen service. Valves shall comply with MSS SP-110.

2½ inches and larger Valves 2½ inches and larger shall be rated 600 psi nonshock CWP, 200 psi for medical gas. They shall have three-piece, cast bronze (ASTM B584) bodies, replaceable reinforced TFE seats, a full port, blowout-proof stems, a chrome-plated brass/bronze ball, and brazed ends. Valves shall be provided by the manufacturer cleaned and bagged for oxygen service. Valves shall comply with MSS SP-110.

Note: Where piping is insulated, ball valves shall be equipped with 2-inch extended handles of nonthermal, conductive material. Also, a protective sleeve that allows operation of the valve without breaking the vapor seal or disturbing the insulation should be provided.

Low-pressure Steam and General Service

This includes service up to 125 psi saturated steam to 353°F (178°C).

Butterfly Valves

Butterfly valves are not allowed in steam service unless stated as acceptable for the application by the manufacturer.

Gate Valves

2 inches and smaller Valves 2 inches and smaller shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP, and have a rising stem. Body, union bonnet, and solid wedge shall be of ASTM B62 cast bronze with threaded ends. Stems shall be of dezincification-resistant silicon bronze (ASTM B371) or low-zinc alloy (ASTM B99). Packing glands shall be bronze (ASTM B62), with aramid fiber, nonasbestos packing, complete with malleable hand wheel. Class 150 valves meeting the above specifications may be used where pressures approach 100 psi. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 100 psi SWP, 150 psi nonshock CWP. They shall have an iron body, bronze-mounted OS&Y, with body and bolted bonnet conforming to ASTM A126 class B cast iron, flanged ends, with aramid fiber, nonasbestos packing, and two-piece packing gland assembly. Class 250 valves meeting the above specifications may be used where pressures approach 100 psi. Valves shall comply with MSS SP-70.

Ball Valves

2 inches and smaller Valves 2 inches and smaller shall be 150 psi SWP and 600 psi nonshock CWP, WOG. They shall have two-piece, cast bronze bodies; reinforced Teflon seats; a full port; blowout-proof stems; an adjustable packing gland; a stainless steel ball and stem; and threaded ends. Valves shall comply with MSS SP-110.

Note: A standard port may be used where pressure drop is not a concern. For on/off service, use ball valves with stainless steel balls. For throttling, use globe valves.

Globe Valves

2 inches and smaller Valves 2 inches and smaller shall be class 125, rated 125 psi SWP, 200 psi nonshock

CWP and have a body and bonnet of ASTM B62 cast bronze composition, with threaded ends. Stems shall be of dezincification-resistant silicon bronze (ASTM B371) or low-zinc alloy (ASTM B99). Packing glands shall be of bronze (ASTM B62), with aramid fiber, nonasbestos packing, complete with malleable hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have an iron body, bronze-mounted OS&Y, with body and bolted bonnet conforming to ASTM A126 class B cast iron and flanged ends, with aramid fiber, nonasbestos packing and two-piece packing gland assembly. Class 250 valves meeting the above specifications may be used where pressures approach 100 psi. Valves shall comply with MSS SP-85.

Check Valves

2 inches and smaller Valves 2 inches and smaller shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have threaded ends with body and cap conforming to ASTM B62 cast bronze composition, Y-pattern swing type with TFE seat disc or spring-loaded lift type with resilient seating. Valves shall comply with MSS SP-80.

Note: Class 150 valves meeting the above specifications may be used where system pressure requires them. For class 150 seat discs, TFE for steam service should be specified.

2½ inches and larger Valves 2½ inches and larger shall be class 125, rated 125 psi SWP, 200 psi nonshock CWP. They shall have an iron body, bronze mounted, with body and bolted bonnet conforming to ASTM A126, class B cast iron, flanged ends, a swing-type disc, and nonasbestos gasket. Valves shall comply with MSS SP-71.

Medium-pressure Steam Service

This includes up to 200-psi saturated steam to 391°F (201°C).

Butterfly Valves

Butterfly valves are not allowed in steam service unless stated as acceptable for the application by the manufacturer.

Gate Valves

2 inches and smaller Valves 2 inches and smaller shall be class 200, rated 200 psi SWP, 400 psi nonshock CWP. They shall have a rising stem; body and union bonnet of ASTM B61: *Standard Specification for Steam or Valve Bronze Castings* cast bronze; threaded ends; ASTM B584 solid wedge; silicon bronze ASTM B371 stem; bronze ASTM B62 or ASTM B584 packing gland; aramid fiber nonasbestos packing; and malleable hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 250, rated 250 psi SWP, 500 psi nonshock CWP. They shall have an iron body; bronze-mounted OS&Y with body and bolted bonnet conforming to ASTM A126; class B cast iron, flanged ends; with aramid fiber nonasbestos packing; and two-piece packing gland assembly. Valves shall comply with MSS SP-70.

Globe Valves

2 inches and smaller Valves 2 inches and smaller shall be class 200, rated 200 psi SWP, 400 psi nonshock CWP. They shall have a rising stem, body and union bonnet of ASTM B61 cast bronze, threaded ends, ASTM A276: *Standard Specification for Stainless Steel Bars and Shapes* type 420 stainless steel plug-type disc and seat ring, silicon bronze ASTM B371 alloy stem, bronze ASTM B62 or ASTM B584 packing gland, aramid fiber nonasbestos packing, and malleable iron hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 250, rated 250 psi SWP, 500 psi nonshock CWP. They shall have an iron body; bronze-mounted OS&Y with body and bolted bonnet conforming to ASTM A126; class B cast iron, flanged ends; with aramid fiber nonasbestos packing and two-piece packing gland assembly. Where steam pressure approaches 150 psi or 366°F, gray iron or ductile iron shall be used. Valves shall comply with MSS SP-85.

Check Valves

2 inches and smaller Valves 2 inches and smaller shall be class 200, rated 200 psi SWP, 400 psi nonshock CWP. They shall have threaded ends with body and cap conforming to ASTM B61 cast bronze composition and a Y-pattern swing-type disc. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 250, rated 250 psi SWP, 500 psi nonshock CWP. They shall have an iron body, bronze mounted, with body and bolted bonnet conforming to ASTM A126, class B cast iron flanged ends, and a swing-type disc assembly. Where steam pressure approaches 150 psi or 366°F, gray iron or ductile iron shall be used. Valves shall comply with MSS SP-71.

High-pressure Steam Service

This includes up to 300-psi saturated steam to 421°F (216°C).

Gate Valves

2 inches and smaller Valves 2 inches and smaller shall be class 300, rated 300 psi SWP. They shall have a rising stem, and body and union bonnet shall be of

ASTM B61 cast bronze composition, with threaded ends, bronze ASTM B61 disc, bronze ASTM B371 stem, stainless steel ASTM A276 type 410 seat rings, bronze packing gland, aramid fiber nonasbestos packing, and malleable hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 300, rated 300 psi SWP and have a cast carbon steel, ASTM A216: *Standard Specification for Steel Castings, Carbon, Suitable for Fusion Welding, for High-Temperature Service* wrought-carbon grade B (WCB) body and bolted bonnet. Disc and stem shall be ASTM A217: *Standard Specification for Steel Castings, Martensitic Stainless and Alloy, for Pressure-containing Parts, Suitable for High-temperature Service* grade CA 15, cast 12–14 percent chromium stainless steel, with stellite-faced seat rings, flanged ends, and two-piece packing gland assembly. Valves shall comply with MSS SP-70.

Globe Valves

2 inches and smaller Valves 2 inches and smaller shall be class 300, rated 300 psi SWP. They shall have a body and union bonnet of ASTM B61 cast bronze composition, threaded ends, stainless steel ASTM A276 hardened plug-type disc and seat ring, silicon bronze ASTM B371 stem, bronze ASTM B62 or ASTM B584 packing gland, aramid fiber nonasbestos packing, and malleable hand wheel. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 300, rated 300 psi SWP. They shall have a cast carbon steel ASTM A216 grade WCB body and bolted bonnet. Disc, stem, and seat rings shall be ASTM A217 grade CA 15, cast 12–14 percent chromium stainless steel, flanged or welded ends, with two-piece packing gland assembly. Valves shall comply with MSS SP-85.

Check Valves

2 inches and smaller Valves 2 inches and smaller shall be class 300, rated 300 psi SWP. They shall have threaded ends with body and cap conforming to ASTM B61, cast bronze composition, and Y-pattern swing-type disc. Valves shall comply with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be class 300, rated 300 psi SWP. They shall have a cast carbon steel, ASTM A216 grade WCB body and bolted bonnet. Disc and seat ring shall be ASTM A217 grade CA 15, cast 12–14 percent chromium stainless steel, with flanged or welded ends. Valves shall comply with MSS SP-71.

High-temperature Hot Water Service

This includes service to 450°F.

Nonlubricated Plug Valves

Valves shall be ANSI class 300, with 70 percent port nonlubricated, wedge plug, and bolted bonnet. Body, bonnet, and packing gland flange shall be cast carbon steel (ASTM A216) grade WCB.

Plug shall be cast from high-tensile, heat-treated alloy iron. The plug shall have two Teflon O-rings inserted into dovetail-shaped grooves machined into the plug faces. O-rings shall provide double seating and ensure vapor-tight shutoff on both the upstream and downstream seats. Valves are to be seated in both open and closed positions to protect body seats.

Stem shall be high-strength alloy steel conforming to American Iron and Steel Institute (AISI) 4150 and sulphurized, with face-to-face dimensions to meet ANSI B16.10: *Face-to-Face and End-to-End Dimensions of Valves*.

Each valve shall be provided with a position indicator for visual indication of the 90-degree rotation of the plug. Valves are to be equipped with a provision for bypass connections.

Types of Operator

1. Valves 3 inches and smaller: Hand wheel or wrench
2. Valves 4 inches and larger: Enclosed gear with hand wheel

Each valve shall be certified to have passed the following minimum test requirements:

- Shell test: 1,100-psi hydrostatic
- Seat test: 750-psi hydrostatic (both sides to be tested) and 100-psi air underwater (both sides to be tested)

Gasoline and LPG Service

Plug valves

Valves shall be ANSI class 150, 70 percent port, nonlubricated tapered plug, bolted bonnet type. Valve body shall be ASTM A216, grade WCB steel with drain plug, suitable for double block and bleed service.

The plug seals shall be two Teflon O-rings inserted into dovetail-shaped grooves machined into the plug faces. Operation is to be such that the plug is lifted clear of the seats before rotating 90 degrees.

End connections shall be ANSI class 150 raised face and flanged. Face-to-face dimensions are to meet ANSI B16.10.

Fire Protection Systems

Gate Valves

2 inches and smaller Valves 2 inches and smaller shall be of class 175 psi water working pressure (WWP) or greater, with body and bonnet conforming to ASTM B62 cast bronze composition, threaded ends, OS&Y, and solid disc and listed by UL, FM approved, and in compliance with MSS SP-80.

2½ inches and larger Valves 2½ inches and larger shall be rated 175 psi WWP or greater. They shall have an iron body, bronze mounted or with resilient rubber-encapsulated wedge, with body and bonnet conforming to ASTM A126, class B cast iron, OS&Y, class 125 flanged or grooved ends. If of resilient-wedge design, the interior of the valve is to be epoxy coated. Valves shall meet or exceed AWWA C509. Valves are to be UL listed, FM approved, and in compliance with MSS SP-70.

Valves 4 inches and larger for underground bury shall be rated 200 psi WWP or greater, with body and bonnet conforming to ASTM A126, class B cast iron, bronze mounted, resilient-seated gate valve with nonrising stem, with O-ring stem seal, epoxy coating inside and outside, and flanged or mechanical joint ends as required. All valves furnished shall open left. All internal parts shall be accessible without removing the valve body from the line. Valves shall conform to AWWA C509. Epoxy coating shall conform to AWWA C550. Valves shall come complete with a mounting plate for an indicator post and be UL listed, FM approved, and in compliance with MSS SP-70.

When required, a vertical indicator post may be used on underground valves. Posts must provide a means of knowing if the valve is open or shut. Indicator posts must be UL listed and FM approved.

High-rise Service

Gate Valves

2½ inches to 12 inches Gate valves 2½ inches to 10 inches shall be rated 300 psi WWP or greater. 12 inches shall be rated 250 psi WWP. They shall have an iron body, bronze mounted, with body and bonnet conforming to ASTM A126, class B, cast iron, OS&Y, with flanged ends for use with class 250/300 flanges. They shall be UL listed, FM approved, and in compliance with MSS SP-70.

Check Valves

2½ inches to 12 inches Check valves 2½ inches to 10 inches shall be rated 300 psi WWP or greater. 12 inches shall be rated 250 psi WWP. They shall have an iron body, bronze mounted, with a horizontal swing check design, with body and bonnet conforming to ASTM A126, class B, cast iron, with flanged ends for use with class 250/300 flanges. They shall be UL listed, FM approved, and in compliance with MSS SP-71.

Note: In New York City, valves are to be approved by the New York City Materials and Equipment Acceptance Division (MEA) in addition to the above specifications.

Ball Valves

2 inches and smaller Valves 2 inches and smaller shall be constructed of commercial bronze, ASTM B584, rated 175 psi WWP or higher, with reinforced TFE seats. Valves shall have a gear operator with a raised position indicator and two internal supervisory switches. Valves shall have threaded or IPS grooved ends and shall have blowout-proof stems and chrome-plated balls. They shall be UL listed, FM approved, and in compliance with MSS SP-110 for fire protection service.

Butterfly Valves

4 inches to 12 inches Butterfly valves may be substituted for gate valves, where appropriate. Valves shall be rated for 250 psi WWP, 175 psig working pressure, UL listed, FM approved, and in compliance with MSS SP-67.

Valves furnished shall have ductile iron ASTM A536 body and may have ductile iron ASTM A395: *Standard Specification for Ferritic Ductile Iron Pressure-retaining Castings for Use at Elevated Temperatures* (nickel-plated) discs or aluminum bronze discs, depending on local water conditions. In addition, wafer style for installation between class 125/150 flanges or lug style or grooved body may be specified, depending on the system's needs.

Valves shall be equipped with weatherproof gear, operator rated for indoor and outdoor use, with hand wheel and raised position indicator with two internal supervisory switches.

Check Valves

Valves 2½ inches and larger shall be 500 psi WWP, bolted bonnet, with body and bonnet conforming to ASTM A126, class B cast iron, flanged end with composition Y-pattern, horizontal, swing-type disc. They shall be UL listed, FM approved, and in compliance with MSS SP-71 type 1 for fire protection service.

4 Pumps

This chapter first explores the similarities among pumps used in plumbing systems, especially regarding energy efficiency. Then the differences are discussed, such as performance characteristics, applications, service, environmental concerns, and installation requirements. Centrifugal pumps stand out as the most common type of pump in plumbing because of their simple design, suitable head, and rotational speeds matching common motor designs. Drive belts or gears rarely are required. Close coupling of the motor to the pump is growing in use among small sizes, while large pumps still require joining of the shafts through a shaft coupler.

PUMP BASICS

Machines that move liquids are called turbo-machines, or pumps. Through the work of the pump, mechanical energy is added to the liquid, resulting in a higher energy downstream. As typically measured, the discharge pressure is greater downstream than upstream. As typically expressed, the head measurement of the liquid downstream is higher than the head upstream. That is, the liquid level in a simple standpipe installed at the outlet is greater than the liquid level in one installed at the inlet.

A previously used term for total head is "total dynamic head." For pumps placed below the inlet water level, either term is defined as the outlet, or discharge, head minus the inlet, or suction, head. For pumps placed above the inlet water level, the term is defined as discharge head plus suction lift.

The basic parts of all pumps consist of a passage and a moving surface. A primer mover, such as an electric motor but sometimes an engine, provides energy to the moving surface. Other parts may include shaft bearings and various seals, such as the shaft seal.

Pumps may be categorized as positive displacement, centrifugal, axial, or mixed flow. Positive displacement pumps deliver energy in successive isolated quantities by the direct application of a moving plunger, piston, diaphragm, or rotary element. Clearances are small between the moving and unmoving parts, and little liquid leaks around the moving part. Common rotary elements include vanes, lobes, and gears.

When a pump with a rotating surface, or impeller, has some clearance between itself and the stationary passage, or pump casing, the pump does not have positive displacement. If the direction of discharge from the impeller radiates at a right angle to the shaft, the pump is a centrifugal pump. If the direction is inline with the shaft, the pump is axial. If the direction is partly radial and partly axial, the pump is mixed flow. Common examples of a centrifugal pump, an axial pump, and a positive displacement pump include an automobile water pump, a boat propeller, and the human heart respectively.

Compared to positive-displacement pumps, centrifugal and axial pumps are more compact, simple, and without flow pulsations. In addition, their shaft speeds are suitable for direct drive on electric motors. Centrifugal pumps provide greater total head than similar-size axial pumps, but have less flow. Operation of a centrifugal pump includes the outward, radial projection of the liquid from the impeller as it rotates. In addition, if a gradual expanding passage is provided after the impeller, the high velocity is converted to high static pressure as a principle of the law of conservation of energy and as quantified in Bernoulli's equation. If the expanding passage wraps around the impeller, it is called a volute. The quantity, angle on the impeller, and shape of blades range from two straight blades positioned radially to many curved blades angled forward or, more commonly, backward to the direction of rotation. While forward blades theoretically impart greater velocity, the conversion to pressure is unstable except within a narrow speed range.

Connecting pipes to pumps generally is done using standard flanges, but may be made by threaded or soldered connections. The centerline of the inlet pipe may be aligned with the pump shaft. Figure 4-1 shows this type; it is referred to as an end-suction design. The outlet generally falls within the plane of the impeller. If the inlet and outlet connections align

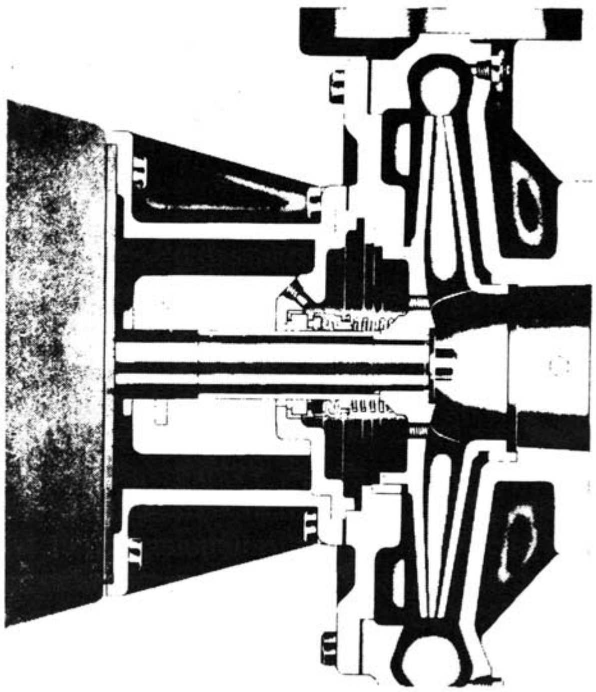


Figure 4-1 Portion of a Close-coupled Centrifugal Pump With an End-suction Design

Figure 4-2 Inline Centrifugal Pump with a Vertical Shaft
Photo courtesy of Peerless Pump Co.

as if in a continuation of the pipe run as shown in Figure 4-2, the pump is referred to as inline.

Casing materials are generally cast iron and, for domestic water supply, cast bronze. Other materials include stainless steel and various polymers. Impeller materials include cast iron, bronze, and various polymers. Pump bearings and motor bearings vary between traditional sleeves and roller elements such as steel ball bearings. Bearings on each side of the impeller minimize shaft stresses compared to a pair of bearings on one side. At the other extreme, the pump itself has no bearings and all hydraulic forces are applied on the motor bearings. The combination of these materials, design features, and the array of pump sizes makes pumps one of the most varied manufactured items.

The greatest pressure in any pumped system is within the pump casing, which includes the shaft seal. Another concern with this seal occurs when the pump is not operating, but a stored supply of pressure applies continuous static head against it. This seal traditionally has been designed with a flexible, composite material stuffed around a clearance between the shaft and the hub portion of the pump casing, referred to as a stuffing box. A mechanical arrangement applies pressure to the flexible material through routine adjustments. Some leakage is deliberately required, so provisions for the trickle flow must be accommodated such as with the installation of a floor drain.

Another seal design consists of a simple O-ring. More advanced seals include the mechanical seal and the wet rotor design. In a mechanical seal, the interface of two polished surfaces lies perpendicular to the shaft. One is keyed and sealed to the shaft, and the other is keyed and sealed to the pump casing. Both are held together by a spring and a flexible boot. Some pumps include two sets of these seals with the space between them monitored for leakage. Often, a special flow diversion continuously flushes the seal area. In the wet rotor design, the rotor winding of the motor and the motor bearings are immersed in the water flow and are separated from the dry stator by a thin, stationary, stainless steel shield. The shield imparts a compromise in the magnetic flux from the stator to the motor; hence, these pumps are limited to small sizes.

EFFICIENCY

High efficiency is not the only characteristic to examine in selecting a pump. It is explored here, nonetheless, to demonstrate the impact of alternatives when various compromises are considered.

An ideal pump transfers all of the energy from a shaft to the liquid. Hence, the product of torque and rotational speed equal the product of mass flow and total head. However, hydraulic losses, such as friction within the liquid through the pump, impeller exit losses, eddies from sudden changes in diameter, leaks, and turns in direction, or short-circuit paths, from high-pressure sections to low-pressure sections result in performance degradation. In addition, mechanical losses include friction in bearings and seals. The amount of both types of losses ranges from 15 to 80 percent in centrifugal pumps and lesser amounts for positive-displacement pumps.

Design features in centrifugal pumps that minimize hydraulic losses include generous passage diameters

Figure 4-3 Enclosed Impeller

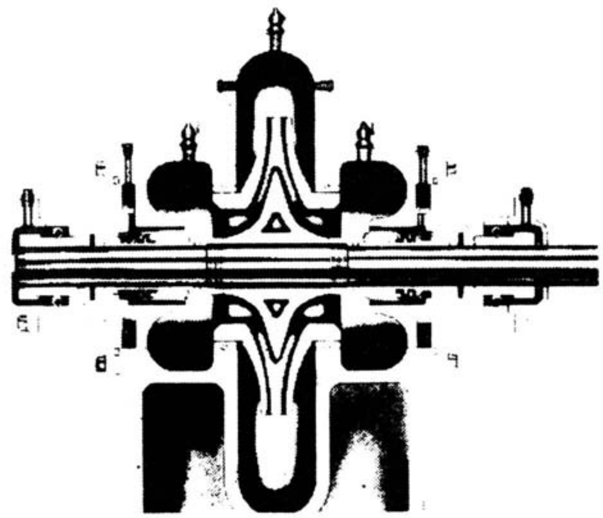


Figure 4-4 Centrifugal Pump with a Double-suction Inlet Design

to reduce friction, optimal impeller design, gradual diameter changes and direction changes, placement of barriers against short-circuits, and optimal matches of impeller diameters to pump casings. The design of a barrier against short-circuits includes multiple impeller vanes, seals at the impeller inlet, and minimal space between the impeller and the pump casing. The seals at the impeller inlet are commonly in the form of wear rings. Enclosed impellers, as shown in Figure 4-3, achieve higher heads because of the isolation of the inlet pressure from the liquid passing through the impeller; thus, the original efficiencies are maintained over the pump's useful life. Equation 4-1 illustrates the relationship among flow, total head, efficiency, and input power for pumps with cold water. For other liquids, the equation is appropriately adjusted.

Equation 4-1

$$P = \frac{Q \times h}{3{,}960 \times e} \left[\frac{Q \times h \times 9.81}{e}\right]$$

where

P = Power through the pump shaft, horsepower, in watts (W)
Q = Flow, gallons per minute (gpm [liters per second, L/s])
h = Total head, feet (meters)
e = Efficiency, dimensionless

Impellers with diameters significantly reduced from an ideal design generally compromise efficiency. The efficiency of centrifugal pumps varies greatly with head and flow. Hence, a pump with 85 percent efficiency at one flow may be 50 percent at one-third of that flow.

Axial flow directed into the impeller of a centrifugal pump may come from one side only (single-suction pump, Figure 4-1) or both sides (double-suction pump, Figure 4-4). The single-suction design creates axial forces on the pump shaft. The double-suction design balances these forces. In addition, double-suction pumps have slower inlet velocities, which aid in preventing cavitation.

Since most pumps are driven by electric motors, a complete review of pump efficiency should include consideration of motor efficiency, which varies with torque, type of motor, speed, type of bearings, and quality of electricity. Many fractional horsepower, single-phase motors experience a dramatic loss of efficiency at light loads. A three-phase motor achieves peak efficiency at slightly less than full load. High-speed motors and large motors offer greater efficiencies than slower or smaller motors. Poly-phase, permanent split-capacitor, and capacitor-start/capacitor-run motors are more efficient than split-phase, capacitor-start/induction-run, and shaded pole motors.

When the operating flow and head of a centrifugal pump fall near its best efficiency point (BEP), the pump's first cost is minimized. In addition, bearing stresses and shaft stresses are less than at part flow because total head is less. Thus, the expected life of the pump is longer.

An appreciation of the benefits of investing in efficiency in various parts of a plumbing system can be realized by identifying the magnitude of power in various parts of a building. For example, a domestic water heater's energy input may be 1,000,000 British thermal units per hour (Btuh) (293 kilowatts [kW]), while its circulation pump may be 700 Btuh (205 W). Hence, in this situation an inefficient pump is of little consequence. Excessive circulation increases standby losses, but a more efficient heat exchanger in the water heater will provide the most tangible benefit. While the importance of a fire pump for fire suppression is paramount, efficiency invested there is less important than a reliable pump design.

COMPARISON OF SIMILAR CENTRIFUGAL PUMPS

The various characteristics of centrifugal pumps can be reduced to two coefficients and one value referred to as "specific speed."

The coefficients and a set of relationships, commonly called affinity laws, allow similarly shaped centrifugal pumps to be compared. In general, the coefficients also apply to axial and mixed-flow pumps, as well as turbines and fans.

Deriving the coefficients starts with the law of conservation of momentum. That is, the summation of forces on the surface of any fixed volume equals the aggregate of angular-momentum vectors multiplied by the flows at each of those vectors. Since the applied energy into the liquid for a pump application, on the fixed volume around the impeller, is only the tangential movement of the impeller, only the tangential velocity vectors are considered. Further, for constant density, radius, and tangential velocity at the inlet and outlet of an impeller, the momentum equation becomes as follows:

$$T = d_2 \times r_2 \times v_{t2} \times Q_2 - d_1 \times r_1 \times v_{t1} \times Q_1$$

where
- T = Torque
- d_2 = Density at the outlet
- r_2 = Radius at the outlet
- v_{t2} = Tangental velocity at the outlet
- Q_2 = Flow at the outlet
- d_1 = Density at the inlet
- r_1 = Radius at the inlet
- v_{t1} = Tangential velocity at the inlet
- Q_1 = Flow at the inlet

From Bernoulli's equation of an ideal flow through any type of pump, total head is a measure of energy per weight or rate of power per flow and specific weight. Since power is the product of torque and rotational speed, relate the above equation with equal flows entering and leaving the impeller as follows:

$$h = \frac{P}{d \times g \times Q} = \frac{(r_2 \times v_{t2} - r_1 \times v_{t1}) \times n}{g}$$

where
- h = Total head created by the pump
- P = Power
- n = Rotational speed
- g = Gravity constant

With the velocity of the tip of a rotating surface at its outside radius designated as U, the equation is:

$$h = \frac{U_2 \times v_{t2} - U_1 \times v_{t1}}{g}$$

For centrifugal pumps, flow is proportional to the outlet radial velocity. In addition, $v_{t1} = 0$ since inlet flow generally is moving in an axial direction and not in a tangential direction. Thus:

$$h = \frac{U_2 \times v_{t2}}{g}$$

Figure 4-5 shows the velocity vectors of the flow leaving the impeller. Vector v_{r2} represents the velocity of the water in a radial direction, Vector X represents the velocity of the water relative to the impeller blade, and Vector Y represents the sum of X and U. Thus, it is possible to resolve these vectors into tangential components and derive the following:

$$v_{t2} = U_2 - v_{r2} \cot B = U_2 \, (1 - (v_{r2} / U_2) \cot B)$$

or

$$h = \frac{U_2 \times U_2 \, (1 - (v_{r2} / U_2) \cot B)}{g}$$

or

Equation 4-2

$$h = \frac{U_2^2 \, (1 - (C_Q) \cot B)}{g}$$

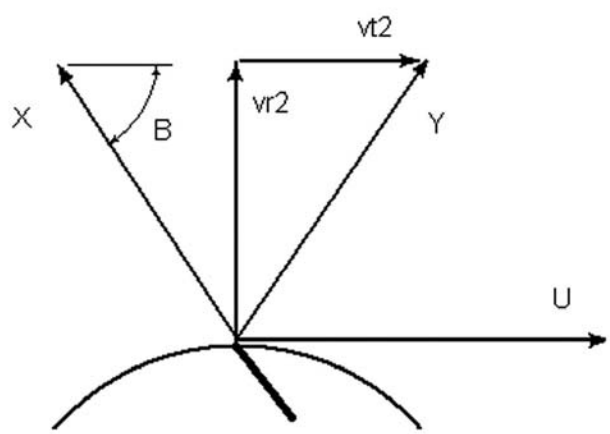


Figure 4-5 Net Fluid Movement From an Impeller Represented by Vector Y

For a given flow, v_{r2} / U_2 is constant, and this ratio is defined as the capacity coefficient, or C_Q. For a given flow and impeller design, C_Q and Angle B are constant, which is referred to as a head coefficient, or C_H, as shown in Equation 4-3.

Equation 4-3

$$C_H = \frac{h \times g}{U_2^2}$$

As commonly expressed as the second pump affinity law, total head is directly proportional to the square of the impeller's tip velocity. Further, flow is directly proportional to this velocity (the first affinity law). Since the product of flow and head is power, power is directly proportional to the cube of the velocity (the third affinity law). Since tip velocity is a product of rotational speed and the impeller's radius, these same relationships regarding rotational speed and impeller radius (or diameter) can be summarized as found in Table 4-1. Each function is directly proportional to the corresponding value in the other columns. In addition, it is customary to combine flow and head with the rotational speed and set exponentials, so this speed appears to the first power. The result, $nQ^{0.5}/h^{0.75}$, is called the specific speed of the pump.

Table 4-1 Centrifugal Pump Affinity Laws

Function	Tip Velocity	Rotational Speed, rpm (radians/sec)	Impeller Radius (or Diameter), in. (mm)
Flow	U	n	R
Head	U^2	n^2	R^2
Power	U^3	n^3	R^3

When flow rate, head, and given pump speed are known, the specific speed can be derived, and the design of an economic pump can be identified, whether centrifugal, axial, or mixed flow. Specific speed also allows a quick classification of a pump's efficient operating range with a mere observation of the shape of the impeller. The affinity laws allow easy identification of pump performance when the speed changes or the impeller diameter changes. For example, doubling the speed or impeller diameter doubles the flow, increases the head by four, and increases the required power by eight.

PERFORMANCE CURVES

Since centrifugal pumps do not supply a nearly constant flow rate like positive-displacement pumps, curves are presented by manufacturers to aid in selection. Under controlled conditions, such as with water at a certain temperature, these curves are created from measurements of impeller speed, impeller diameter, electric power, flow, and total head. The standard conditions are created by such groups as the Hydraulic Institute. As can be observed, the shape of the curve in Figure 4-6 agrees with Equation 4-2. This characteristic pump curve represents a particular impeller diameter measured at a constant speed, with its total head varied and its resulting flow recorded. Efficiency is plotted on most curves and the BEP is sometimes marked. Additional curves include shaft input power, measured in horsepower (watts), efficiency, and net positive suction head.

While each curve is plotted for a given pump and various diameter impellers, a pump in operation under a constant head and speed has one particular flow. The flow and the head on the curve that represents the selected impeller's diameter commonly are referred to as a duty point or system balance point. This point is located on the curve where a vertical line at a particular flow crosses the pump curve. The pump will provide that flow if that head applies.

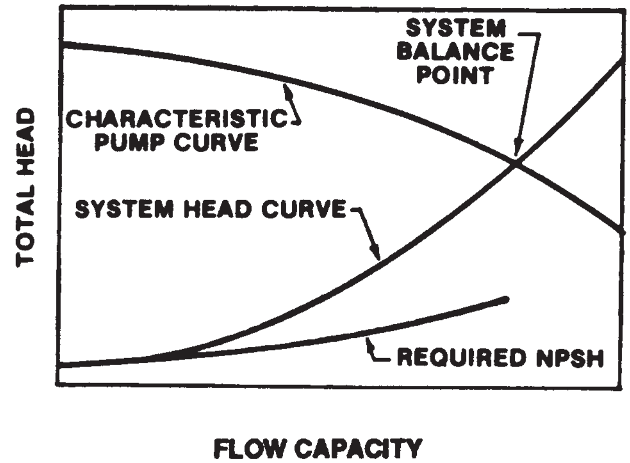


Figure 4-6 Typical Pump Curve Crossing a System Curve

In plumbing, a particular flow may be required for a sump pump or hot water circulation pump. In domestic water or fire suppression supply systems, the head varies with the quantity of open faucets, outlets, hose streams, or sprinkler heads. Further, that quantity varies with time. Thus, the duty point rides left and right along the curve with time.

A curve that represents the building's distribution piping at peak demand can be drawn on the pump curve. This second curve, called the system head curve, is shown in Figure 4-6. Equation 4-4 represents this familiar curve, where p_1 represents a pressure gauge reading at the pump inlet, p_2 and h_2 represent pressure and elevation head respectively at a particular system location such as at a remote fixture, and the last term represents the entire friction head in the piping between the two points. The curve's shape is parabolic. This curve is applicable to any liquid with a constant absolute viscosity over a wide flow range (a Newtonian fluid).

Equation 4-4

$$h_p = (p_2 - p_1)/d + h_2 + f(L/D)(v^2/2g)$$

At no flow, the friction term becomes zero since velocity is zero, and the point where this curve crosses the vertical axis is the sum of the remaining terms.

To select a pump, determine the peak flow and use Equation 4-4 to determine the required pump head. These two numbers identify the minimally required duty point. Most manufacturers' pump catalogues present a family of pumps with many pump curves for two or more pump speeds. Pick a pump size that at least includes the required duty point. An optimal pump is one whose curve crosses the duty point, but with most pump selections, the pump curve crosses above the duty point. Mark the duty point on the detailed curves for the selected pump size. The pump's motor size, in horsepower or watts, can be identified by the input shaft power curve that is immediately to the right of the duty point. The pump's efficiency can be estimated from the efficiency curves wrapping around the duty point. Comparing the efficiencies of several pumps can lead to the more ideal choice.

The shape of various pump curves varies with pump designs. Steep curves are characterized with a rapidly dropping head as the flow increases. Flat curves have a slight variation from no flow to BEP, often defined as 20 percent. The latter is preferred in most plumbing applications that employ one pump because of the nearly uniform head. However, a pump with a steep curve has an advantage when a high head is required in an economical pump design and the flow is of less consequence. For example, a sump pump, which has a sump to collect peak flows into its basin, may have a high static head. With a generous volume in the sump, the total time to evacuate is secondary; therefore, the pump's flow is of less concern than its head. Further, as the inlet flow increases and the water level rises, the head reduces and the pump flow increases.

A pump design with some slope in its curve is desired for parallel pump configurations. The sum of the flows at each head results in a more flat curve. For control, the drop in head as the demand increases may serve as an indicator to stage the next pump. A pump with nearly vertical steepness is desired for drainage pumps that are part of a system of pumps that discharge into a force main. This performance characteristic allows a nearly uniform flow at varying heads. Some centrifugal and all positive-displacement pumps exhibit this characteristic.

TERMINOLOGY

The following terms typically are used by engineers when discussing pumps.

Standpipe A theoretical vertical pipe placed at any point in a piping system so that the static head can be identified by observing the elevation of the free surface of the liquid. The connection of the standpipe to the piping system for a static head reading is perpendicular to the general flow stream.

Head The energy of a fluid at any particular point of a flow stream per weight of the fluid. Units of measurement are generally in feet (meters).

Static head Elevation of water in a standpipe relative to the pipe centerline of a piping system. Any pressure gauge reading can be converted to static head if the density of the liquid is known.

Velocity head The velocity portion of head with its units converted to an equivalent static head.

Total discharge head The sum of static head and velocity head at a pump discharge.

Suction head Static head near the inlet of a pump relative to the pump centerline.

Suction lift In contrast to suction head, this vertical dimension is between the pump centerline and a liquid's surface that is below the pump.

Total head Total head at the pump discharge minus suction head or plus suction lift.

Churn Maximum static head of a pump. This is typically the head when all flow is blocked.

Net positive suction head Static head, velocity head, and equivalent atmospheric head at a pump inlet minus the absolute vapor pressure of the liquid being pumped.

Head coefficient Ratio that expresses pump head divided by the square of the impeller tip's velocity.

Capacity coefficient Ratio of radial velocity of the liquid at the impeller to the velocity of the impeller's tip.

Specific speed An index relating pump speed, flow, and head so that an optimal pump impeller can be selected.

Figure 4-7 Multistage or Vertical Lineshaft Turbine Pump
Photo courtesy of Peerless Pump Co.

STAGING

To obtain greater total head, two pumps can be connected in series; that is, the discharge of one pump becomes the inlet of the other. As a convenience, pump manufacturers have created multistage pumps where two or more centrifugal pumps are joined in a series by combining all of the impellers on a common shaft and arranging the casing to direct the flow of a volute into the eye of the next impeller. (See Figure 4-7.) Another way to obtain a greater head is by using a regenerative turbine pump. Unlike other centrifugal pumps, the outer edge of the impeller and its volute intentionally employ higher velocities through the recirculation of a portion of the flow from the volute to just inside the tip of the impeller. The close dimensions of these pumps limit their use to clean liquids. Applications of high-head pumps include water supplies in high-rise buildings, deep water wells, and fire pumps for certain automatic standpipe systems.

APPLICATIONS

Pump applications in plumbing include specialty pumps for liquid supplies, pressure boost for domestic water supply, similar supply for fire suppression, water circulation for temperature maintenance, and elevation increases for drainage systems. Except for the circulation application, pump systems theoretically are open systems, meaning that the liquid is transferred from one reservoir to another of a higher elevation. The applications vary in the nature of the liquid, the duty—whether for daily use or for rare firefighting—and the magnitude of elevation changes.

To select a specialty pump, the following must be considered: pressure increase, range of flow, nature of the energy source (electricity, air, manual, other), whether the liquid contains particulates, whether pulses are tolerable, accuracy in dispensing, self-priming requirement, whether the pump is submerged, and if the pump requires an adaptation to its supply container.

A domestic booster pump system typically uses multiple parallel centrifugal pumps to increase municipal water pressure for the building's domestic water distribution. Particular design issues such as sizing, pump redundancy, pressure-reducing valves, other pump controls, adjustable-frequency drives, high-rise buildings, and break tanks are described in *Plumbing Engineering Design Handbook, Volume 2,* Chapter 5: "Cold Water Systems." The same issues apply for private water systems that require a well pump.

The water supply for fire suppression requires a pump that is simple and robust. In addition, the slope of the performance curve is limited by fire pump standards. National Fire Protection Association (NFPA) 20: *Standard for the Installation of Stationary Fire Pumps for Fire Protection* limits the curve to not less than 65 percent of rated total head for 150 percent of rated flow. A variety of listing agencies monitor pump manufacturing to certify compliance with one or more standards. The design of a single-stage or multistage centrifugal pump generally qualifies. A double-suction centrifugal pump with enclosed impeller, horizontal shaft, wear rings, stuffing-box shaft seals, and bearings at both ends historically has been used. The pump inlet connection generally is in line with the outlet connection.

A recent variation, for small fire pumps, includes a vertical shaft and a single-suction design with the impeller fastened directly to the motor shaft. Pump bearings, shaft couplings, and motor mounts are eliminated in this compact design. In applications for tank-mounted fire pumps, the impeller is suspended near the bottom of the tank, and the motor or other prime mover is located above the cover of the tank. Between the two is a vertical shaft placed within a discharge pipe. NFPA labels these pumps as vertical lineshaft turbine pumps. Flexibility in its design includes multistaging, a wide range of tank depths, and several types of prime movers.

Maintaining adequate water temperature in plumbing is achieved through circulation pumps. Applicable generally for hot water, but equally effective for chilled water to drinking fountains served by a remote chiller, the circulation pump maintains a limited temperature change. Heat transfer from hot water distribution piping to the surrounding space is quantified for each part of the distribution network. For a selected temperature drop from the hot water source to the remote ends of the distribution, an adequate flow in the circulation can be determined from Equation 4-5. Since the nature of circulation is as if it were a closed system, pump head is simply the friction losses associated with the circulation flow.

Equation 4-5

$$Q = \frac{q}{500 \times T} \left[\frac{q}{4{,}187 \times T} \right]$$

where

Q = Flow, gpm (L/s)
q = Heat transfer rate, Btuh (W)
T = Temperature difference, °F (°C)

For example, if it is determined that 1,000 Btuh transfers from a length of hot water piping and no more than 8°F is acceptable for a loss in the hot water temperature, the flow is determined to be 1,000/(500 × 8) = 0.250 gpm. In SI, if it is determined that 293 W transfers from a length of hot water piping and no more than 4.4°C is acceptable for a loss in the hot water temperature, the flow is determined to be 293/(4,187 × 4.4) = 0.0159 L/s.

Where the elevation of the municipal sewer is insufficient or other elevation shortfalls occur, pumps are added to a drainage system. The issue may apply only to one fixture, one floor, or the entire building. Sub-soil drainage generally is pumped. In addition, if backflow is intolerable from floor drains in a high-value occupancy, pumps are provided for the floor drains. Terminology varies to describe these pumps, but typical names include sewage pump, sump pump, sewage ejector, lift station pump, effluent pump, bilge pump, non-clog pump, drain water pump, solids-handling sewage pump, grinder pump, dewatering pump, or wastewater pump. This chapter uses the broader term, drainage pump, to include sub-soil drainage.

The nature of solids and other contaminants in the water through these pumps necessitates several types of pump designs. For minimal contaminants, the design may be with an enclosed impeller, wear rings, and clearance dimensions that allow ¾-inch (19-mm) diameter spheres to pass through. For drainage flows from water closets and similar fixtures, manufacturers provide pumps of two designs. One design uses an open recessed impeller, no wear rings, and clearance dimensions that allow 2-inch (50-mm) diameter spheres to pass through. The other, referred to as a grinder pump (see Figure 4-8), places a set of rotating cutting blades upstream of the impeller inlet, which slices solid contaminants as they pass through a ring or disc that has acute edges. Efficiency is compromised in both for the sake of effective waste transport, in the latter more so than the former, but with the benefit of a reduced pipe diameter in the discharge piping. Grinder pumps are available in centrifugal and positive-displacement types.

Drainage pumps generally have vertical shafts, cylindrical basins, and indoor or outdoor locations. Some pumps are designed to be submerged in the inlet basin, others in a dry pit adjacent to the basin, and others mount the motor above with only the pump casing and impeller submerged. In any design, provision is required for air to enter or leave the basin as the water level varies. The installation of a pump in a sanitary drain system includes a sealed basin and vent piping to the exterior or vent stack. In some cases, the pump is above the water level but only if a reliable provision is included in the design to prime the pump prior to each pumping event.

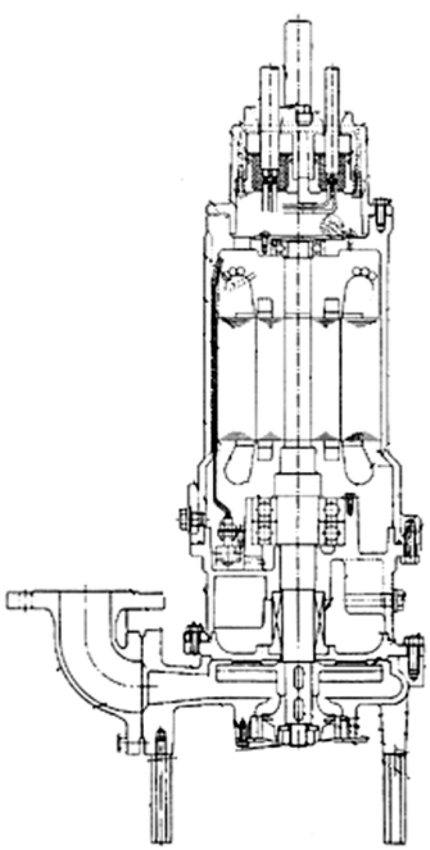


Figure 4-8 Cross-section of a Grinder Pump with Cutting Blades at the Inlet

Photo courtesy of Ebara.

PUMP SERVICE

The selection of a pump includes factors such as the need to monitor, repair, or replace the pump. Pumps in accessible locations can be readily monitored. Sensors on remote pumps, such as seal-leak probes and bearing vibration sensors, assist in pump monitoring to avert a catastrophic pump failure.

Pump maintenance can be facilitated when disassembly requires minimal disturbance of piping or wiring. Disassembly may be with the casing split horizontally along a horizontal shaft or with the casing split perpendicularly to the shaft. The latter allows impeller replacement without disturbing the pipe connection to the pump body.

Complete pump replacement can be facilitated with adequate access, shutoff valves, nearby motor disconnects, minimal mounting fasteners, direct mounting of the motor on the pump housing (close-coupled pump), and pipe joints with bolted fasteners. A simpler arrangement, commonly used for submersible drainage pumps, provides the pump removal from a basin by merely lifting a chain to extract it. The lift or return is facilitated by special guide rails, a discharge connection joint held tight by the weight of the pump, and a flexible power cable.

ENVIRONMENTAL CONCERNS

In addition to concerns about how pumps may affect the environment, the environment may affect the design requirements for pumps. An example of the former is a provision in an oil-filled submersible pump to detect an oil leak. A probe in the space between a pair of shaft seals signals a breach of the lower seal. Another example is vibration isolation for pumps near sensitive spaces.

Examples of the latter include provisions in the pump design for potential explosions, loss of electric power, or corrosive environments. That is, the pump, its motor, and its cabling may be subjected to methane gas in a sewage ejector; a loss of power to a drainage pump may be supplemented locally with a parallel pump powered from a marine battery; or the material of any pump must consider any corrosive environments surrounding it. Other examples of the environment affecting a pump include the temperature of the water through the pump, temperature of the air around the pump, and nature of contaminants in the water.

PUMP CONTROL

Pump controls vary with applications. A small simplex sump pump may have a self-contained motor overload control, one external float switch, an electric plug, and no control panel. A larger pump of any application may have a control panel with a motor controller, run indicator light, hand-off auto switch, run timer, audio/visual alarm for system faults, and building automation system interface. The manufacturing of the control panel may be certified as complying with one or more safety standards. The panel housing may be classified to match its installation environment. Motor control generally includes an electric power disconnect and related control wiring as well as power-interrupting controls against motor overload, under-voltage, over-current, and various alarm conditions. The largest pumps often include reduced-voltage starters. Duplex or triplex pump arrangements include these control features for each pump and an alternator device that alternates which pump first operates on rising demand. A microprocessor may be economically chosen for applications involving at least a dozen sensor inputs.

A booster pump has additional controls such as low flow, low suction pressure, high discharge pressure, time clock for an occupancy schedule, and possibly a speed control such as a variable-frequency drive.

A circulation pump may include a temperature sensor that shuts down the pump if it senses high demand, which presumably indicates adequate hot water in each distribution branch. A time clock for an occupancy schedule shuts down the pump during off-hours.

The control of a fire pump may include automatic transfer between two power sources, engine control, and pressure maintenance through a secondary pump (jockey pump).

The control of a drainage pump includes one or more float switches and possibly a high-water alarm.

PUMP INSTALLATION

Pumping effectiveness and efficiency require a uniform velocity distribution across the pipe diameter or basin dimensions at the pump inlet. An elbow, increaser with a sudden diameter change, check valve, and other flow disturbances create an irregular velocity profile that reduces flow and possibly discharge head. To avoid air entrapment, eccentric reducers, with the straight side up, are used on inlet piping rather than concentric reducers.

In addition to shutoff valves, general pump installations may include drain ports, pressure gauges, automatic or manual air release vents, and vibration isolation couplings. A pressure gauge upstream and downstream of the pump allows easy indication of rated pump performance. Check valves are provided for each pump of duplex and similar multiple-pump arrangements, fire pumps, and circulation pumps.

A fire pump includes provisions for periodic flow testing. Fire pumps may include a pressure relief valve if low flows create high heads that exceed pipe material ratings.

All pumps require a minimum pressure at their inlet to avoid harmful cavitation. Destructive effects occur when low absolute pressures at the entry to the impeller cause the water to vaporize and then collapse further into the impeller. The resulting shock wave erodes the impeller, housing, and seals as well as overloads the bearings and shaft. Anther effect is reduced flow due to the blockage caused by the pockets of water vapor. Cavitation is avoided by verifying Equation 4-6.

Equation 4-6

$$h_r \leq h_a - h_v + h_s - h_f$$

where

h_r = Net positive suction head required, from pump manufacturer, feet (m)
h_a = Local ambient atmospheric pressure converted to feet (m) of water
h_v = Vapor pressure of water at applicable temperature, feet (m)
h_s = Suction head (negative value for suction lift), feet (m)
h_f = Friction head of piping between pump and where h_s is measured, feet (m)

Increasing h_s resolves most issues regarding cavitation, generally by mounting the pump impeller as low as possible. Note that h_r varies with flow and impeller diameter, $h_a = 33.96$ feet (10.3 m) for an ambient of 14.7 pounds per square inch (psi) (101 kilopascals [kPa]) and $h_v = 0.592$ feet (0.180 m) for water at 60°F (15.5°C). Suction head, h_s, may be the inlet pressure converted to head, but it also may be the vertical distance from the impeller centerline to the surface of the water at the inlet. The ambient head, h_a, also may need adjusting for sewage pumps, with the basin connected to an excessively long vent pipe. Reciprocating positive-displacement pumps have an additional acceleration head associated with keeping the liquid filled behind the receding piston.

Submergence is a consideration for pumps joined near or in a reservoir or basin. A shallow distance from the pump inlet to the surface of the water may create a vortex formation that introduces air into the pump unless the reservoir exit is protected by a wide plate directly above. In addition to lost flow capacity, a vortex may cause flow imbalance and other harm to the pump. Extra depth can be added to a basin to mount the pump lower, and the elevation of the water surface can be unchanged to keep the same total head.

Like all parts of engineering, redundancy can be considered for any pump application. The aggregate capacity of a set of pumps may exceed the peak demand by any amount; however, the summation for centrifugal pumps involves adding the flow at each head to create a composite performance curve. Discretion is further made to the amount of redundancy, whether for each duplex pump at 100 percent of demand or each triplex pump at 40 percent, 50 percent, or 67 percent. For efficiency's sake, a mix may be considered for a triplex, such as 40 percent for two pumps and 20 percent for the third pump.

CONCLUSION

Pumps in plumbing systems generally take advantage of the inherent qualities of the centrifugal type, even in a wide range of applications. While water is the primary liquid considered in plumbing, its temperature varies by more than 100°F (56°C) with different applications, and contaminants range from sand to human waste to whatever a vandal imagines to add into plumbing. Issues concerning reliability range from continuous, but inconsequential, operation to rare, but essential, operation. For example, minor inconveniences may occur when a circulation pump is lost, but great harm may occur when a fire pump fails to respond. Consequentially, booster pumps and drainage pumps fall in between these two extremes.

Efficiency of a pump installation can be improved with careful selection and inlet piping. Safe and effective control varies with various applications. A motorized centrifugal pump is used with nearly all plumbing applications, but each pump varies greatly with its selection of materials, mounting type, shaft seals, bearings, shaft orientation, impeller type, pipe connection configuration, and shaft coupling. Hence, the centrifugal pump in plumbing is manufactured in a wide range of designs.

RESOURCES

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5 Piping Insulation

Insulation and its ancillary components are major considerations in the design and installation of the plumbing and piping systems of modern buildings. The insulation and methods discussed herein are used on a regular basis primarily for plumbing and drainage work.

Insulation is used for the following purposes:

- The retardation of heat or cooling temperature loss through pipe
- The elimination of condensation on piping
- Personnel protection by keeping the surface temperature low enough to touch
- The appearance of the pipe, where aesthetics are important
- The protection of pipe from abrasion or damage from external forces
- The reduction of noise from a piping system

To ensure understanding of the mechanism of heat, the following glossary of terms is provided.

GLOSSARY

British thermal unit (Btu) The heat required to raise the temperature of 1 pound of water 1°F.

Conductance Also known as "conductivity," the measurement of the flow of heat through an arbitrary thickness of material, rather than the 1-inch thickness used in thermal conductivity. (See also thermal conductivity.)

Convection The large-scale movement of heat through a fluid (liquid or gas). It cannot occur through a solid. The difference in density between hot and cold fluids produces a natural movement of heat.

Degree Celsius The measurement used in international standard (SI) units found by dividing the ice point and steam point of water into 100 divisions.

Degree Fahrenheit The measurement used in inch-pound (IP) units found by dividing the ice point and steam point of water into 180 divisions.

Heat A type of energy that is produced by the movement of molecules. The more movement of molecules, the more heat. All heat (and movement) stops at absolute zero. It flows from a warmer body to a cooler body. It is calculated in such units such as Btu, calories, or watt-hours.

Kilocalorie (kcal) The heat required to raise 1 kilogram of water 1°C.

Thermal conductivity The ability of a specific solid to conduct heat. This is measured in British thermal units per hour (Btuh) and is referred to as the "k" factor. The standard used in the measurement is the heat that will flow in one hour through a material 1 inch thick, with a temperature difference of 1°F over an area of 1 square foot. The metric equivalent is watts per square meter per degree Kelvin ($W/m^2/K$). As the "k" factor increases, so does the flow of heat.

Thermal resistance Abbreviated "R," the reciprocal of the conductance value. (See conductance.)

Thermal transmittance Known as the "U" factor, this is the rate of flow, measured in thermal resistance, through several different layers of materials taken together as a whole. It is measured in Btuh per square foot per degree Fahrenheit ($Btuh/ft^2/°F$).

WATER VAPOR

Water vapor is present in the air at all times. A water vapor retarder does not stop the flow of water vapor. Rather, it serves as a means of controlling and reducing the rate of flow and is the only practical solution to the passage of water vapor. Its effectiveness depends on its location within the insulation system, which is usually as close to the outer surface of the insulation as practical. Water vapor has a vapor pressure that is a function of both temperature and relative humidity. The effectiveness of an insulation system is best when it is completely dry.

The water vapor transmission rate is a measure of water vapor diffusion into or through the total insulation system and is measured in perms. A perm is the weight of water, in grains, that is transmitted through 1 square foot of insulation 1 inch thick in one hour. A generally accepted value of 0.10 perms is considered the maximum rate for an effective vapor retarder. A formula for the transmission of water vapor diffusing through insulation systems is given in Equation 5-1.

Equation 5-1

$$W = \mu A T \Delta \frac{P}{L}$$

where

W = Total weight of vapor transmitted, grains (7,000 grains = 1 pound of water)

μ = Permeability of insulation, grains/ft^2/h/in. Hg ΔP/in.

A = Area of cross-section of the flow path, square feet

T = Time during which the transmission occurred, hours

ΔP = Difference of vapor pressure between ends of the flow path, inches of mercury (in. Hg)

L = Length of flow path, inches

FLAME AND SMOKE REQUIREMENTS

When a fire starts within a building, many of its contents contribute to the fire by either generating smoke (if the product is incombustible) or supporting combustion. Code limits for these factors have been established. These ratings are for complete insulation systems tested as a whole and not for individual components. The maximum code values for a flame spread index of 25 or less and smoke developed index is 50 or less. These values have been established for noncombustible construction. Combustible construction may be different.

The tunnel test is used to find the requirements for the different combinations of materials that are used. They are tested for flame spread and smoke developed. The ratings are compared to red oak flooring (indexed at 100) and cement board (indexed at zero). Each test is given a different name by the agency that conducts it. The American Society for Testing and Materials calls it ASTM E84: *Standard Test Method for Surface Burning Characteristics of Building Materials,* the National Fire Protection Association calls it NFPA 255: *Standard Method of Test of Surface Burning Characteristics of Building Materials,* and Underwriters Laboratories calls it UL 723: *Test for Surface Burning Characteristics of Building Materials*.

A test conducted by UL determined, however, that a smoke-developed index of 200 or less did not appreciably reduce visibility for periods of up to six minutes. From this report, it seems likely that smoke developed index of up to 200 could provide good visibility.

CLEANING AND STERILIZATION

Insulation used for the chemical, pharmaceutical, and food-processing industries (for example) must have the ability to withstand repeated cleaning by various methods. This is provided by application of the proper jacketing material. Important properties of this jacket shall be resistance to growth of any organism, smooth, white finish, resistance to repeated cleaning by the method of choice by the owner, and nontoxicity.

TYPES OF INSULATION

All the various named types of insulation have different trade names given by manufacturers. The discussions that follow use the generic names for the most often used materials in the plumbing and drainage industry.

The various properties are based on the following conditions:

- All materials have been tested to ASTM, NFPA, and UL standards for a flame spread index of 25 or less and a smoke developed index of 50 or less.
- The temperature at which the k and R ratings were calculated was 75°F (24°C).

Fiberglass

Fiberglass insulation shall conform to ASTM C547: *Standard Specification for Mineral Fiber Pipe Insulation*. It is manufactured from glass fiber bonded with a phenolic resin. It is the chemical composition of this resin that determines the highest temperature rating of this insulation. (Consult the manufacturer for exact figures.) This insulation is tested to fall below the index of 25 for flame spread and 50 for smoke developed. It has a low water absorption and no to very limited combustibility. It has poor abrasion resistance.

This is the most commonly used insulation for the retardation of heat loss from plumbing lines and equipment. The recommended temperature range is from 35°F to 800°F (1.8°C to 422°C), with ratings depending on the binder. It is available as premolded pipe insulation, boards, and blankets. Typical k values range from 0.22 to 0.26, and R values range from 3.8 to 4.5. Its density is about 3–5 pounds per cubic foot (48–80 kilograms per cubic meter).

Fiberglass by itself is not strong enough to stay on a pipe or piece of equipment, prevent the passage of water vapor, or present a finished appearance. Because of this, a covering or jacket must be used.

Elastomeric

Elastomeric insulation, commonly called "rubber," shall conform to ASTM C534: *Standard Specification for Preformed Flexible Elastomeric Cellular Thermal*

Insulation in Sheet and Tubular Form. This is a flexible, expanded foam, of closed-cell material manufactured from nitrile rubber and polyvinyl chloride resin. This insulation depends on its thickness to fall below a specific smoke-developed rating. All thickness has a flame-spread index of 25. It can absorb 5 percent of its weight in water and has a perm rating of 0.10. Its density ranges between 3 pounds per cubic foot and 6 pounds per cubic foot.

The recommended temperature range is from –297°F to 220°F (–183°C to 103°C). A typical k value is 0.27, and a typical R value is 3.6. Recommended use for this insulation includes preformed insulation for pipe sizes up to 6 inches (DN 150) in ½-inch, ¾-inch, and 1-inch thicknesses. It is also available in 48-inch (1,200-mm) wide rolls and in sheet sizes of 36 × 48 inches (900 × 1,200 mm). An adhesive must be used to seal the seams and joints and adhere it to the equipment.

Rubber insulation can be painted without treatment. It is widely used in mechanical equipment rooms and pipe, and the ease of application makes it less costly. The recommended temperature range is from -297°F to 220°F (-183°C to 103°C)

Cellular Glass

Cellular glass shall conform to ASTM C552: *Standard Specification for Cellular Glass Thermal Insulation.* This insulation is pure glass foam manufactured with hydrogen sulfide and has closed-cell air spaces. The smoke-developed rating is zero, and the flame spread is 5. The recommended application temperature is between –450°F and 450°F (–265°C and 230°C), with the adhesive used to secure the insulation to the pipe or equipment the limiting factor. It has no water retention and poor surface abrasion resistance.

It is rigid and strong and commonly used for high-temperature installations. It generally is manufactured in blocks and must be fabricated by the contractor to make insulation for pipes or equipment. A saw is used for cutting. It has a typical k value of 0.37 and an R rating of 2.6. Its density is 8 pounds per cubic foot.

It is resistant to common acids and corrosive environments. It shall be provided with a jacket of some type.

Foamed Plastic

Foamed plastic insulation is a rigid, closed-cell product, which shall conform to the following standards, depending on the material. Polyurethane shall conform to ASTM C591: *Standard Specification for Unfaced Preformed Rigid Cellular Polyisocyanurate Thermal Insulation;* polystyrene shall conform to ASTM C578: *Standard Specification for Rigid, Cellular Polystyrene Thermal Insulation;* and polyethylene shall conform to ASTM C1427: *Standard Specification for Extruded Preformed Flexible Cellular Polyolefin Thermal Insulation in Sheet and Tubular Form.* It is made by the expansion of plastic beads or granules in a closed mold or using an extrusion process. The fire-spread index varies among manufacturers, but its combustibility is high. Additives can be used to improve fire retardency. It is available molded into boards or premolded into pipe insulation.

This is most commonly used in 3-inch or 4-inch thickness for insulation of cryogenic piping. The recommended temperature range for installation is from cryogenic to 220°F (103°C). The density varies from 0.7 pounds per cubic foot and 3 pounds per cubic foot. The k value varies between 0.32 and 0.20, depending on the density and age of the material. The average water absorption is 2 percent.

Calcium Silicate

Calcium silicate shall conform to ASTM C533: *Standard Specification for Calcium Silicate Block and Pipe Thermal Insulation.* It is a rigid granular insulation composed of calcium silicate, asbestos-free reinforcing fibers, and lime. This material has a k value of 0.38 and an R rating of 2.0.

A mineral fiber commonly referred to as "calsil," it is used for high-temperature work and does not find much use in the plumbing industry except as a rigid insert for installation at a hanger to protect the regular insulation from being crushed by the weight of the pipe.

Insulating Cement

This insulation is manufactured from fibrous and/or granular material and cement mixed with water to form a plastic substance. Sometimes referred to as "mastic," it has typical k values ranging between 0.65 and 0.95, depending on the composition.

This material is well suited for irregular surfaces.

TYPES OF JACKET

A jacket is any material, except cement or paint, that is used to protect or cover insulation installed on a pipe or over equipment. It allows the insulation to function for a long period by protecting the underlying material and extending its service life. The jacket is used for the following purposes:

- As a vapor retarder to limit the entry of water into the insulation system
- As a weather barrier to protect the underlying insulation from the outside
- To prevent mechanical abuse due to accidental conditions or personnel
- Corrosion and additional fire resistance
- Appearance

- Cleanliness and disinfection

All-service Jacket

Known as ASJ, the all-service jacket is a lamination of brown (kraft) paper, fiberglass cloth (skrim), and a metallic film. A vapor retarder also is included. This jacket also is called an "FSK" jacket because of the fiberglass cloth, skrim, and kraft paper. It most often is used to cover fiberglass insulation.

The fiberglass cloth is used as a reinforcement for the kraft paper. The paper is generally a bleached, 30-pound (13.5-kg) material, which actually weighs 30 pounds per 30,000 square feet (2,790 m^2). The metallic foil is aluminum. It is this complete jacket that gives the fire rating for the insulation system.

The jacket is adhered to the pipe with either self-sealing adhesive or staples. The butt joint ends are first sealed with adhesive, placed together, and then covered with lap strips during installation. Staples are used when the surrounding conditions are too dirty or corrosive to use self-sealing material. The staple holes shall be sealed with adhesive.

Aluminum Jacket

Aluminum jackets shall conform to ASTM B209: *Standard Specification for Aluminum and Aluminum-alloy Sheet and Plate.* They are manufactured in corrugated or smooth shape and available in various thicknesses ranging from 0.010 inch to 0.024 inch, with 0.016 inch being the most common. The corrugated material is used where expansion and contraction of the piping may be a problem. These jackets also are made in various tempers and alloys. Vapor retarder material also can be applied. This vapor retarder may be necessary to protect the aluminum from any corrosive ingredient in the insulation. Fittings are fabricated in the shop.

Aluminum jackets may be secured by one of three methods: banded by straps on 9-inch (180-mm) centers, by a proprietary S or Z shape, or by sheet metal screws.

Stainless Steel Jacket

Stainless steel jackets shall conform to ASTM A240: *Standard Specification for Chromium and Chromium-nickel Stainless Steel Plate, Sheet, and Strip for Pressure Vessels and for General Applications.* They are manufactured in corrugated or smooth shape and available in various thicknesses ranging from 0.010 inch to 0.019 inch, with 0.016 inch being the most common. They are also available in various alloy types conforming to ASTM A304: *Standard Specification for Carbon and Alloy Steel Bars Subject to End-quench Hardenability Requirements*. They can be obtained in different finishes. Vapor retarder material also can be applied, although it is not required for corrosive environments except where chlorine or fluorides are present.

Stainless steel jackets are used for hygienic purposes and are adhered in a manner similar to that used for aluminum.

Plastic Jacket and Laminates

Plastic jackets are manufactured from polyvinyl chloride (PVC), polyvinylidene fluoride (PVDF), acrylonitrile butadiene styrene (ABS), polyvinyl acetate (PVA), and acrylics. Thicknesses range from 3 mils to 35 mils. Local code authorities shall be consulted prior to use.

Laminates are manufactured as a composite that is alternating layers of foil and polymer. Thicknesses range from 3 to 25 mils. The local code authorities shall be consulted prior to use.

They are adhered by the use of an appropriate adhesive.

Wire Mesh

Wire mesh is available in various wire diameters and widths. Materials for manufacture are Monel, stainless steel, and Inconel. Wire mesh is used where a strong, flexible covering that can be removed easily is needed.

It is secured with lacing hooks or stainless steel wire that must be additionally wrapped with tie wire or metal straps.

Lagging

Lagging is the covering of a previously insulated pipe or piece of equipment with a cloth or fiberglass jacket. It is used where appearance is the primary consideration, since this type of jacket offers little or no additional insulation protection. This material also is used as a combination system that serves as a protective coat and adhesive.

This jacket typically is secured to the insulation with the use of lagging adhesive and/or sizing. It is available in a variety of colors and may eliminate the need for painting.

INSTALLING INSULATION FOR VALVES AND FITTINGS FOR PIPING

The fittings and valves on a piping system require specially formed or made-up sections of insulation to complete the installation.

One type of insulation is the preformed type that is manufactured by specific size and shape to fit over any particular fitting or valve. Such insulation is available in two sections that are secured with staples, adhesive, or pressure-sensitive tape depending on the use of a vapor retarder. This is the quickest method of installation, but the most costly.

Another system uses a preformed plastic jacket the exact size and shape of the fitting or valve. A fiberglass blanket or sheet is cut to size and wrapped around the bare pipe, then the jacket is placed over the insulation. The exposed edges are tucked in, and the jacket is secured with special tacks with a barb that prevents them from pulling apart. The ends are sealed with pressure-sensitive tape.

For large piping, it is common to use straight lengths of fiberglass, mitering the ends and securing them with a fiberglass jacket (lagging).

INSTALLING INSULATION FOR TANKS

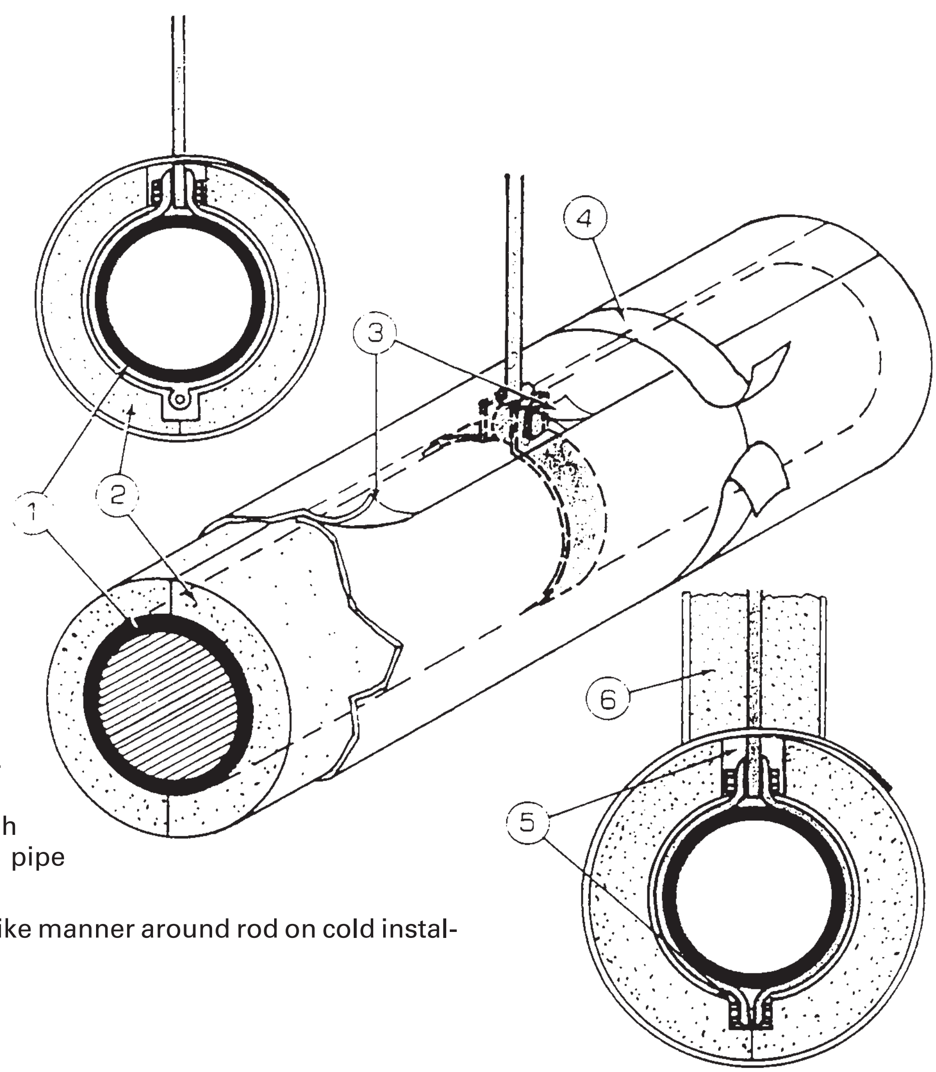
Where fiberglass is specified, tanks are insulated using 2 × 4-foot boards in the thickness required. The boards are placed on the tank in an appearance similar to bricks. They are secured with metal bands. Wire is placed over the bands as a foundation for insulating cement applied over the tank to give a finished appearance.

Where rubber is specified, the tank is coated with adhesive, and the rubber sheets are placed on the tank. The edges are coated with adhesive to seal it. Painting is not required.

PIPE SUPPORT METHODS

As the installation on a project progresses, a contractor must contend with different situations regarding the vapor retarder. Since the insulation system selected shall be protected against the migration of water vapor into the insulation, the integrity of the vapor retarder must be maintained. Where a hanger is installed directly on the pipe, the insulation must be placed over both the pipe and the hanger. Figure 5-1 illustrates a split-ring hanger attached directly on the pipe. This type of hanger is not recommended for use in chilled drinking water or other low-temperature lines.

Since low-density insulation is the type most often used, a situation arises wherein the primary considerations are keeping the vapor retarder intact and preventing the weight of the pipe from crushing the insulation. Figure 5-2 illustrates several high-density



1. Pipe
2. Insulation (shown with factory-applied, non-metal jacket).
3. Overlap at logitudinal joints (cut to allow for hanger rod).
4. Tape applied at butt joints (Pipe covering section at hanger should extend a few inches beyond the hanger to facilitate proper butt joint sealing.)
5. Insulation altered to compensate for projections on split ring hangers (If insulation thickness is serverely altered and left insufficient for high temperature applications or condensation control, insulate with a sleeve of oversized pipe insulation.)
6. Insulation applied in like manner around rod on cold installations.

Source: MICA

Figure 5-1 Split Ring Hanger Detail

1. Pipe
2. Insulation (type specified for the line).
3. High density insulation insert (Extend beyond the shield to facilitate proper butt joint sealing.)
4. Factory-applied vapor-retarder jacket securing two insulation sections together (cold application).
5. Jacketing (field-applied metal shown)
6. Metal shield
7. Wood block or wood dowel insert.

Source: MICA

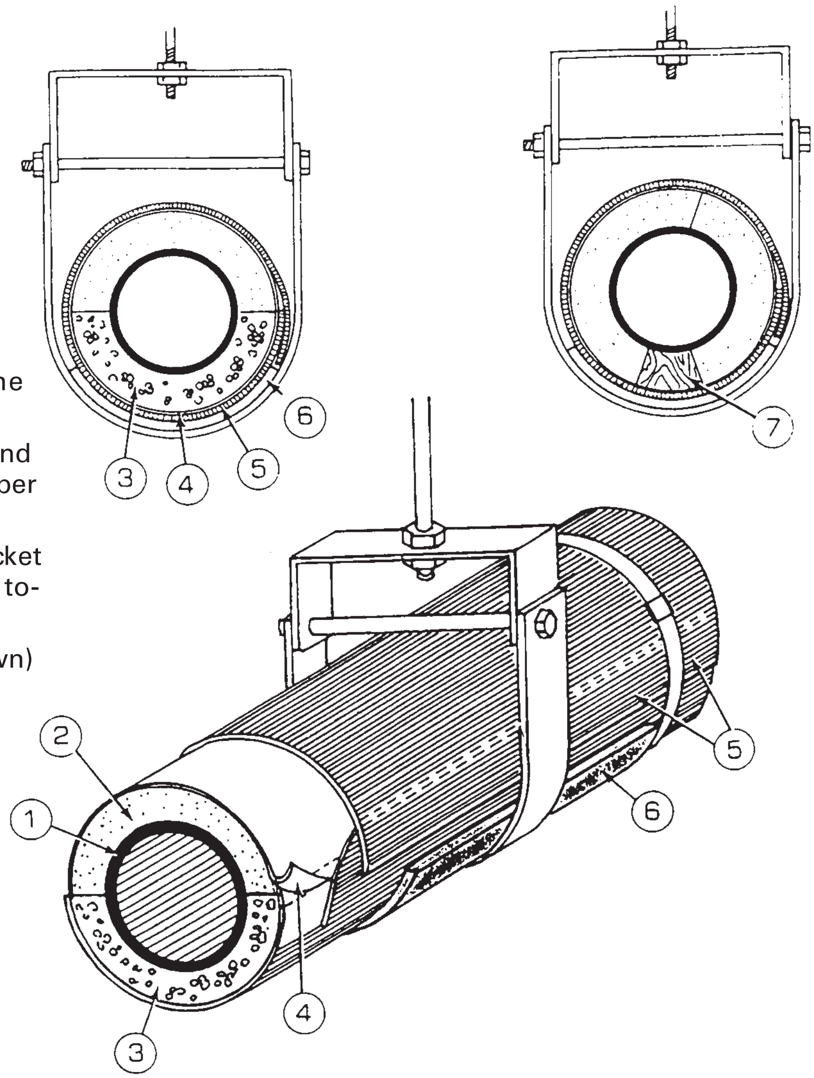


Figure 5-2 Clevis Hanger - High Density Inserts

Table 5-1 Heat Loss in Btuh/ft Length of Fiberglass Insulation, ASJ Cover 150°F Temperature of Pipe

Horizontal

NPS	½		¾		1		1¼		1½		2		2½		3		4		5		6		8	
THK	HL																							
BARE	36		44		54		67		75		92		110		131		165		200		235		299	
½"	10	92	10	90	13	93	20	98	18	94	20	93	23	94	30	95	36	95	43	95	53	97	68	97
1"	7	86	8	87	9	86	11	88	11	87	13	87	15	88	18	88	22	88	27	89	32	89	38	89
1½"	5	84	6	84	7	84	8	84	9	85	10	85	10	84	14	85	17	86	20	86	23	86	28	8
2"	5	82	5	83	6	83	7	83	7	83	9	83	9	83	11	84	14	84	16	84	18	84	23	85

Vertical

	½		¾		1		1¼		1½		2		2½		3		4		5		6		8	
THK	HL																							
BARE	32		40		49		61		69		84		100		120		152		185		217		277	
½"	9	92	10	90	13	93	19	99	18	95	20	94	23	94	30	96	35	96	43	96	52	97	67	98
1"	7	86	8	87	9	86	11	88	11	87	13	88	15	88	18	89	22	89	26	89	31	90	38	89
1½"	5	84	6	84	7	84	8	84	9	85	10	85	10	84	14	86	16	86	20	86	23	87	28	8
2"	5	83	5	83	6	83	7	83	7	83	9	83	9	83	11	84	14	84	16	85	18	85	23	85

Source: Courtesy of Owens/Corning.
Notes: 80°ambient temperature,
0 wind velocity,
0.85 bare surface emittance,
0.90 surface emittance

HL = heat loss (BTU/h/ft length)
ST = surface temperature (°F)
Bare = bare pipe, iron pipe size
THK = thickness

Table 5-2 Heat Loss from Piping

Insulation Type	Insulation Factor	Heat Loss per Inch Thickness, Based on K Factor @ 50°F Mean Temp. (Btu/h • °F • ft²)
Glass fiber (ASTM C547)	1.00	0.25
Calcium silicate (ASTM C533)	1.50	0.375
Cellular glass (ASTM C552)	1.60	0.40
Rigid cellular urethane (ASTM C591)	0.66	0.165
Foamed elastomer (ASTM C534)	1.16	0.29
Mineral fiber blanket (ASTM C553)	1.20	0.30
Expanded perlite (ASTM C610)	1.50	0.375

Insulation Thickness (in.)	ΔT, °F	IPS												
		½	¾	1	1¼	1½	2	2½	3	4	6	8	10	12
		Tubing Size (in.)												
		¾	1	1¼	1½									
0.5	10	0.5	0.6	0.7	0.8	0.9	1.1	1.3	1.5	1.8	2.6	3.3	4.1	4.8
	50	2.5	2.9	3.5	4.1	4.8	5.5	6.5	7.7	9.6	13.5	17.2	21.1	24.8
	100	5.2	6.1	7.2	8.6	9.9	11.5	13.5	15.9	19.9	28.1	35.8	43.8	51.6
	150	8.1	9.5	11.2	13.4	15.5	17.9	21.0	24.8	31.9	43.8	55.7	68.2	80.2
	200	11.2	13.1	15.5	18.5	21.4	24.7	29.0	34.3	42.7	60.4	76.9	94.1	110.7
	250	14.6	17.1	20.2	24.1	27.9	32.2	37.8	44.7	55.7	78.8	100.3	122.6	144.2
1.0	10	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	1.0	1.4	1.8	2.2	2.6
	50	1.6	1.9	2.2	2.5	2.9	3.2	3.7	4.4	5.4	7.4	9.4	11.4	13.4
	100	3.4	3.9	4.5	5.2	5.9	6.8	7.8	9.1	11.2	15.5	19.5	23.8	27.8
	150	5.3	6.1	7.0	8.2	9.3	10.5	12.2	14.2	17.4	24.1	30.4	37.0	43.3
	200	7.4	8.4	9.7	11.3	12.8	14.6	16.8	19.6	24.0	33.4	42.0	51.2	59.9
	250	9.6	11.0	12.6	14.8	16.7	19.0	22.0	25.6	31.4	43.6	54.9	66.9	78.2
1.5	10	0.3	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.8	1.0	1.3	1.4	1.8
	50	1.3	1.5	1.7	1.9	2.2	2.4	2.8	3.2	3.9	5.3	6.6	8.0	9.3
	100	2.7	3.1	3.5	4.0	4.5	5.1	5.8	6.7	8.1	11.1	13.8	16.7	19.5
	150	4.3	4.8	5.5	6.3	7.1	7.9	9.1	10.4	12.6	17.2	21.5	26.0	30.3
	200	5.9	6.7	7.6	8.7	9.8	11.0	12.5	14.5	17.5	23.8	29.7	36.0	41.9
	250	7.8	8.7	9.9	11.4	12.8	14.4	16.4	18.9	22.8	31.1	38.9	47.1	54.8
2.0	10	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.6	0.8	1.0	1.2	1.4
	50	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.6	3.1	4.2	5.2	6.3	7.3
	100	2.4	2.7	3.0	3.4	3.8	4.2	4.8	5.5	6.5	8.8	10.9	13.1	15.2
	150	3.7	4.2	4.7	5.3	5.9	6.6	7.5	8.5	10.2	13.7	17.0	20.4	23.6
	200	5.2	5.8	6.5	7.4	8.2	9.1	10.3	11.8	14.1	19.0	23.5	28.2	32.7
	250	6.8	7.5	8.5	9.6	10.7	11.9	13.5	15.4	18.5	24.8	30.7	36.9	42.7
2.5	10	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.7	0.8	1.0	1.2
	50	1.0	1.1	1.3	1.4	1.6	1.8	2.0	2.3	2.7	3.6	4.4	5.2	6.0
	100	2.2	2.4	2.7	3.0	3.3	3.7	4.1	4.7	5.6	4.7	9.1	10.9	12.6
	150	3.4	3.7	4.2	4.7	5.2	5.8	6.5	7.3	8.7	11.5	14.2	17.0	19.6
	200	4.7	5.2	5.8	6.5	7.2	8.0	9.0	10.2	12.1	16.0	19.6	23.5	27.1
	250	6.1	6.8	7.5	8.5	9.4	10.4	11.7	13.3	15.8	20.9	25.7	30.7	35.4
3.0	10	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	0.5	0.6	0.7	0.9	1.0
	50	1.0	1.1	1.2	1.3	1.4	1.6	1.8	2.0	2.4	3.1	3.8	4.5	5.2
	100	2.0	2.2	2.4	2.7	3.0	33	3.7	4.2	4.9	6.5	7.9	9.4	10.8
	150	3.1	3.4	3.8	4.3	4.7	5.2	5.8	5.6	7.7	10.1	12.3	14.7	16.8
	200	4.3	4.8	5.3	5.9	6.5	7.2	8.0	9.0	10.7	14.0	17.0	20.3	23.3
	250	5.7	6.2	6.9	7.7	8.5	9.4	10.5	11.8	13.9	18.3	22.3	26.5	30.5

insert solutions for a clevis hanger supporting an insulated pipe.

The jacketing method shown in both figures can be used interchangeably with any type of insulation for which it is suited.

SELECTION OF INSULATION THICKNESS

There are four basic reasons for using insulation:

1. Controlling heat loss from piping or equipment
2. Condensation control
3. Personnel protection
4. Economics

Controlling Heat Loss

Increased concern about conservation and energy use has resulted in the insulation of piping to control heat loss becoming one of the primary considerations in design. Heat loss is basically an economic consideration, since the lessening of heat loss produces a more cost-efficient piping system. The proper use of insulation can have dramatic results.

Table 5-3 Insulation Thickness - Equivalent Thickness (in.)

		½		1		1½		2		2½		3	
DN	**NPS**	**L_1**	**A**	**L_1**	**A**	**L_1**	**A**	**L_1**	**A**	**L_1**	**A**	**L_1**	**A**
15	½	0.76	0.49	1.77	0.75	3.12	1.05	4.46	1.31				
20	¾	0.75	0.56	1.45	0.75	2.68	1.05	3.90	1.31				
25	1	0.71	0.62	1.72	0.92	2.78	1.18	4.02	1.46	—	—	—	—
32	1¼	0.63	0.70	1.31	0.92	2.76	1.31	3.36	1.46				
40	1½	0.60	0.75	1.49	1.05	2.42	1.31	4.13	1.73				
50	2	0.67	0.92	1.43	1.18	2.36	1.46	3.39	1.73	4.43	1.99	—	—
65	2½	0.66	1.05	1.38	1.31	2.75	1.73	3.71	1.99	4.73	2.26		
80	3	0.57	1.18	1.29	1.46	2.11	1.73	2.96	1.99	3.88	2.26	4.86	2.52
90	3½	0.92	1.46	1.67	1.73	2.46	1.99	3.31	2.26	4.22	2.52	5.31	2.81
100	4	0.59	1.46	1.28	1.73	2.01	1.99	2.80	2.26	3.65	2.52	4.68	2.81
115	4½	0.94	1.74	1.61	1.99	2.35	2.26	3.15	2.52	4.11	2.81	5.02	3.08
125	5	0.58	1.74	1.20	1.99	1.89	2.26	2.64	2.52	3.54	2.81	4.40	3.08
150	6	0.54	2.00	1.13	2.26	1.79	2.52	2.60	2.81	3.36	3.08	4.17	3.34
	7	—	—	1.11	2.52	1.84	2.81	2.54	3.08	3.27	3.34	4.25	3.67
200	8	—	—	1.18	2.81	1.81	3.08	2.49	3.34	3.39	3.67	4.15	3.93
	9	—	—	1.17	3.08	1.79	3.34	2.62	3.67	3.32	3.93	4.06	4.19
250	10	—	—	1.09	3.34	1.85	3.67	2.50	3.93	3.18	4.19	3.90	4.45
300	12	—	—	1.22	3.93	1.82	4.19	2.45	4.45	3.10	4.71	3.79	4.97
350	14	—	—	1.07	4.19	1.65	4.45	2.26	4.71	2.90	4.97	3.57	5.24
400	16	—	—	1.06	4.71	1.63	4.97	2.23	5.24	2.86	5.50	3.50	5.76
450	18	—	—	1.05	5.24	1.62	5.50	2.21	5.76	2.82	6.02	3.45	6.28
500	20	—	—	1.05	5.76	1.61	6.02	2.19	6.28	2.79	6.54	3.41	6.81
600	24	—	—	1.04	6.81	1.59	7.07	2.16	7.33	2.74	7.59	3.35	7.85

Source: Owens/Corning.
DN = nominal diameter
NPS = nominal pipe size
L_1 = equivalent thickness (in.)
$L_1 = r_2 \ln (r_2/r_1)$

where
r_1 = inner radius of insulation (in.)
r_2 = outer radius of insulation (in.)
ln = log to the base e (natural log)
A = square feet of pipe insulation surface per lineal foot of pipe

Table 5-4 Dew-point Temperature

Dry Bulb Temp. (°F)	Percent Relative Humidity																		
	10	**15**	**20**	**25**	**30**	**35**	**40**	**45**	**50**	**55**	**60**	**65**	**70**	**75**	**80**	**85**	**90**	**95**	**100**
5	-35	-30	-25	-21	-17	-14	-12	-10	-8	-6	-5	-4	-2	-1	1	2	3	4	5
10	-31	-25	-20	-16	-13	-10	-7	-5	-3	-2	0	2	3	4	5	7	8	9	10
15	-28	-21	-16	-12	-8	-5	-3	-1	1	3	5	6	8	9	10	12	13	14	15
20	-24	-16	-11	-8	-4	-2	2	4	6	8	10	11	13	14	15	16	18	19	20
25	-20	-15	-8	-4	0	3	6	8	10	12	15	16	18	19	20	21	23	24	25
30	-15	-9	-3	2	5	8	11	13	15	17	20	22	23	24	25	27	28	29	30
35	-12	-5	1	5	9	12	15	18	20	22	24	26	27	28	30	32	33	34	35
40	-7	0	5	9	14	16	19	22	24	26	28	29	31	33	35	36	38	39	40
45	-4	3	9	13	17	20	23	25	28	30	32	34	36	38	39	41	43	44	45
50	-1	7	13	17	21	24	27	30	32	34	37	39	41	42	44	45	47	49	50
55	3	11	16	21	25	28	32	34	37	39	41	43	45	47	49	50	52	53	55
60	6	14	20	25	29	32	35	39	42	44	46	48	50	52	54	55	57	59	60
65	10	18	24	28	33	38	40	43	46	49	51	53	55	57	59	60	62	63	65
70	13	21	28	33	37	41	45	48	50	53	55	57	60	62	64	65	67	68	70
75	17	25	32	37	42	46	49	52	55	57	60	62	64	66	69	70	72	74	75
80	20	29	35	41	46	50	54	57	60	62	65	67	69	72	74	75	77	78	80
85	23	32	40	45	50	54	58	61	64	67	69	72	74	76	78	80	82	83	85
90	27	36	44	49	54	58	62	66	69	72	74	77	79	81	83	85	87	89	90
95	30	40	48	54	59	63	67	70	73	76	79	82	84	86	88	90	91	93	95
100	34	44	52	58	63	68	71	75	78	81	84	86	88	91	92	94	96	98	100
110	41	52	60	66	71	77	80	84	87	90	92	95	98	100	102	104	106	108	110
120	48	60	68	74	79	85	88	92	96	99	102	105	109	109	112	114	116	118	120
125	52	63	72	78	84	89	93	97	100	104	107	109	111	114	117	119	121	123	125

Table 5-5 Insulation Thickness to Prevent Condensation, 50°F Service Temperature and 70°F Ambient Temperature

Relative Humidity (%)

		20			50			70			80			90		
DN	Nom. Pipe Size (in.)	THK	HG	ST	THK	HG	ST	THK	HG	ST	THK	HG	ST	THK	HG	ST
15	0.50	Condensation control not required for this condition			0.5	2	66	0.5	2	66	0.5	2	66	1.0	2	68
20	0.75				0.5	2	67	0.5	2	67	0.5	2	67	0.5	2	67
25	1.00				0.5	3	66	0.5	3	66	0.5	3	66	1.0	2	68
32	1.25				0.5	3	66	0.5	3	66	0.5	3	66	1.0	3	67
40	1.50				0.5	4	65	0.5	4	65	0.5	4	65	1.0	3	67
50	2.00				0.5	5	66	0.5	5	66	0.5	5	66	1.0	3	67
65	2.50				0.5	5	65	0.5	5	65	0.5	5	65	1.0	4	67
75	3.00				0.5	7	65	0.5	7	65	0.5	7	65	1.0	4	67
90	3.50				0.5	8	65	0.5	8	65	0.5	8	65	1.0	4	68
100	4.00				0.5	8	65	0.5	8	65	0.5	8	65	1.0	5	67
125	5.00				0.5	10	65	0.5	10	65	0.5	10	65	1.0	6	67
150	6.00				0.5	12	65	0.5	12	65	0.5	12	65	1.0	7	67
200	8.00				1.0	9	67	1.0	9	67	1.0	9	67	1.0	9	67
250	10.00				1.0	11	67	1.0	11	67	1.0	11	67	1.0	11	67
300	12.00				1.0	12	67	1.0	12	67	1.0	12	67	1.0	12	67

Source: Courtesy Certainteed.
Notes: 25 mm = 1 in.
THK = Insulation thickness (in.).
HG = Heat gain/lineal foot (pipe) 28 ft (flat) (Btu). ST = Surface temperature (°F).

The insulation installed on domestic hot water, hot water return, and chilled drinking water systems is intended to keep heat loss from the water to a minimum. Since fiberglass insulation is the type most often used, Table 5-1 is provided to give the heat loss through vertical and horizontal piping as well as the heat loss through bare pipe. Table 5-2 is given for piping intended to be installed outdoors.

When calculating the heat loss from round surfaces, such as a pipe, the plumbing engineer should remember that the inside surface of the insulation has a different diameter than the outside. Therefore, a means must be found to determine the equivalent thickness that shall be used. This is done by the use of Table 5-3. To read this table, enter with the actual pipe size and insulation thickness, and then read the equivalent thickness of the insulation.

Software endorsed by the U.S. Department of Energy and distributed by the North American Insulation Manufacturers Association (NAIMA) is available from www.pipeinsulation.org that will calculate heat loss, condensation control, and environmental emissions.

Condensation Control

As mentioned, water vapor in the air condenses on a cold surface if the temperature of the cold surface is at or below the dew point. If the temperature is above the dew point, condensation does not form. The purpose of a vapor retarder is to minimize or eliminate such condensation. For this to be accomplished, the joints and overlaps must be sealed tightly. This is done through one of three methods:

1. Rigid jackets such as metallic or plastic
2. Membranes such as laminated foils
3. Mastics applied over the pipe, either emulsion or solvent type

Table 5-4 shows the dry-bulb dew point temperature at which condensation forms. Table 5-5 is provided to indicate the thickness of fiberglass insulation with water at 50°F (10°C) needed to prevent condensation.

Personnel Protection

When hot water flows through an uninsulated piping system, it is usually at a temperature that may scald any person touching the pipe. Insulation is used to lower the surface temperatures of hot water pipes to prevent such harm. A surface temperature of 120°F (49°C) has been shown to not cause harm to a person coming in contact with the pipe. Table 5-6 gives the thickness of fiberglass insulation and the surface temperature of the insulation. The thickness shown in this table should be compared with that shown in Table 5-1 or 5-2 to see which thickness is greater. The larger thickness should be used.

Economics

The two economic factors involved are the cost of insulation and the cost of energy. To calculate the energy savings in financial terms, the following are needed:

Table 5-6 Insulation Thickness for Personnel Protection, 120°F Maximum Surface Temperature, 80°F Ambient Temperature

Service Temperature

Nom. Pipe Size (in.)	250				350				450				550			
	TH	HL LF	HL SF	ST	TH	HL LF	HL SF	ST	TH	HL LF	HL SF	ST	TH	HL LF	HL SF	ST
0.50	0.5	25	51	109	1.0	30	40	104	1.0	48	64	118	1.5	55	52	113
0.75	0.5	25	41	104	0.5	42	68	120	1.5	45	43	107	1.5	64	61	118
1.00	0.5	34	55	112	1.0	37	40	105	1.0	60	66	120	1.5	69	58	117
1.25	0.5	37	49	109	1.0	47	51	112	1.5	55	42	107	1.5	77	59	118
1.50	0.5	46	61	117	1.0	48	46	109	1.5	62	47	110	2.0	70	40	106
2.00	0.5	50	55	114	1.0	56	47	110	1.5	70	48	111	2.0	84	48	112
2.50	0.5	59	56	115	1.5	45	26	97	1.5	72	41	107	1.5	102	59	119
3.00	0.5	75	64	120	1.0	76	52	114	1.5	93	53	115	2.0	110	55	117
3.50	1.0	43	25	96	1.0	71	41	107	1.5	93	46	111	2.0	112	49	113
4.00	0.5	89	61	119	1.0	90	52	114	1.5	112	56	117	2.0	131	58	119
5.00	1.0	67	33	102	1.0	110	55	117	1.5	134	59	120	2.5	131	46	112
6.00	1.0	79	35	103	1.0	130	57	119	2.0	124	44	110	2.5	150	48	114
8.00	1.0	95	33	103	1.0	157	55	118	2.0	153	45	112	2.5	177	48	114
10.00	1.0	121	36	105	1.5	136	37	106	2.0	179	45	112	2.5	215	51	117
12.00	1.0	129	32	103	1.0	212	54	118	2.0	207	46	113	2.5	248	52	118

Source: Certainteed.
Notes: TH = Thickness of insulation (in.)
HL = heat loss (Btu/h)
LF = Heat loss per lineal foot of pipe (Btu/h)
SF = Heat loss per square foot of outside insulation surface (Btu/h)
ST = Surface temperature of insulation (°F)

Table 5-7 Time for Dormant Water to Freeze

Fiberglass Insulation

Pipe or Tubing Size (in.)	Air Temp., °F (°C)	Water Temp., °F (°C)	Insulation Thickness, in. (mm)	Time to 32°F (0°C) DORMANT water (h)	Time to 32°F (0°C) Solid Ice (h) [a]	Flow [b]
⅝ OD CT	-10 (-23.3)	50 (10)	0.66 (N¾) (19.1)	0.30	3.10	0.33
1⅛ OD CT	-10 (-23.3)	50 (10)	0.74 (N¾) (19.1)	0.75	8.25	0.44
1⅝ OD CT	-10 (-23.3)	50 (10)	0.79 (N¾) (19.1)	1.40	14.75	0.57
3⅛ OD CT	-10 (-23.3)	50 (10)	0.88 (N¾) (19.1)	3.5	37.70	0.83
1 IPS	-10 (-23.3)	50 (10)	0.76 (N¾) (19.1)	0.75	8.25	0.48
2 IPS	-10 (-23.3)	50 (10)	0.85 (N¾) (19.1)	2.10	22.70	0.67
3 IPS	-10 (-23.3)	50 (10)	0.89 (N¾) (19.1)	3.60	38.40	0.90
5 IPS	-10 (-23.3)	50 (10)	0.95 (N¾) (19.1)	6.95	73.60	1.25

Foamed Plastic Insulation

Pipe or Tubing Size (in.)	Air Temp., °F (°C)	Water Temp., °F (°C)	Insulation Thickness, in. (mm)	Time to 32°F (0°C) DORMANT water (h)	Time to 32°F (0°C) Solid Ice (h) [a]	Flow [b]
⅝ OD CT	-10 (-23.3)	50 (10)	1 (25.4)	0.60	6.20	0.16
1⅛ OD CT	-10 (-23.3)	50 (10)	1 (25.4)	1.30	13.70	0.26
1⅝ OD CT	-10 (-23.3)	50 (10)	1 (25.4)	2.35	24.75	0.32
3⅛ OD CT	-10 (-23.3)	50 (10)	1 (25.4)	5.55	58.65	0.52
1 IPS	-10 (-23.3)	50 (10)	1 (25.4)	1.50	15.75	0.25
2 IPS	-10 (-23.3)	50 (10)	1 (25.4)	3.80	40.15	0.39
3 IPS	-10 (-23.3)	50 (10)	1 (25.4)	6.05	64.20	0.53
5 IPS	-10 (-23.3)	50 (10)	1 (25.4)	11.15	118.25	0.78

[a] No way to calculate slush. 32°F (0°C) ice value higher due to heat of fusion.
[b] Flow is expressed as gal/h/ft of pipe (12.4 Uhr-m).
Example: For 100 ft. (30.5m) pipe run, multiply value shown by 100. This is the minimum continuous flow to keep water from freezing.
OD CT = outside diameter, copper tube
IPS = iron pipe size

- Service temperature of the surface
- Pipe size or flat
- Btu difference between air and surface or flat (linear feet or square feet)
- Efficiency of heating equipment
- Annual operating hours
- Cost of fuel

If the plumbing designer wishes to make an economic comparison among various insulation systems, many formulas and computer programs are available for the purpose. Discussion of these methods is beyond the scope of this chapter.

FREEZE PROTECTION

No amount of insulation can prevent the freezing of water (or sewage) in a pipeline that remains dormant over a period of time. Studies by the U.S. Army Cold Regions Research and Engineering Laboratory (CRREL) have shown that the freezing of water in pipes is much more complicated and can be blocked much earlier than had been thought.

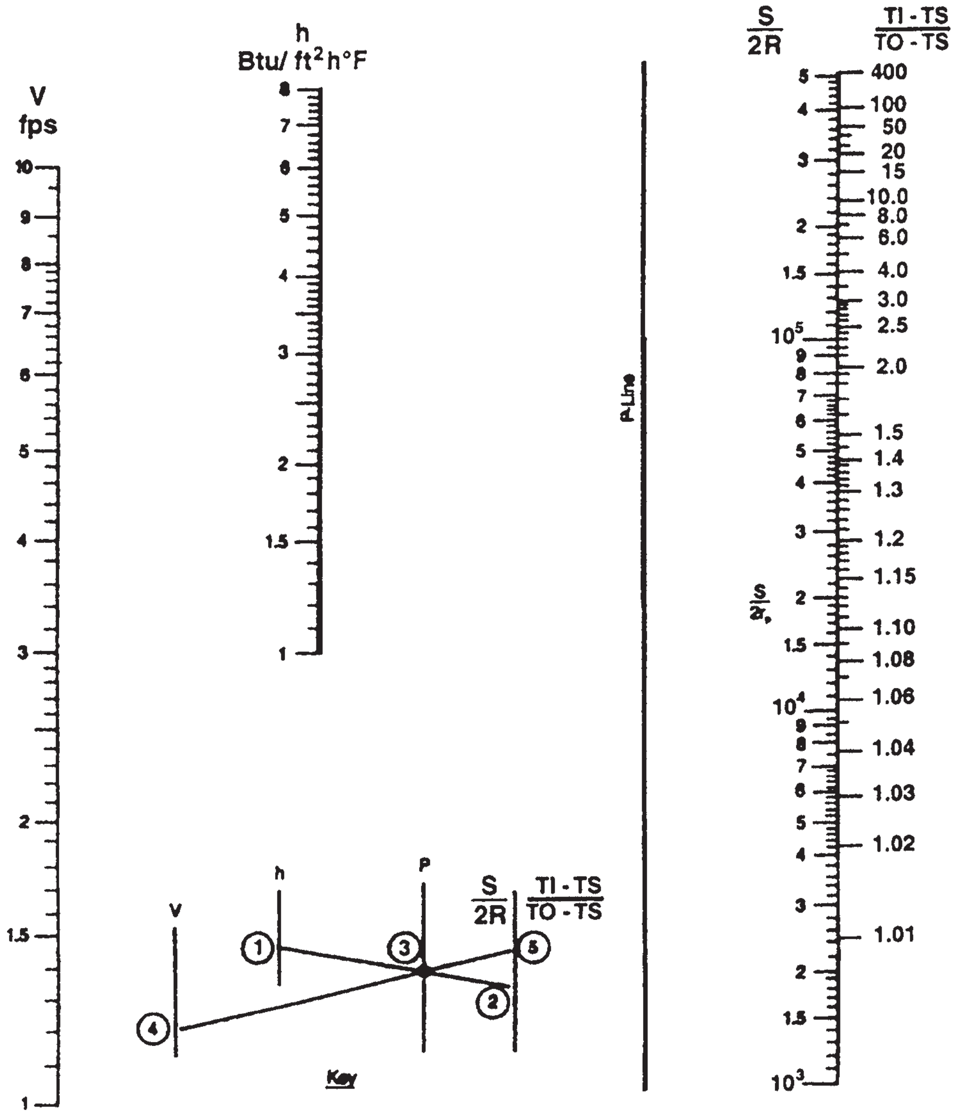


Figure 5-3 Temperature Drop of Flowing Water in a Pipeline

Table 5-7 is provided as a direct reading table for estimating the time it takes for dormant water to freeze. For some installations, it is not possible for the water to remain dormant. If the water is flowing, as it does in a drainage line, use Figure 5-3, a nomogram that gives the temperature drop of flowing water. If the contents cannot be prevented from freezing, the plumbing engineer can add hot water to raise the temperature, heat trace the line, or provide sufficient velocity to keep the contents from freezing.

To calculate the flow of water in a line to prevent freezing, use Equation 5-2.

Equation 5-2

$$\text{gpm} = \frac{A_1 \times A_2 \times (0.5TW - TA + 16)}{40.1\ D^2\ (TW - 32)}$$

where

gpm = Flow rate, gallons per minute
A_1 = Pipe flow area, square feet
A_2 = Exposed pipe surface area, square feet
TW = Water temperature, °F
TA = Lowest air temperature, °F
D = Inside diameter of pipe, feet

INSULATION DESIGN CONSIDERATIONS

Following are some general items to consider when designing the insulation for a plumbing system.

1. Insulation attenuates sound from the flow of pipe contents. Where sound is a problem, such as in theaters, adding a mass-filled vinyl layer over the insulation can lessen the sound.
2. The health and safety involved with the storage and handling of the insulation and/or jacketing materials can be alleviated by proper adherence to established safe storage and handling procedures.

3. The rate of expansion affects the efficiency of the insulation over a long period. The difference between the expansion of insulation and the expansion of the pipe eventually leads to gaps after numerous flexings.
4. Protect the insulation against physical damage by adding a strong jacket or delaying installation on a piping system. It has been found that workmen walking on the pipe pose the greatest danger.
5. If the insulation is to be installed in a corrosive atmosphere, the proper jacket shall be installed to withstand the most severe conditions.
6. Union regulations should be reviewed to ensure that the insulation contractor installs a jacket. Some metal jackets above a certain thickness are installed by the general contractor.
7. Space conditions may dictate the use of one insulation system over another to fit in a confined space.

RESOURCES

American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) 90.1: *Energy Standard for Buildings Except Low-Rise Residential Buildings*.

Frankel, M. *Facility Piping Systems Handbook*. McGraw-Hill. 1996.

Kenny, T. M. “Guard Against Freezing in Water Lines.” *Chemical Engineering Progress,* September 1991.

Commercial and Industrial Insulation Standards Manual. Midwest Insulation Contractors Association. 1999.

O’Keefe, W. “Thermal Insulation.” *Power Magazine,* 1974.

Depth of Freeze and Thaw in Soils. Technical Manual TM-5-852-6. U.S. Army.

6 Hangers and Supports

Properly holding piping systems in place requires more than simply specifying hangers, supports, and anchors. The plumbing engineer also must account for the specific environmental considerations and the substances, including quantity and composition, expected to flow through the system.

In the early 1900s, when simpler environments prevailed, piping system supports and hangers were specified to help support or firmly anchor piping systems, prevent pipe runs from sagging, allow for some motion to help alleviate breakage, and provide for an adequate slope to accommodate drainage or flow. It was recognized that vibration within piping systems could have various effects, and early engineering texts suggested that some soft material, such as felt, be used to help stop motion and deaden sound.

However, what was once an easy design exercise that specified a simple device for attaching a pipe to a horizontal or vertical surface, holding a pipe in place, or supporting a long run of pipe has evolved into an elaborate evaluation of the total environment in which the piping system will function. The plumbing engineer now must be aware of structural components, chemical interactions, metal fatigue analysis, acoustics, and even electric current transference.

The previously simple pipe support has become a complex element in the overall design and specification of a piping and plumbing system. The plumbing engineer must be cognizant of a multitude of environmental and physical characteristics that may interact with and affect the overall system. The engineer often needs to go beyond the simple specifications for support types and hanger distances prescribed in basic plumbing codes. In fact, he or she may need to consult with other engineering disciplines and with the pipe and pipe support manufacturers for the correct materials to specify for particular applications.

The engineer must not underestimate the importance of the hangers and supports used for the plumbing system. Supporting a pipe on a wall or from a ceiling seems simple enough—just find the right hanger for the job in the catalog and leave the rest to the installers. However, choosing the correct hanger is an integral part of the engineering and design of the plumbing system. The improper selection of hangers and supports invites failure of an entire piping system.

HANGER AND SUPPORT CONSIDERATIONS

A major element of the plumbing engineer's design role is to properly study, evaluate, and analyze the piping layout in relation to the structure and equipment. He or she also must consider the totality of the piping systems that will be utilized and the surrounding environmental and physical characteristics that will come to bear on the overall performance of the completed system.

Often overlooked is the need for a more technical specification or performance characteristic regarding piping support. The most common hanger and support detail specified on plans is a simple statement that indicates "the piping shall be supported in a good and substantial manner in accordance with all local codes and ordinances." The detail may go on to specify the horizontal or vertical spacing of the supports.

The standard codes on plumbing systems provide little help to the plumbing engineer. Their admonitions are simple:

- All water piping shall be adequately supported to the satisfaction of the administrative authority.
- Piping shall be supported for the weight and the design of the material used.
- Supports, hangers, and anchors are devices for properly supporting and securing pipe, fixtures, and equipment.
- Suspended piping shall be supported at intervals not to exceed those shown in Table 6-1.
- All piping shall be supported in such a manner as to maintain its alignment and prevent sagging.

- Hangers and anchors shall be of sufficient strength to support the weight of the pipe and its contents.
- Piping shall be isolated from incompatible materials.

HANGERS AND SUPPORTS AS PART OF THE PIPING SYSTEM

The plumbing engineer must consider a number of factors to incorporate hangers, supports, and anchors into the design of a proper piping system. Given the wide variety of environmental and physical characteristics around which projects are designed, it is not possible to provide an exhaustive listing of potential areas that need evaluation. However, some basic considerations include the following.

Loads

What will be the total load of the piping system? First and foremost, basic engineering requires a performance and load calculation to be conducted to determine the physical amount and weight of all the specific piping system elements. In this initial determination, the engineer considers not only the weight of the piping itself, but also that of all associated elements, including valves; fittings; the bulk weight and flow characteristics of the substance to flow through or be carried within the pipe; and thermal or acoustical insulation or other pipe-covering material.

In addition, depending on the piping system's location, other natural and manmade forces that may create an additional load on the piping system, such as rain, ice, and snow for piping systems exposed to natural weather conditions, must be considered. When a portion of the piping system will be exposed and relatively easy to reach, the engineer may want to give some consideration to the potential for unintended uses, such as people using exposed portions of the piping system to hang from or use as supports for various items or devices (e.g., plants, lights, etc.).

The chosen hanger, support, and anchor system must, at a minimum, accommodate the piping system load. Moreover, the plumbing engineer needs to work closely with the structural engineer to ensure that the

Table 6-1 Maximum Horizontal Pipe Hanger and Support Spacing

Nominal Pipe or Tube Size		1	2	3	4	5	6	7	8	9	10
		Std Wt Steel Pipe		Copper Tube							
		Water Service	Vapor Service	Water Service	Vapor Service	Fire Protection	Ductile Iron Pipe	Cast Iron Soil	Glass	Plastic	Fiberglass Reinforced
in	(mm)	ft (m)	ft (m)	ft (m)	ft (m)						
¼	(6)	— —	— —	5(1.5)	5(1.5)	Follow requirements of the National Fire Protection Association.	20 ft (6.1 m) max spacing; min of one (1) hanger per pipe section close to the joint behind the bell and at change of direction and branch connections. For pipe sizes six (6) in. (150 mm) and under, installed on ASME B31 projects, that are subject to loading other than weight of pipe and contents, the span should be limited to the maximum spacing for water service steel pipe.	10 ft (3.0 m) max spacing; min of one (1) hanger per pipe section close to joint on the barrel, also at change of direction and branch connections.	8 ft (2.4 m) max spacing, follow pipe manufacturer's recommendations.	Follow pipe manufacturer's recommendations for material and service condition.	Follow pipe manufacturer's recommendations for material and service condition.
⅜	(10)	7(2.1)	8(2.4)	5(1.5)	6(1.8)						
½	(15)	7(2.1)	8(2.4)	5(1.5)	6(1.8)						
¾	(20)	7(2.1)	9(2.7)	5(1.5)	7(2.1)						
1	(25)	7(2.1)	9(2.7)	6(1.8)	8(2.4)						
1¼	(32)	7(2.1)	9(2.7)	7(2.1)	9(2.7)						
1½	(40)	9(2.7)	12(3.7)	8(2.4)	10(3.0)						
2	(50)	10(3.0)	13(4.0)	8(2.4)	11(3.4)						
2½	(65)	11(3.4)	14(4.3)	9(2.7)	13(4.0)						
3	(80)	12(3.7)	15(4.6)	10(3.0)	14(4.3)						
3½	(90)	13(4.0)	16(4.9)	11(3.4)	15(4.6)						
4	(100)	14(4.3)	17(5.2)	12(3.7)	16(4.9)						
5	(125)	16(4.9)	19(5.8)	13(4.0)	18(5.5)						
6	(150)	17(5.2)	21(6.4)	14(4.3)	20(6.1)						
8	(200)	19(5.8)	24(7.3)	16(4.9)	23(7.0)						
10	(250)	22(6.7)	26(7.9)	18(5.5)	25(7.6)						
12	(300)	23(7.0)	30(9.1)	19(5.8)	28(8.5)						
14	(350)	25(7.6)	32(9.8)								
16	(400)	27(8.2)	35(10.7)								
18	(450)	28(8.5)	37(11.3)								
20	(500)	30(9.1)	39(11.9)								
24	(600)	32(9.8)	42(12.8)								
30	(750)	33(10.1)	44(13.4)								

Source: From MSS SP-69-2002, *Pipe Hangers and Supports: Selection and Application*, reprinted with permission of Manufacturers Standardization Society.

Notes:

1. For spacing supports incorporating type 40 shields, see MSS SP–69-2002, Table 5.
2. Does not apply where span calculations are made or where there are concentrated loads between supports, such as flanges, valves, and specialties, or changes in direction requiring additional supports.
3. Unbalanced forces of hydrostatic or hydrodynamic origin (thrust forces) unless restrained externally can result in pipe movement and separation of joints if the joints of the system are not of a restrained joint design. (For pressure piping with joints not having a restraining design, other positive restraining means such as clamps, rods, and/or thrust blocking shall be used to maintain the integrity of the joints.)

building's structure will be able to support the load created by the attachment of the piping system. This load calculation also may incorporate other elements as indicated below.

Thermal Stresses

What stresses and accompanying limitations will be imposed on the piping system? A wide variety of external, internal, and thermal stresses need to be accommodated by the hangers, supports, and anchors for the piping system.

A number of external and internal influences may need to be considered as they relate to thermal effects and the accompanying movements that can occur within a system. Hangers and supports must provide for flexibility and axial (twisting), latitudinal, and longitudinal motions.

Thermal events subject the piping system to both internal and external influences resulting in contractions and expansions, which can be gradual or sudden in their movements. Here again, natural and manmade environments must be taken into account. Whenever the piping system and its surrounding environment are subject to any heating or cooling events, the hangers and supports must be able to accommodate the contraction and expansion effects. In addition, the hangers also must be able to accommodate the effects of heating and cooling events that affect the substances being carried within the piping system (e.g., certain liquids flow at different velocities under different temperatures).

Even in a piping system with thermal considerations accounted for by design elements such as expansion loops, the accompanying lateral movement should be accommodated by buttressing with the proper hangers and supports.

Pressure Fluctuations

Just as with thermal stresses, pressure fluctuations that occur because of the substance being transported within the piping system are accompanied by contraction and expansion effects that need to be accommodated by the proper hangers and supports. These pressure fluctuations are often complex, as they involve the conduct of fluids, gases, and semisolids being transported in an enclosed environment.

Changes in pressure can create unrealized stresses on the hangers and supports for the piping system. The condition referred to as "water hammer" can cause movement and vibration within a piping system that, if too firmly or rigidly anchored, can fail, which exacerbates the condition. Water hammer can occur within any piping system carrying liquids when there is a significant fluctuation of flow volume or pressure or when a contaminant substance, such as air, enters the piping system.

The plumbing engineer must design a piping hanger and support system to handle extreme pressure fluctuations and also ensure that the building's structure can handle the applied loads created by the movement of the piping system.

Structural Stresses

Perhaps the most obvious of all external influences on a piping system are the structural elements to which the piping system must be attached and pass through, such as wood, steel, and glass. Every natural and manmade material is subject to contraction and expansion due to internal and external effects. Many of these structural stresses must be accommodated by the plumbing engineer within the design of the hangers and supports for the piping system. Every building must itself be engineered to handle the stresses of the basic structural components.

For example, the diameter of the metal dome of the Capitol building in Washington, D.C., is known to expand by up to 6 inches when heated by the sun during the summer. Anchors and supports of piping systems that initially are attached to vertical metal structural components and transition to horizontal attachments to concrete structural components must contend with the contraction and expansion of the piping system materials as well as the expansion and contraction of the structural elements.

Natural Environmental Conditions

The susceptibility of a piping system to natural conditions must be accounted for within the piping system and the accompanying hangers, supports, and anchors. The major effect of these natural environmental conditions is on the basic building structure. However, within structures designed to handle extreme natural phenomena, the piping system itself must be hardened, or conditioned.

Typical natural phenomena consist of seismic forces and sustainable periods of high winds, including hurricanes and typhoons. These types of phenomena create major stresses and loads on a building's structure. For instance, an extreme high-rise building, such as the Empire State Building in New York City, is known to move 4 inches to 12 inches laterally in high winds. In zones of known natural phenomena, such as areas susceptible to earth movement, the plumbing engineer must engineer the piping and support systems to sustain the shocks, stresses, and loads inherent with and applied by these extreme forces. The engineer must refer to applicable building codes to determine the seismic design category for any mandated piping system support requirements.

While a plumbing system may not be expected to survive the complete destruction of a building's structure, it is expected to survive intact and working in the event that the building structure itself survives.

Reactivity and Conductivity Considerations

The plumbing engineer often needs to be an environmental and engineering detective to design a piping system for a building. The hangers and supports vital to providing piping system integrity often also must provide protection from unexpected natural and manmade activities, events, and phenomena totally unrelated to structure, stresses, loads, and similar engineering events.

Just as the engineer must consider the makeup of the interior surfaces of the piping material, he or she also must consider the exterior components of the piping system that will be subject to environmental and manmade conditions. The hangers and supports must be factored into this reactive equation.

Reactive conditions can consist of chemical reactions between unlike materials or the introduction of a reactive substance or electrical conductivity that can occur between different materials due to electrical "leakage" onto a piping system. These reactive and conductivity concerns can be unobtrusive and unexpected. Regardless, they can be the cause of unexpected failure in the hangers or supports of the piping system.

This type of failure can be especially acute in unexpected areas. Chemical fumes, salt water, and cleaning liquids can cause a chemical reaction between two differing metals, one of the hanger or support and one of the pipe. Initial indicators of potential failure can be seen in corrosion or in the compounds produced by chemical reaction that attach to the hangers and supports in inhospitable environments such as boiler rooms or specialty gas and liquid systems.

It is vital that such reactive conditions be considered and that the engineer specify compatible pipe and support materials or provide for protective coatings or materials. It is especially important to ensure that the interior portions of hangers, supports, and clamps that come in contact with piping also are subject to the protective coatings; otherwise, they will be prone to failure as the material is destroyed from the inside out.

Similarly, the effects of electrical current seepage or leakage can cause unexpected but known effects between two dissimilar materials. The plumbing engineer may need to evaluate the potential for this electrical leakage, especially in common raceways where piping and conduit are placed side by side, and provide suitable protection via the hangers and supports. A common example of this is the galvanic corrosion that occurs in copper pipe when steel hangers are used.

Acoustics

For certain structures, the engineer may need to consider various acoustical aspects related to piping systems. In general, two significant types of acoustical annoyances must be considered. The first is noise such as the sound of liquid rushing through a pipe or a harmonic resonance that starts a pipe "ringing." In these instances, the engineer must ensure that the piping system and the accompanying supports receive proper insulation.

The second type of acoustic effect that must be considered is that created by vibration and movement within the piping system. This acoustic anomaly requires a hanger and support system that offers a combination of three-dimensional flexibility to account for lateral, longitudinal, and axial movements of the piping system and a sound- and vibration-insulating material or anchor integrated into the hanger.

Manmade Environmental Conditions

The plumbing engineer also should be cognizant of any manmade environmental conditions that can affect the piping system. These created conditions can cause uncalculated stresses and loads on the system and lead to premature failure. Created environmental conditions that can result in resonance or vibration affecting interior structural systems include major traffic arteries with significant automotive and truck traffic; airport takeoff and landing patterns; nearby rivers and canals; potential for nearby future construction; underground digging; and underground traffic, such as subways and railroad tunnels.

General

The old adage "the whole is only as strong as its individual parts" applies directly to piping hangers and supports. Countless environmental and physical conditions can be considered when choosing the correct hanger, support, or anchor.

Nothing, however, substitutes for experience and knowledge. The engineer should work directly with a pipe's manufacturer regarding the proper spacing criteria and hanging methods for the pipe that is to be specified.

In the end, plumbing engineering is as much a science as an art. While the number of variables that can be examined in choosing hangers and supports for a plumbing system has no limits, practicality and resource limitations also must be taken into consideration.

HANGER AND SUPPORT SELECTION AND INSTALLATION

Hanger Types

Hangers, supports, and clamps come in a wide variety of materials, shapes, and sizes (see Figure 6-1). While

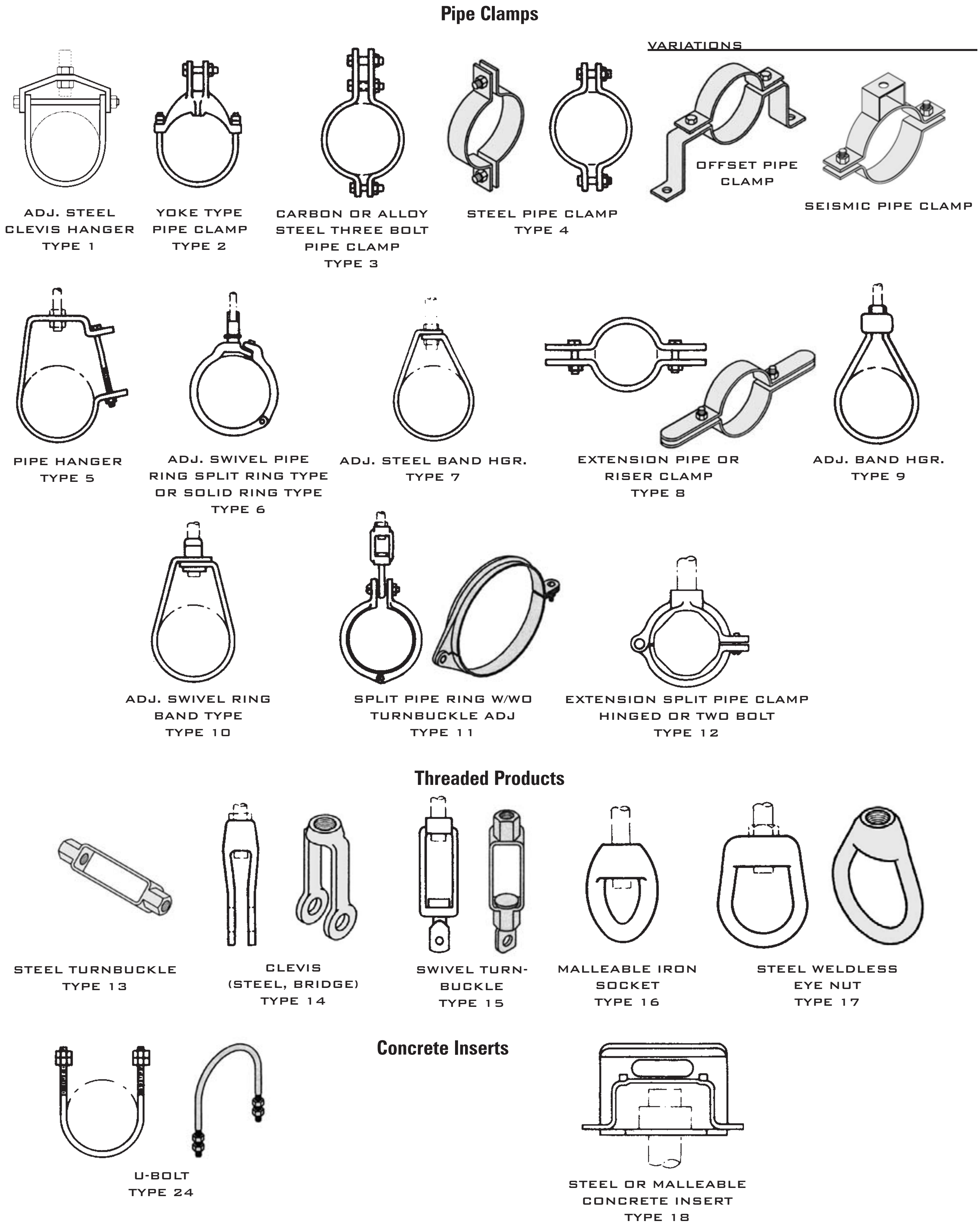


Figure 6-1 Types of Hangers and Supports

Sources: Details of hanger and support types are from MSS SP-69-2002, *Pipe Hangers and Supports: Selection and Application,* reprinted with permission of Manufacturers Standardization Society; supplementary details are courtesy of TOLCO®.

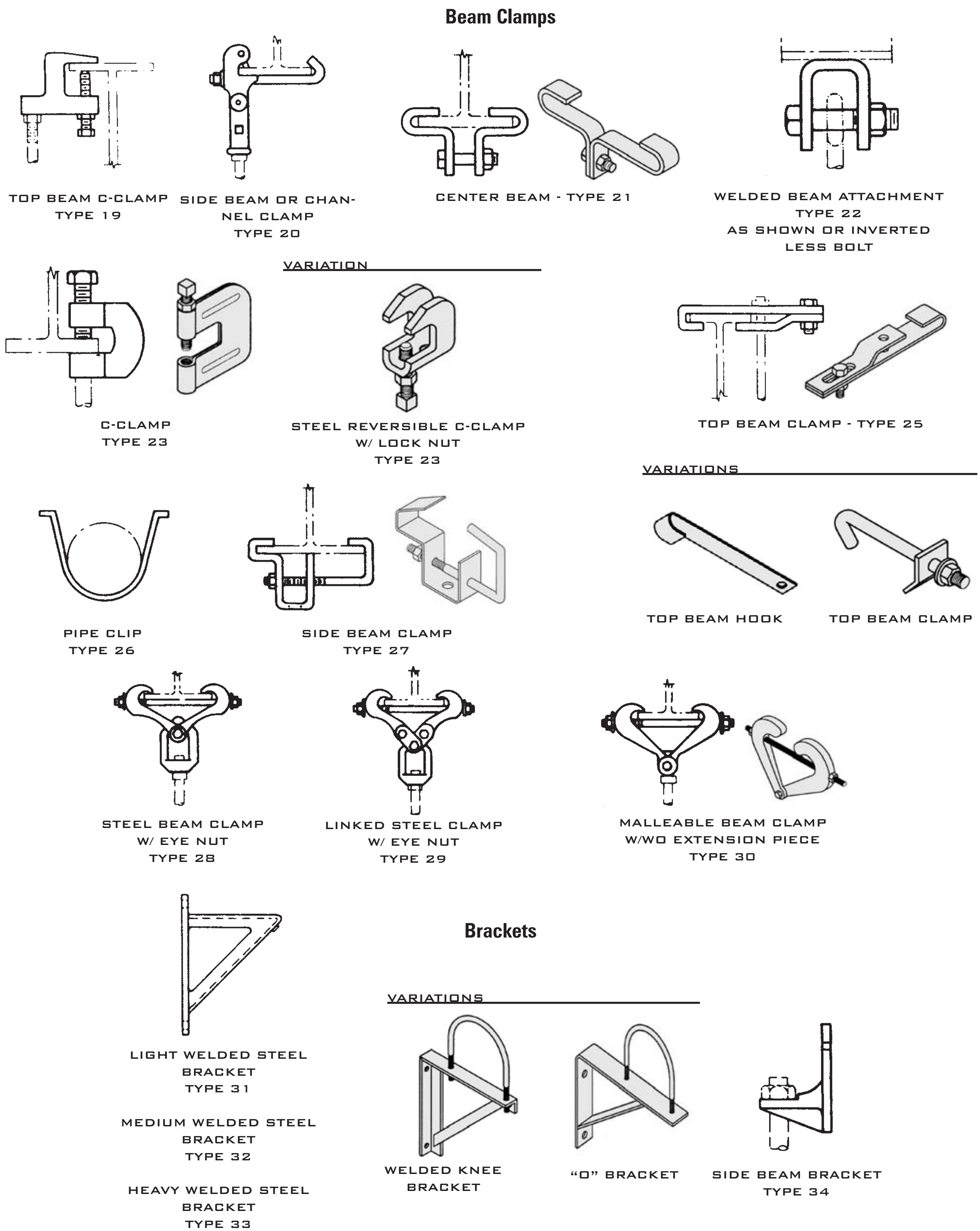
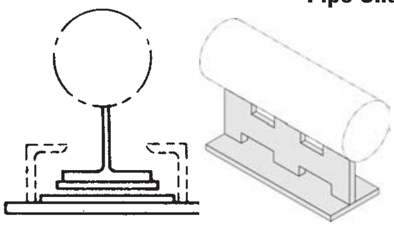
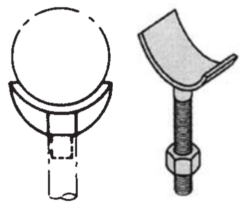


Figure 6-1 Types of Hangers and Supports (continued)

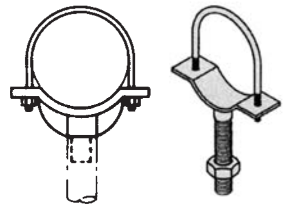
Pipe Slides, Supports, Anchors, and Shields



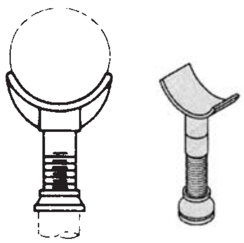
PIPE SLIDE & SLIDE PLATE
TYPE 35



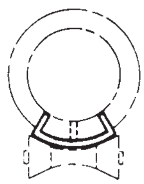
PIPE SADDLE SUPPORT
TYPE 36



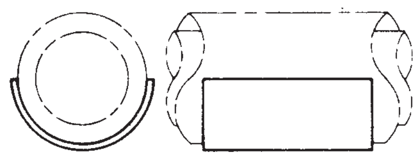
PIPE STANCHION SADDLE
TYPE 37



ADJ. PIPE SADDLE SUPPORT
TYPE 38

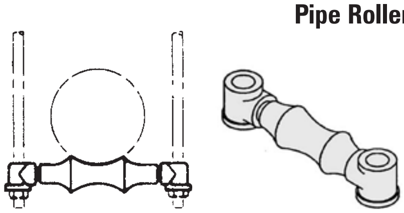


STEEL PIPE COVERING
PROTECTION SADDLE
TYPE 39



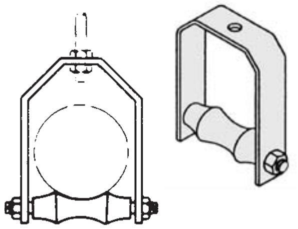
PROTECTION SHIELD
TYPE 40

Pipe Rollers

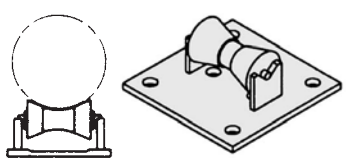


SINGLE PIPE ROLL
TYPE 41

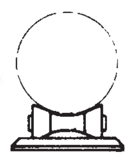
CARSON OR ALLOY STEEL
RISER CLAMP
TYPE 42



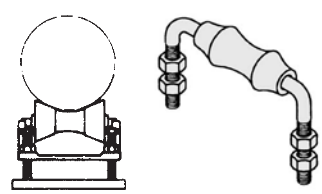
ADJ. ROLLER HANGER
W/WO SWIVEL
TYPE 43



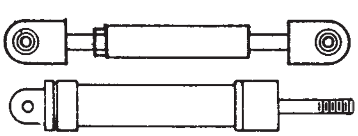
PIPE ROLL COMPLETE
TYPE 44



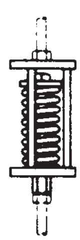
PIPE ROLL & PLATE
TYPE 45



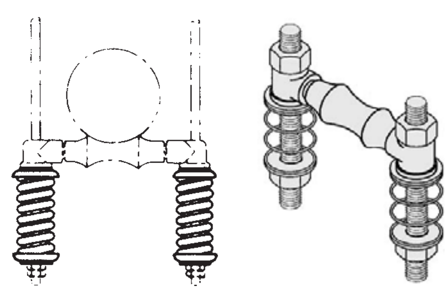
ADJ. PIPE ROLL & BASE
TYPE 46



RESTRAINT CONTROL
TYPE 47



SPRING CUSHION
TYPE 48



SPRING CUSHION ROLL
TYPE 49

Figure 6-1 Types of Hangers and Supports (continued)

Spring Hangers and Constant Supports

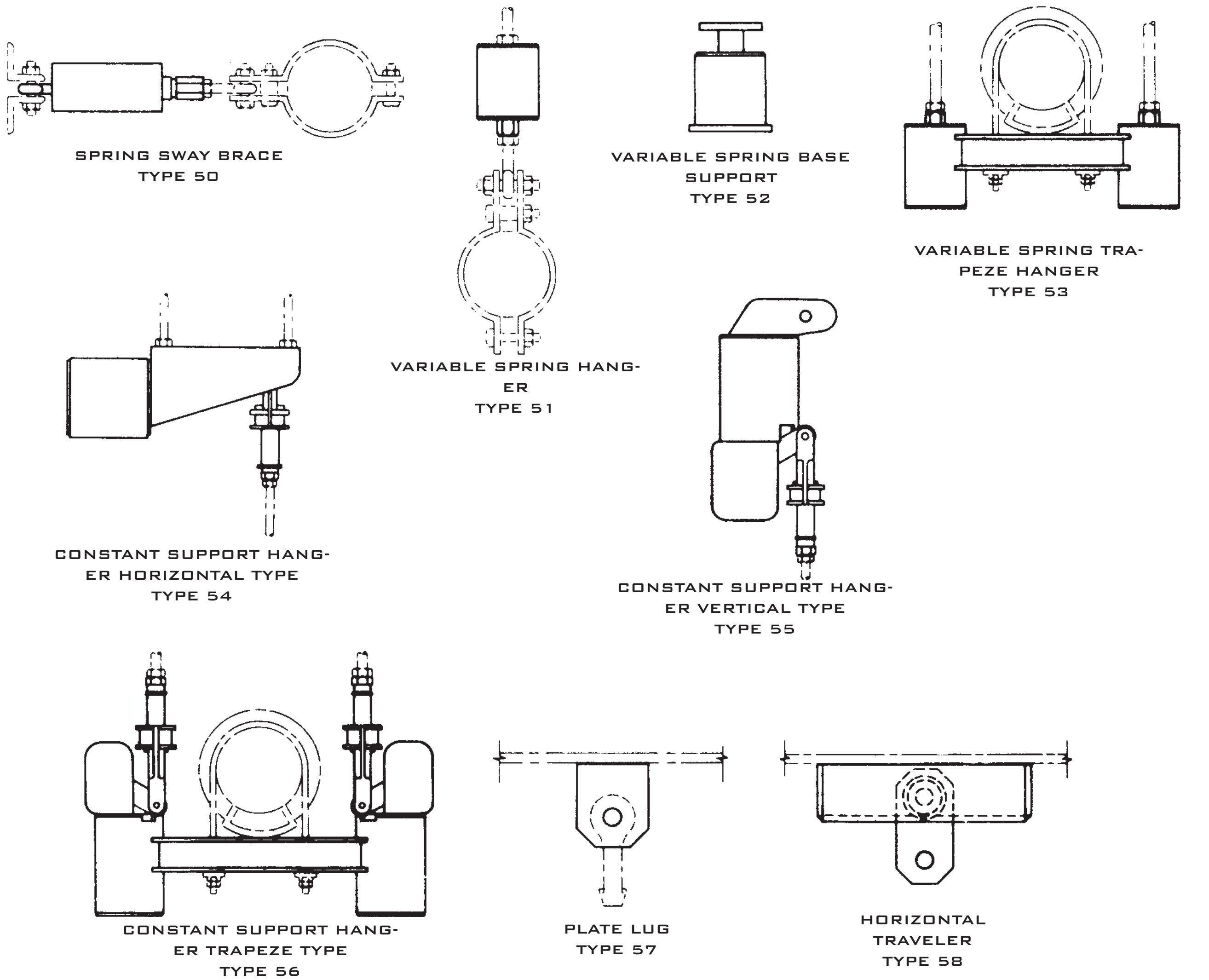


Figure 6-1 Types of Hangers and Supports (continued)

the major purpose of the hangers shown is to support the loads and stresses imposed on a piping system, specification of the correct hanger is a vital component for the overall structural integrity of the building itself. The structure must be able to handle the loads and stresses of the piping system, and the hanger and support system must be engineered to provide flexibility, durability, and structural strength.

Selection Criteria

To ensure proper hanger and support selection, the plumbing engineer must determine or be cognizant of the degrees of freedom that will be necessary within the piping system due to its operating characteristics. These degrees of freedom need to be considered in a three-dimensional space to account for lateral, horizontal, vertical, and axial movements and fluctuations.

The most typical selection criterion used is the one most closely associated with the type of pipe material and the temperature fluctuations within the system. This simple selection process requires the correct hanger choice to be made from Table 6-2. Then, based on that hanger choice and the temperature of the overall piping system, Table 6-3 can be used to select the appropriate hanger.

However, this selection process relies on averages and standards. It does not take into account all the three-dimensional fluctuations and movements that, depending on the structure and all the associated or potential stresses and loads, will affect the overall plumbing system.

Tables 6-2 and 6-3 should be used as guidelines for selecting the most suitable type of hanger for the support requirement at each incremental step of the design process. These tables offer the basics of hanger selection—a variety of hanger choices and the material composition most suited for the temperature characteristics that will affect the piping system.

What these tables cannot do is substitute for the engineering and design processes that determine the proper hanger selection based on the environmental and physical influences that will affect the different elements of the piping system under varying conditions. The most instructive aspect of Table 6-3 is found in the notes at the end of the table (see Notes b, c, and e).

Hanger and Support Spacing

After the appropriate hanger components have been selected for the type of piping system and the type of building or structural support available, the plumbing engineer must identify the spacing appropriate to the type of pipe used. Table 6-1 provides support criteria for some of the most common pipe materials. The plumbing engineer must ensure that the design criteria are in compliance with local code requirements.

Table 6-2 Pipe Classification by Temperature

System	Class	Temperature Rating, °F (°C)
Hot	A-1	120 to 450 (49 to 232)
Hot	A-2	451 to 750 (233 to 399)
Hot	A-3	Over 750 (over 400)
Ambient	B	60 to 119 (16 to 48)
Cold	C-1	33 to 59 (1 to 15)
Cold	C-2	–20 to 32 (–29 to 0)
Cold	C-3	–39 to –20 (–39 to –29)
Cold	C-4	–40 and below (–40 and below)

Again, just as with Table 6-3, it needs to be noted that Table 6-1 provides guidelines only, and the piping systems are presumed to exist under ideal circumstances with little environmental or physical influences. Therefore, these spacing guidelines are at the upper end of the specifications. That is, they should be considered the maximum spacing for hangers and supports.

For proper hanger spacing, the engineer needs, once again, to evaluate and take into account the three-dimensional fluctuations and movements as well as the environmental and physical influences that will affect the entirety of the plumbing system. Proper spacing is a function of stress, vibration, and the potential for misuse (e.g., exposed piping used as a ladder, scaffolding, or exercise equipment). Spacing criteria depend on pipe direction changes; structural attachment material and anchor points; additional plumbing system loadings, such as valves, flanges, filters, access ports, tanks, motors, drip, splash and condensate drainage, pipe shielding and insulation; and other specialty design requirements.

Anchoring

The strength, safety, and integrity of the plumbing system depend on the hangers or supports that are specified. How much additional design work is required as part of the plumbing system depends on the specification of the original proposal and the overall responsibilities of the plumbing engineer. It is not enough to simply specify a hanger or support—an important consideration is how it is anchored.

The plumbing system must be viewed as a complete entity. Thus, the engineer must be fully versed in the methodologies of anchoring hangers and supports in various structural elements and materials. At a minimum, the engineer needs to ensure close coordination between the engineered design and that of the other design engineers, including iron and concrete structural engineers, to ensure properly spaced and applied hangers and supports and their anchors.

The anchoring of hangers and supports requires different methodologies depending on the structural elements, transitions from vertical and horizontal surfaces, and differing materials (e.g., from steel to concrete). A hanger or support will perform only up to the capability of its attachment to a structural element.

Figure 6-2 shows some common materials and devices often used for anchoring hangers and supports. Figure 6-3 shows additional supports that might be preferred by the engineer in very particular circumstances. The extent of detail required within the plumbing system design depends on the project's parameters and the practicality and responsibility of the engineer to the overall building assembly.

Perhaps the most difficult hanger and support attachment requirement is that to concrete in an existing structure. It might be necessary for the plumbing engineer to contact the original concrete designer or supplier. Depending on experience, it is wise to involve an experienced hanger manufacturer or contractor for the proper anchoring of hangers and supports.

Anchor Types

The types of anchors vary according to the structural elements and materials to be used for attachment. The basic attachment elements are shown in Figure 6-2. However, a wide variety of anchor bolts, screws, washers, nuts, rods, plates, and strengtheners is available. It might be in the engineer's scope to establish loading, shear, and stress specifications for the hanger and support anchoring structure.

Table 6-3 Hanger and Support Selections

To find recommended hanger or support components,
1. Locate the system temperature and insulation condition in the two columns at left.
2. Read across the column headings for the type of component to be used.
3. Numbers in boxes refer to those types shown in Table 6-1.

System		Horizontal Pipe Attachments										Vertical Pipe Attachments			Hanger Rod Fixtures Steel or Malleable Iron			Building Structure Attachments Steel and/or Malleable Iron				
Temp. Range, °F (°C)	Insulation	Steel Clips A	Malleable Iron Rings B	Steel Bands C	Steel Clamps D	Cast Iron Hanging Rolls E	Cast Iron	Steel Trapezes G	Steel Protection Saddles & Shields H	Steel or Cast Iron Stanchions I	Steel Welded Attachments J	Riser Clamps 2 bolt K	Steel Riser Clamps 4 bolt L	Steel Welded Attachments Steel M	Turn Buckles N	Swing Eyes O	Clevises P	Inserts Q	C-Clamps R	Beam Clamps S	Welded Attachments T	Brackets U
HOT A-1	COVERED[a]	24 W/ 39	NONE	1, 5, 7, 9, 10 W/ 39 OR 40	2, 3	41, 43 W/ 39 OR 40	44, 45, 46 W/ 39 OR 40	59 W/ 39 OR 40	39, 40	36, 37, 38 W/ 39 OR 40	35[c]	8	42[c]	[c]	13, 15	16, 17	14	18[e]	19, 23	20, 21, 25, 27	22, 57, 58[c]	31, 32, 33, 34
120 (49) to 450 (232)	BARE	24, 26	6, 11, 12	1, 5, 7, 9, 10	3, 4	41, 43	44, 45, 46	59	NONE	36.37, 38												
HOT A-2 34	COVERED[a]	24 W/ 39	NONE	1 W/ 39 OR 40	3	41 W/ 39 OR 40	44, 45, 46 W/ 39 OR 40	59 W/ 39 OR 40	39, 40	36, 37, 38 W/ 39 OR 40	35[c]	NONE	42[c]	[c]	13, 15	16, 17	14	18[e]	NONE	20, 21, 25, 27, 28, 29, 30	22, 57, 58[c]	31 , 32, 33
451 (233) to 750 (399)	BARE	NONE	NONE	NONE	3,4	NONE	NONE	[c]	NONE	NONE												
HOT A-3 34	COVERED[a]	NONE	NONE	1 W/ 40	ALLOY 2, 3	41, 43 W/ 40 OR ALLOY 39	44, 45, 46 W/ 40 OR ALLOY 39	59 W/ 40 OR ALLOY 39	40 ALLOY 39	36, 37, 38 W/ 40 OR ALLOY 39	ALLOY 35[c]	NONE	ALLOY 42[c]	ALLOY 39[c]	13	17	14	[c, e]	NONE	20, 21, 25, 27, 28, 29, 30	22, 57, 58[c]	31, 32, 33,
OVER 750 (399)	BARE	NONE	NONE	NONE	ALLOY 2, 3, 4	NONE	NONE	[c]	NONE	NONE												
AMBIENT B	COVERED[a]	24, 26	NONE	1, 5, 7, 9, 10 W/ 39 OR 40	3, 4	41, 43 W/ 39 OR 40	44, 45, 46 W/ 39 OR 40	59 W/ 39 OR 40	39, 40	36, 37, 38 W/ 39 OR 40	35[c]	8	42[c]	[c]	13, 15	16, 17	14	18[e]	19, 23	20, 21, 25, 27, 28, 29, 30	22, 57, 58[c]	31, 32, 33, 34
60 (16) to 119 (48)	BARE	24, 26	6, 11, 12	1, 5.7.9, 10	3, 4	41, 43	44, 45, 46	59	NONE	36, 37.38												
COLD C-1 34	COVERED[a]	26 W/40	NONE	1, 5, 7, 9, 10 W/40	3, 4 W/40	41, 43 W/40[d]	44, 45, 46 W/40[d]	59 W/40	40	36, 37, 38 W/40	[c]	8	42[c]	[c]	13, 15	16, 17	14	18[e]	19, 23	20, 21, 25, 27 28, 29, 30	22, 57, 58[c]	31, 32, 33
33(1) to 59 (15)	BARE	24, 26	6, 11, 12	1, 5, 7, 9, 10	3, 4	41, 43	44, 45, 46	[c]	NONE	36, 37, 38												
COLD C-2	COVERED[a]	NONE	NONE	1, 5, 7, 9, 10 W/ 40	NONE	41, 43 W/ 40[d]	44, 45, 46 W/ 40[d]	[c, d] W/ 40	40	36, 37, 38 W/ 40	[c]	8	42	[c]	13,15	16,17	14	18[e]	19,23	20, 21, 25, 27, 28, 29, 30	22,57,58[c]	31,32,33, 34
–19(–28) to 32 (0)	BARE	NONE	NONE	1, 5, 7, 9.10	3, 4	41, 43	44, 45, 46	[c]	NONE	36, 37.38												
COLD C-3 & C4	COVERED[a]	NONE	NONE	1, 5, 7, 9.10 W/ 40	NONE	41, 43 W/ 40[d]	44, 45, 46 W/ 40[d]	[b, c, d] W/ 40	40	36, 37, 38 W/ 40	[b, c]	[b, c]	[b, c]	[b, c]	13, 15	16, 17	14	18[e]	19, 23	20, 21, 25, 27, 28, 29, 30	22, 57, 58[c]	31.32, 33, 34
BELOW –19 (–28)	BARE	NONE	NONE	[b, c]	[b, c]	NONE	NONE	[b, c]	NONE	[b, c]												

Source: From MSS SP-69-2002, *Pipe Hangers and Supports: Selection and Application,* reprinted with permission of Manufacturers Standardization Society.

[a] Hangers on insulated systems shall incorporate protection saddles, shields, pipe clamps, or welded lugs which project through the insulation to provide external attachment.

[b] The selection of type and material shall be made by the piping design engineer.

[c] The design shall be in accordance with MSS SP-58 or as specified by the piping design engineer.

[d] For shields used with rollers or subject to point loading, see MSS SP-69, Table 5.

[e] Continuous inserts, embedded plates, anchor bolts, and concrete fasteners may be used as specified by the piping design engineer.

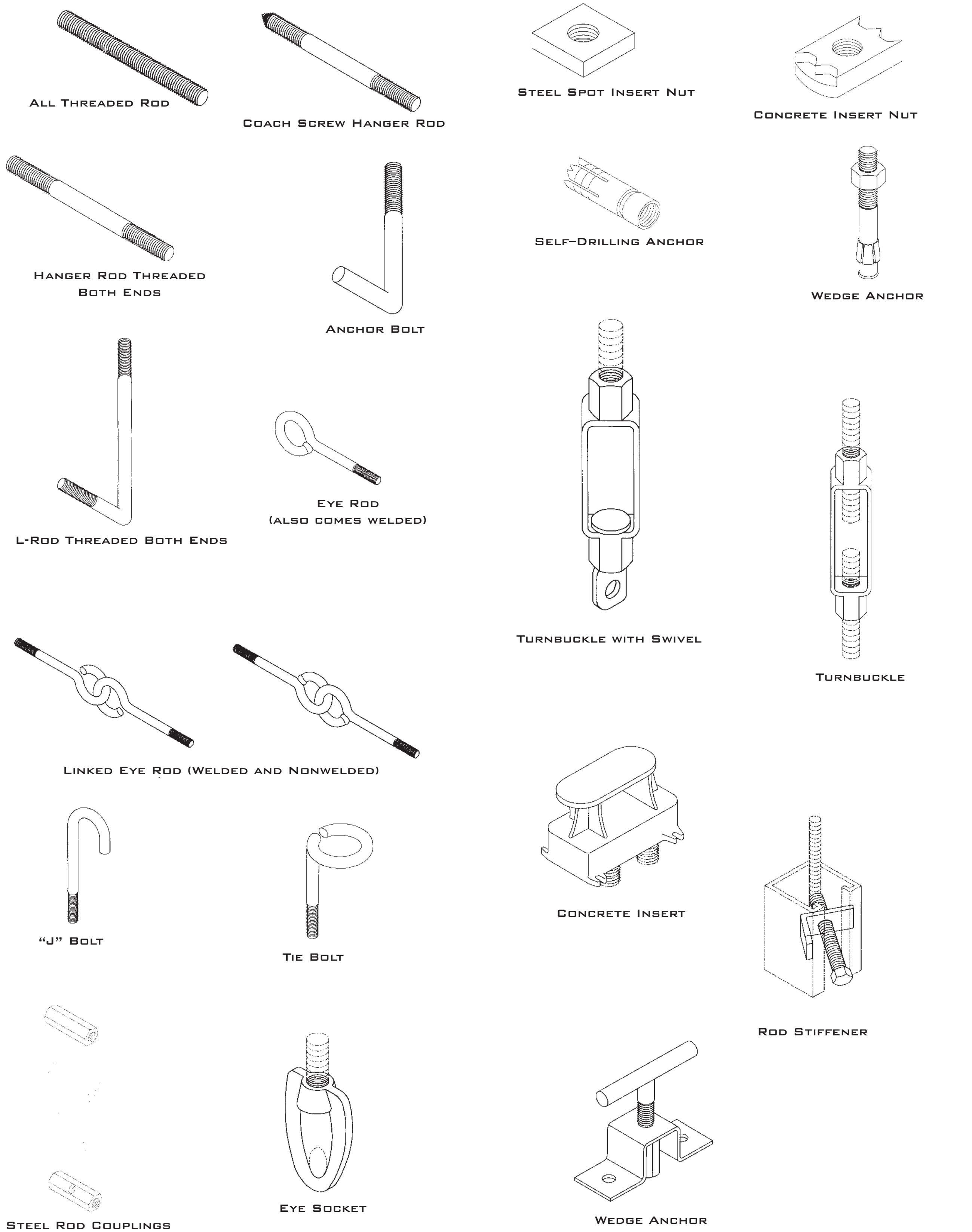


Figure 6-2 Types of Hanger and Support Anchors

Source: Anchor details courtesy of TOLCO®.

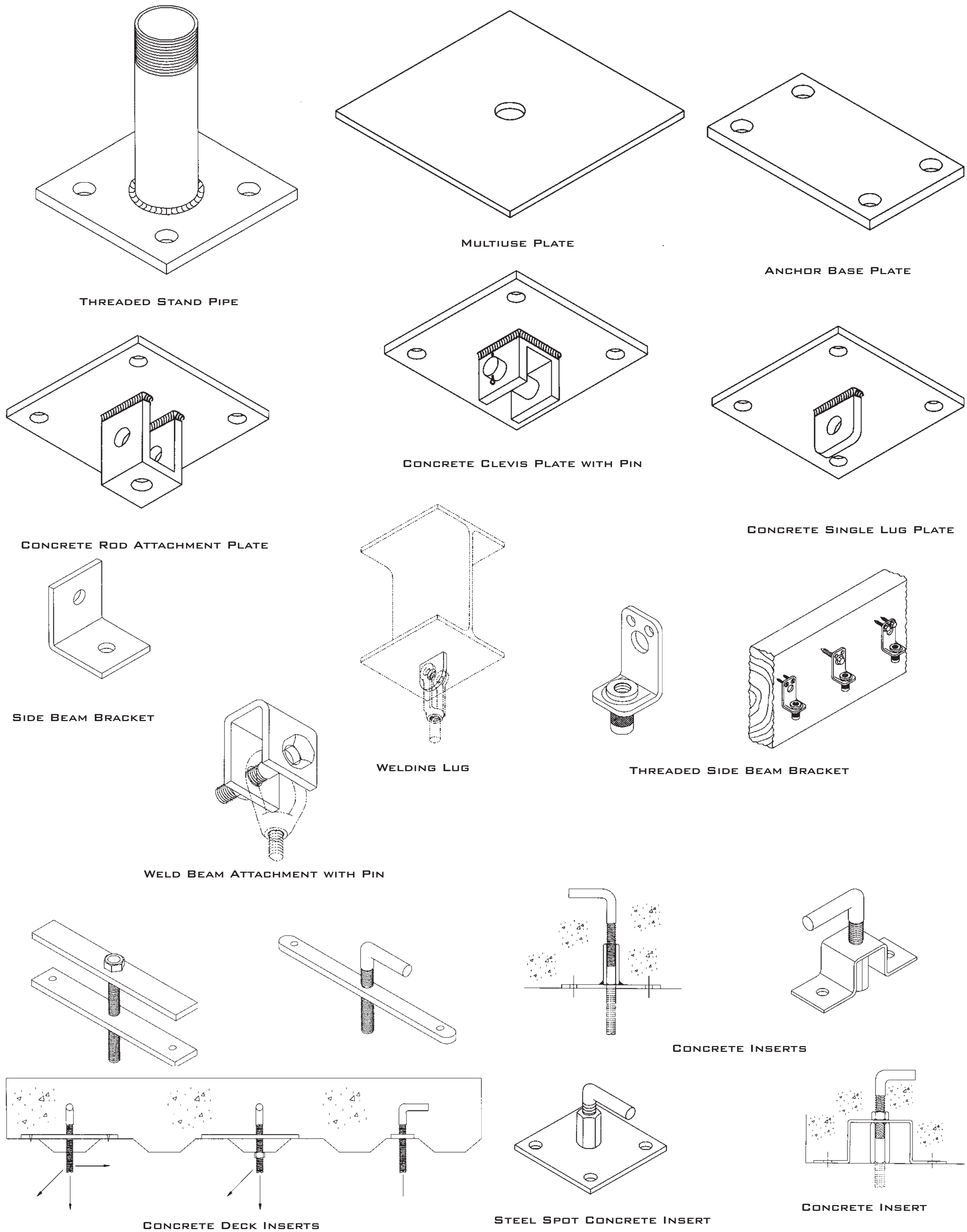


Figure 6-2 Types of Hanger and Support Anchors (continued)

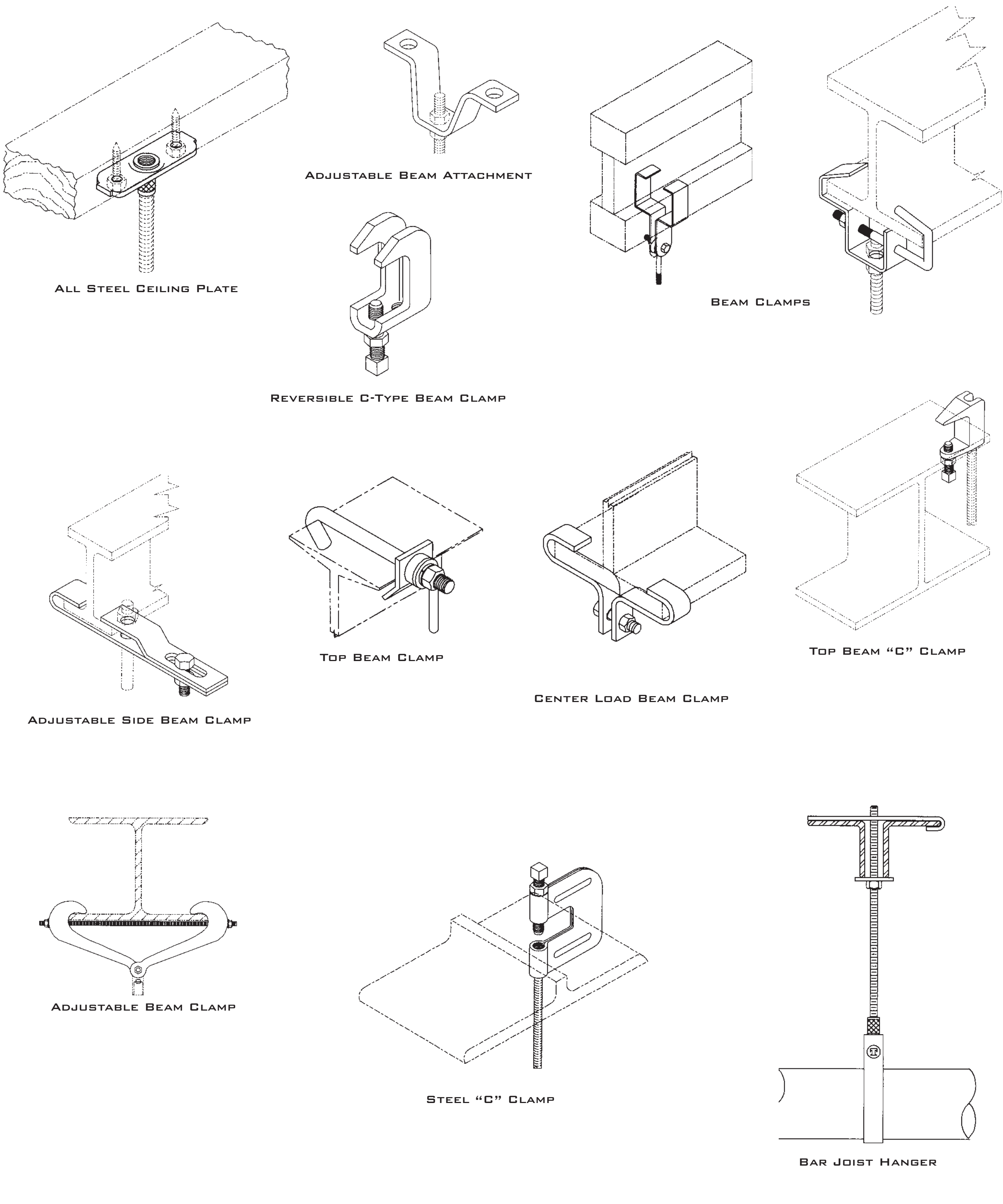
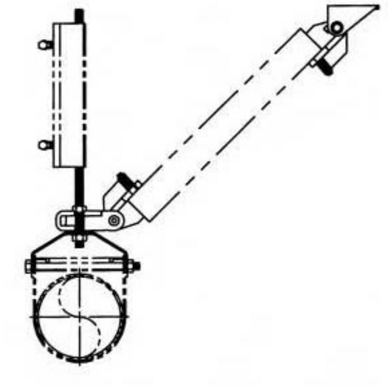
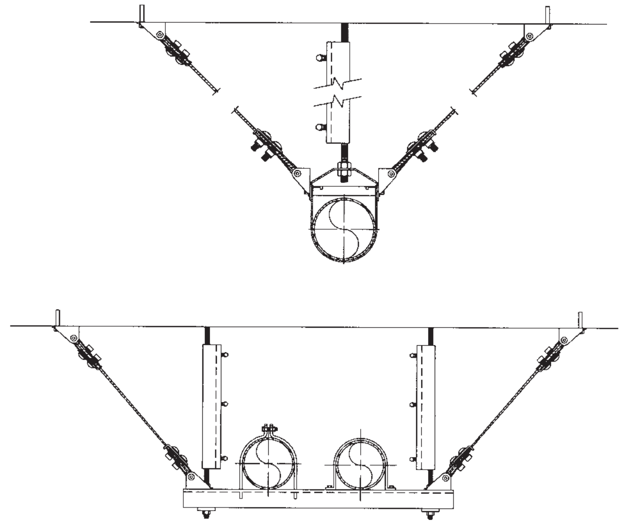
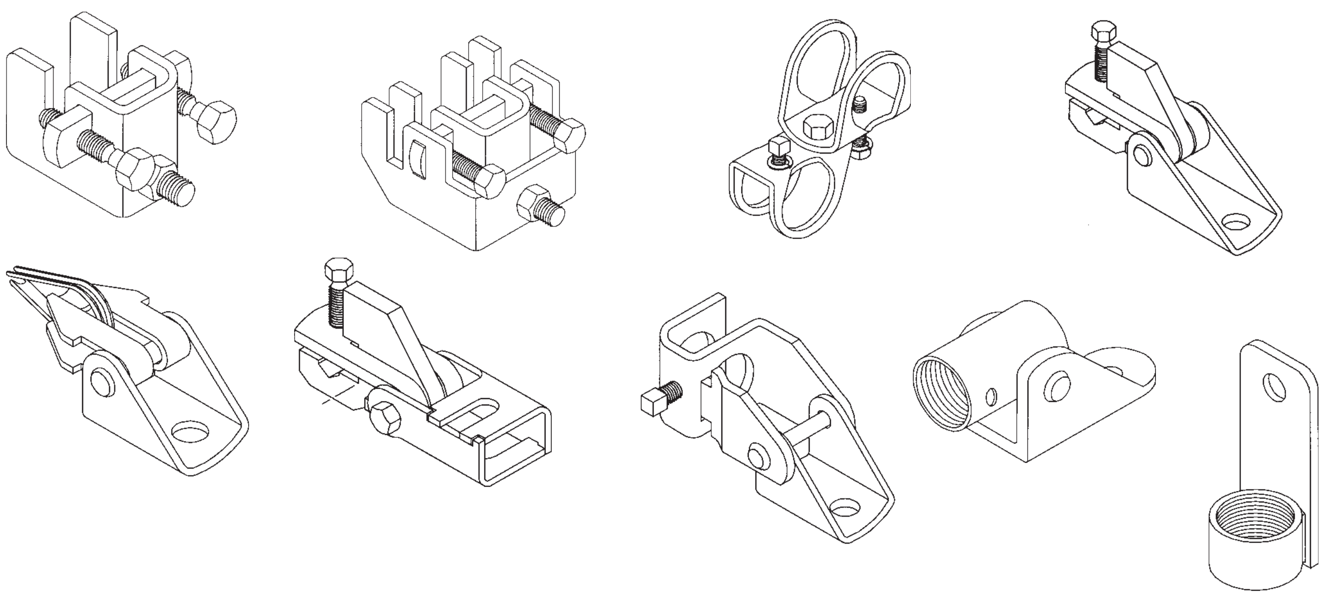


Figure 6-2 Types of Hanger and Support Anchors (continued)

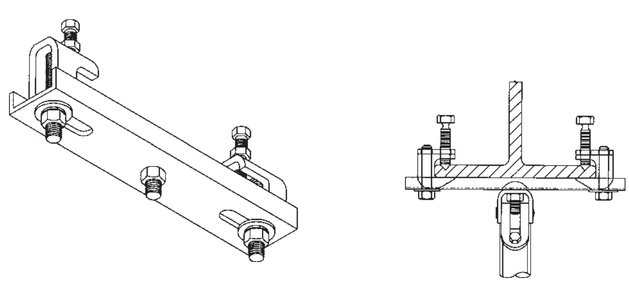




Cable Sway Braces: Examples



Examples: Sway Brace Attachments



Sway Brace Attachments: Bar Joists

Figure 6-2 Types of Hanger and Support Anchors (continued)

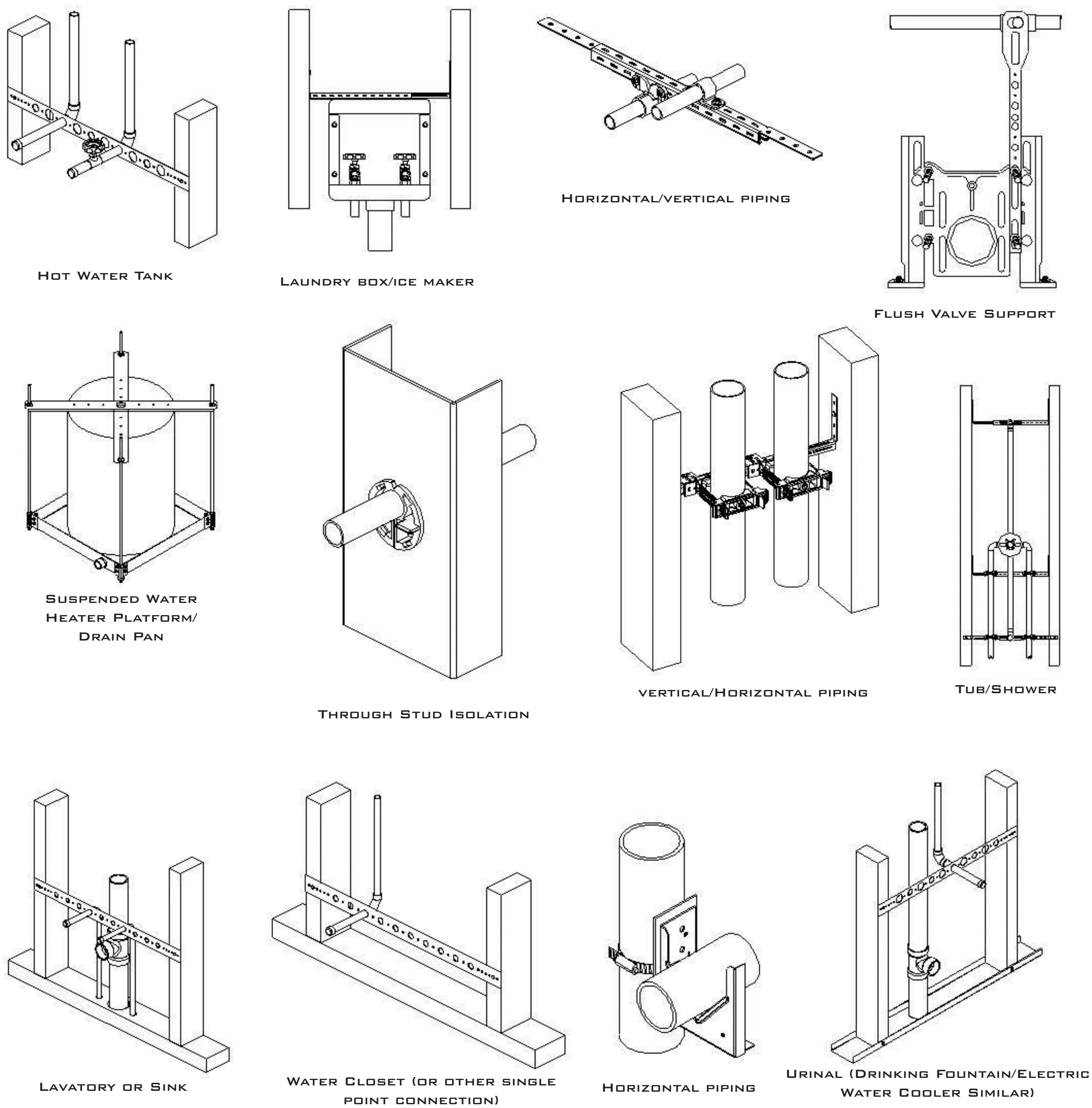


Figure 6-3 Hanger and Support Anchors for Particular Applications

Source: Support details courtesy of Holdrite®

Depending on the elements and materials of the structure, the requirements and specifications for hanger and support anchors vary widely. Anchoring to wood is significantly different from anchoring to steel. In the latter case, welding specifications may need to be included and bonding material compatibility ensured.

Anchoring to concrete requires the use of implanted anchors during the pouring of the concrete or subsequent attachment using anchor bolts and plates. Table 6-4 shows the pipe hanger rod size for a single rigid rod hanger. Care should be taken to observe the loading associated with special conditions that may induce a load beyond the hanger rod strength. Moreover, lateral stress and axial tension affect the choice of rod size and material. See Table 6-5 for load ratings of threaded hanger rods and Table 6-6 for minimum design load ratings for rigid pipe hanger assemblies. These tables show acceptable standards for hanger materials. However, it is important to check a particular manufacturer's specifications as well. See Table 6-7 for sample design load tables for a manufacturer's concrete inserts. In the overall engineered design, load and stress calculations for multiple hanger and support assemblies and the use of multiple anchor assemblies (such as concrete rod inserts) require additional evaluation and analysis to properly incorporate the effects of a distributed load.

Sleeves

Pipes often must pass through walls, floors, and other penetrations. If unlike materials come into contact, there is the possibility of chemical reactions between them that can damage the pipe, the structure, or both. Likewise, when a pipe passes through a penetration, what happens if for some reason the structure being passed through collapses on or damages the pipe? For this reason, the engineer must provide for protection of the pipes. This protection is achieved by using pipe sleeves. Pipe sleeves can be constructed of any of a variety of materials that should be selected based on the application as well as the materials of the structure and the pipe.

Table 6-4 Recommended Minimum Rod Diameter for Single, Rigid Rod Hangers

		Types of Pipe			
		Steel Water Service Steel Vapor Service Ductile Iron Pipe Cast Iron Soil		Copper Water Service Copper Vapor Service Glass, Plastic Fiberglass Reinforced	
Nominal Pipe or Tubing Size		Nominal Rod Diam.		Nominal Rod Diam.	
in.	(mm)	in.	(mm)	in.	(mm)
¼	(6)	⅜	(M10)	⅜	(M10)
⅜	(10)	⅜	(M10)	⅜	(M10)
½	(15)	⅜	(M10)	⅜	(M10)
¾	(20)	⅜	(M10)	⅜	(M10)
1	(25)	⅜	(M10)	⅜	(M10)
1¼	(32)	⅜	(M10)	⅜	(M10)
1½	(40)	⅜	(M10)	⅜	(M10)
2	(50)	⅜	(M10)	⅜	(M10)
2½	(65)	½	(M12)	½	(M12)
3	(80)	½	(M12)	½	(M12)
3½	(90)	½	(M12)	½	(M12)
4	(100)	⅝	(M16)	½	(M12)
5	(125)	⅝	(M16)	½	(M12)
6	(150)	¾	(M20)	⅝	(M16)
8	(200)	¾	(M20)	¾	(M20)
10	(250)	⅞	(M20)	¾	(M20)
12	(300)	⅞	(M20)	¾	(M20)
14	(350)	1	(M24)		
16	(400)	1	(M24)		
18	(450)	1	(M24)		
20	(500)	1¼	(M30)		
24	(600)	1¼	(M30)		
30	(750)	1¼	(M30)		

Source: From MSS SP-69-2002, *Pipe Hangers and Supports: Selection and Application,* reprinted with permission of Manufacturers Standardization Society.

Notes:

1. For calculated loads, rod diameters may be sized in accordance with Table 6-5 (MSS SP-58-2002, Table 3) provided the requirements of Table 6-6 (MSS SP-58-2002, Table 1) are satisfied. In addition, hanger rods shall be a minimum of ⅜ in. (9.6 mm) diameter and shall be limited to pipe or tubing NPS 4 (DN100) and less. For pipe and tubing NPS 4 (DN100) and greater, the rod diameter shall be not less than ½ in. (12.7 mm) and sized for loads per Table 6-5. In addition, the minimum rod diameter for rigid hangers must be sized for the loads shown in Table 6-6.
2. Rods may be reduced one size for double rod hangers. Minimum rod diameter shall be ⅜ in. (M10).

Hangers, Supports, and Anchor Materials

There is an almost unlimited variety of materials that can be used for producing hangers, supports, and anchors. With the increased use of plastic, fiberglass, and other lightweight and corrosion-resistant pipe materials has come an increased availability of matching hangers and supports.

It is up to the plumbing engineer to match and coordinate the various materials available. Because of possible chemically reactive and galvanic effects, it is of special importance to match the hanger, support, and anchor materials' composition to the composition of the piping system material. The plumbing engineer must be extremely aware of the proper spacing and

Table 6-5 Load Ratings of Carbon Steel Threaded Hanger Rods

Nominal Rod Diameter		Root Area of Thread		Max. Safe Load at Rod Temp. of 650°F (343°C)	
in.	(mm)	$in.^2$	(mm^2)	lb	(kg)
⅜	(9.6)	0.068	(43.8)	730	(3.23)
½	(12.7)	0.126	(81.3)	1,350	(5.98)
⅝	(15.8)	0.202	(130.3)	2,160	(9.61)
¾	(19.0)	0.302	(194.8)	3,230	(14.4)
⅞	(22.2)	0.419	(270.3)	4,480	(19.9)
1	(25.4)	0.551	(356.1)	5,900	(26.2)
1¼	(31.8)	0.890	(573.5)	9,500	(42.4)
1½	(38.1)	1.29	(834.2)	13,800	(61.6)
1¾	(44.4)	1.74	(1125)	18,600	(82.8)
2	(50.8)	2.30	(1479)	24,600	(109)
2¼	(57.2)	3.02	(1949)	32,300	(144)
2½	(63.5)	3.72	(2397)	39,800	(177)
2¾	(69.8)	4.62	(2980)	49,400	(220)
3	(76.2)	5.62	(3626)	60,100	(267)
3¼	(82.6)	6.72	(4435)	71,900	(320)
3½	(88.9)	7.92	(5108)	84,700	(377)
3¾	(95.2)	9.21	(5945)	98,500	(438)
4	(101.6)	10.6	(6844)	114,000	(505)
4¼	(108.0)	12.1	(7806)	129,000	(576)
4½	(114.3)	13.7	(8832)	146,000	(652)
4¾	(120.6)	15.4	(9922)	165,000	(733)
5	(127.0)	17.2	(11074)	184,000	(819)

Source: From MSS SP-58-2002, *Pipe Hangers and Supports: Materials, Design, and Manufacture,* reprinted with permission of Manufacturers Standardization Society.

Notes:

1. For materials other than carbon steel, see requirements of MSS SP-58-2002, Section 4.7 and Table 2.
2. Tabulated loads are based on a minimum actual tensile stress of 50 ksi (345 MPa) divided by a safety factor of 3.5, reduced by 25%, resulting in an allowable stress of 10.7 ksi. (The 25% reduction is to allow for normal installation and service conditions.)
3. Root areas of thread are based on the following thread series:
   diam. 4 in. and below: coarse thread (UNC)
   diam. above 4 in.: 4 thread (4-UN)

Table 6-6 Minimum Design Load Ratings for Pipe Hanger Assemblies

Applicable to all components of complete assembly, including pipe attachment, rod, fixtures, and building attachment.			
Nominal Pipe or Tube Size		Min. Design Load Ratings at Normal Temp. Range [a]	
in.	(mm)	lb	(kg)
⅜	(10)	150	(0.67)
½	(15)	150	(0.67)
¾	(20)	150	(0.67)
1	(25)	150	(0.67)
1¼	(32)	150	(0.67)
1½	(40)	150	(0.67)
2	(50)	150	(0.67)
2½	(65)	150	(0.67)
3	(80)	200	(0.89)
3½	(90)	210	(0.93)
4	(100)	250	(1.11)
5	(125)	360	(1.60)
6	(150)	480	(2.14)
8	(200)	760	(3.38)
10	(250)	1120	(4.98)
12	(300)	1480	(6.58)
14	(350)	1710	(7.61)
16	(400)	2130	(9.47)
18	(450)	2580	(11.48)
20	(500)	3060	(13.61)
24	(600)	3060	(13.61)
30	(750)	3500	(15.57)

Source: From MSS SP-58-2002, *Pipe Hangers and Supports: Materials, Design, and Manufacture,* reprinted with permission of Manufacturers Standardization Society.

Notes:

1. See MSS SP-58-2002, Section 4, for allowable stresses and temperatures.
2. Minimum rod diameter restrictions: Hanger rods shall be a minimum of 3/8 in. (9.6 mm) diameter and shall be limited to pipe or tubing NPS 4 (DN100) and less. For pipe and tubing NPS 4 (DN100) and greater, the rod diameter shall be not less than ½ in. (12.7 mm) and shall be sized for loads per Table 6-5. In addition, the minimum rod diameter for rigid hangers must be sized for loads as shown above.
3. For loads greater than those tabluated, hanger component load ratings shall be established by the manufacturer. Design shall be in accordance with all criteria as outlined in MSS SP-58-2002.
4. Pipe attachment ratings for temperature ranges between 650 and 750°F (343 and 398°C) shall be reduced by the ratio of allowable stress at service temperature to the allowable stresses at 650°F (343°C).
5. For services over 750°F (398°C), attachments in direct contact with the pipe shall be designed to allowable stresses listed in MSS SP-58-2002, Tables 2 and A2.

a Normal temperature range is –20 to 650°F (–29 to 343°C) for carbon steel, –20 to 450°F (–29 to 231°C) for malleable iron, and –20 to 400°F (–29 to 204°C) for gray iron.

Table 6-7(A) Sample Design Load Tables for Manufacturer's Concrete Inserts

Design Load Chart for 3000 psi Hard Rock Concrete												
Rod Size (in.)	Design Load Vertical (psi)				Design Load Shear (psi)				Design Load 45° (psi)			
	A	B	C	De[a] (in.)	A	B	C	De[a] (in.)	A	B	C
⅜	1207	457	457	1	675	675	675	2	612	364	385
½	2043	496	496	1.4	912	912	912	2	892	454	454
⅝	1690	532	532	1.7	1148	1148	1148	2	967	514	514
¾	2321	567	567	2	1368	1368	1368	2.5	1217	567	567
⅞	2321	878	878	4	1596	1596	1596	3	1338	801	801

Design Load Chart for Lightweight Concrete												
Rod Size (in.)	Design Load Vertical (psi)				Design Load Shear (psi)				Design Load 45° (psi)			
	A	B	C	De[a] (in.)	A	B	C	De[a] (in.)	A	B	C
⅜	905	343	343	⅞	590	590	590	2	547	307	321
½	1632	372	372	⅞	590	590	590	2	828	323	374
⅝	1268	399	399	⅞	590	590	590	2	852	337	419
¾	1741	426	426	⅞	590	590	590	2½	1084	350	459
⅞	1741	656	656	⅞	590	590	590	3	1178	439	654

Table 6-7(B) Sample Design Load Tables for Manufacturer's Concrete Inserts

Rod Size (in.)	Design Load Vertical (psi)		Design Load Shear (psi)		Design Load 45° (psi)		"E"Embedment Depth (in.)	De[a] min. (in.)
	Hard Rock	Lt. Wt.	Hard Rock	Lt. Wt.	Hard Rock	Lt. Wt.		
⅜	1255	753	978	733	777	525	3½	2
½	2321	1392	978	733	980	679	3½	2
⅝	780	468	1278	958	688	445	4	2
¾	1346	806	1278	958	927	619	4	2½
⅞	2321	1392	1278	958	1166	803	4	6

Source: Table 6-7(A) and (B) courtesy of Tolco

[a] De = distance to the edge of the concrete that must be maintained for the rod to meet the design load.

anchoring of hangers and, where questionable, must confirm with the pipe, hanger, support, and anchor manufacturers the loads, stresses, and spacing criteria specifications.

GLOSSARY

The basic word set for this glossary has been excerpted and/or adapted from Manufacturers Standardization Society (MSS) SP-90: *Guidelines on Terminology for Pipe Hangers and Supports,* with permission from MSS.

Acceleration limiter A device, hydraulic, mechanical, or spring, used to control acceleration and control shock and sway in piping systems.

Access channel Conduit or channel that is cast in place within concrete structural elements and that provides for the passing through of pipe. It is placed horizontally throughout a concrete structure to facilitate future access.

Access opening An opening or conduit that is cast in place within concrete structural elements and that provides for the passing through of pipe. The most typical usage is for short vertical conduit in concrete slabs to eliminate the subsequent drilling of core holes.

Accumulator A container, used in conjunction with a hydraulic cylinder or rotating vane device for the control of shock or sway in piping systems, that is used to accommodate the difference in fluid volume displaced by the piston. It also serves as a continuous supply of reserve fluid.

Adjustable Mechanical or automated movement providing for linear adjustment capability (regardless of the plane or dimension). Adjustment may be mechanical, such as a threaded rod, or assisted with vacuum or air pressure.

Adjustment device Component(s) that provides for adjustability. (See adjustable.)

After cold pull elevation The mechanical drawing view incorporating additional piping elements during installation that will be necessary for thermal fluctuations once piping system is “hot” or operational.

Alloy A chrome-moly material (often less than 5 percent chrome) used as a material to resist the effects of high temperatures (750°F to 1,100°F [399°C to 593°C]). Alloys are used as pipe, hanger, support, and anchor materials.

Anchor To fasten or hold a material or device to prevent movement, rotation, or displacement at the point of application. Also an appliance used in conjunction with piping systems to fasten hangers and supports to prevent movement, rotation, or displacement.

Anchor bolt A fastener (e.g., bolt or threaded rod) that is used for attachment or connection of materials, devices, or equipment. Often refers to the bolt that is embedded in concrete or passed through an opening in steel that is used to attach a hanger or support to a concrete or steel structure.

As built Refers to the actual installation and configuration of construction or placement.

Assembly A preformed arrangement or a gathered collection of various appliances and components used to carry, hold, and/or restrain devices, equipment, or a piping system load in tension.

Auxiliary stop A supplemental restraint that temporarily locks or holds in place movable parts. Often used in conjunction with spring devices, such as a spring hanger, to provide for a fixed position enabling a load to be transferred to a supporting structure in a desired placement during construction or installation.

Axial brace An assembly or bracket device used to resist twisting or to restrain a piping run in the axial direction.

Band or strap hanger An appliance or device used as a hanger or support for pipe that provides for vertical adjustment. It also is used to connect pipe to a hanger assembly.

Base support A device that carries a load from beneath and is used to carry a load’s weight in compression.

Beam clamp A mechanical device used to connect, as a hanger or support, or to hold part of a piping system to a structural beam element (typically a steel beam). A clamp firmly holds multiple materials or devices together and does not require welding.

Bearing plate See slide plate and roll plate.

Bent An assembly or frame consisting of two vertical members joined by one or more horizontal members used for the support of a piping system to a structural element.

Bolting Use of bolts, studs, and nuts as fasteners.

Brace, brace assembly A preformed appliance or assembly consisting of various components that, depending on its location, is used to hold and/or restrain a piping system from horizontal, vertical, and lateral forces.

Brace, hanger, or support drawing The mechanical drawing detailing the elements and components of an assembly or frame structure that incorporates a bill of material, load and movement data, and both general and specific identification.

Bracket A preformed support or fastener, usually constructed in a cantilevered manner, with or without additional diagonal structural members for load stability and designed to withstand a gravity load and horizontal and vertical forces.

C clamp A preformed appliance in a C shape that attaches to a flange or other part of a structural member and acts as an anchor for a hanger, support, or other device such as a threaded rod.

Cable A component used to brace structural assemblies and piping systems (also called "wire rope").

Cable sway brace Components added to a standard pipe support or hanger system to limit sway during movement such as during a seismic event. The components include cable, pipe attachments, and attachment to the structure. Cable bracing requires two attachment locations as it works under tension only and not tension and compression like rigid bracing.

Cantilever A projecting structural element or member supported at only one end.

Center beam clamp A jaw-type mechanical device used to connect, as a hanger or support, or used to hold part of a piping system to a structural beam element (typically a steel beam). It is used with I beams and wide flange beams to provide a centered beam connection.

Channel clamp A mechanical device with a channel adapter and hook rod that provides an off-center attachment to the bottom flange of a channel beam for a hanger, support, or other part of a piping system.

Clamp A mechanical device used to connect, as a hanger or support, or used to hold part of a piping system to a structural beam element. (A clamp firmly holds multiple materials or devices together and does not require welding.) See beam clamp, C clamp, channel clamp, double bolt pipe, three-bolt clamp, double-bolt riser, riser clamp, and pipe clamp.

Clevis A connector device or metal shackle with drilled ends to receive a pin or bolt and that is used for attaching or suspending parts.

Clevis hanger A support device providing vertical adjustment consisting of a clevis-type top bolted to a formed steel bottom strap.

Cold elevation See design elevation and after cold pull elevation.

Cold hanger location The location of the pipe hangers, supports, and assemblies of the installed piping system in reference to the building's structure and structural elements prior to the invoking of an operating environment.

Cold load The stress or loading put on a piping system prior to the occurrence of a normal or steady-state operating environment (as measured at ambient temperature). The cold load equals the operating load plus or minus load variations.

Cold setting The position at which a mechanical control device indicator, such as that on a spring hanger, is set to denote the proper nonoperating position installation setting of the unit.

Cold shoe A T section hanger or support with integrated insulation that has been designed for cold temperature piping system application.

Cold spring The act of prestressing a piping system during installation to condition it for minimal fluctuations, expansions, and other reactions when the finished piping system and related equipment are used in the designed operating environment.

Colored finish A generic term to describe various color finishes that are used as an identifier for product compatibility. For example, a copper-colored finish on connectors or piping denotes that the product was sized for copper tubing.

Commercial piping system A piping system located in a commercial building structure that generally includes fire protection, plumbing, heating, and cooling piping systems.

Component(s) Any individual item, appliance, or device that is combined with others to create an assembly or is part of a whole.

Concrete fastener A device installed in or attached to concrete by various means (often precast, drilled, or epoxied) to which a pipe hanger or support can be attached.

Concrete insert and concrete insert box An anchor device that is cast in place in a concrete structure and provides for a hanger, support, rod, or similar attachment. The insert provides load assistance to a piping system and has nominal lateral adjustment.

Continuous insert An anchoring device in the form of a channel (which can be of varying lengths) that is cast in place in a concrete structure and provides for multiple hangers, supports, rods, or similar attachments. The insert provides load assistance to a piping system and has the capability for lateral adjustments.

Constant support hanger A mechanical, spring-coil device that provides constant support for a piping system, while permitting some dimensional movement.

Constant support hanger indicator A device attached to the movable arm of a constant support hanger that measures vertical pipe movement.

Copper plating See plating.

Corrosion The process that describes the oxidation of a metal that is weakened or worn down by chemical action.

Cut short The shortening or lengthening of a section of pipe to provide for reduced fluctuations, expansions, and other reactions when the finished piping system and related equipment are used in the designed operating environment.

DWV Drain, waste, and venting.

Deadweight load The combination of all stress or loading put on a piping system that takes into consideration only the weight of the piping system, including the pipe, hangers, supports, insulation, and pipe contents.

Design elevation The overall mechanical drawing view of the piping system as designed.

Design load The combination of all stress or loading put on a piping system as defined in the engineered drawing or as part of the engineered design specification.

Deviation A measurement of difference often expressed as a percentage. It often is used to describe the accuracy difference between actual and specified performance criteria.

Double acting A descriptor for a mechanical device that provides resistance in both tension and compression cycles.

Double-bolt pipe clamp See three-bolt pipe clamp.

Drag The retarding force that acts on a portion of a hydraulic or mechanical device as it moves through fluid, gas, or other friction-generating substances. It also refers to the force required to extend and retract a hydraulic or mechanical element of a hanger or support device during activation at low velocity.

Dual-use brace A single brace that can be used as both a longitudinal and lateral brace in a single location.

Dynamic force or dynamic loading The additional loading and stress conditions that must be taken into consideration over and above a steady-state condition.

Dynamic load The temporary stress or loading put on a piping system as the result of internal or external forces that create movement or motion in the system.

Elbow lug An elbow-shaped device with a pipe connector welded to it for use as an attachment.

Electrogalvanized A protective coating of electroplated zinc. (See also galvanized.)

Electroplated Plating by using an electro-deposition process. (See also plating.)

Electrolysis The producing of chemical changes due to the differences in electrical potential between dissimilar materials in the presence of moisture. (See also corrosion.)

Elevation A mechanical drawing view that is a geometrical projection as seen on a vertical plane.

Embedded A device or fastener that is cast in place in a concrete structure

Engineered drawing A mechanical drawing that details the elements and components of a piping system and incorporates a bill of material, load and movement data, location information, and both general and specific identification.

Engineered hanger assembly A mechanical drawing that details the elements and components of a hanger assembly and incorporates a bill of material, load and movement data, location information, and both general and specific identification. (See also semi-engineered hanger assembly.)

Erected elevation See design elevation.

Extension riser clamp An attachment device for the support of vertical piping that provides for the transfer of the piping load to the bearing surface to which the clamp is attached.

Eye rod A bolt or rod with a circular or pear-shaped end that permits other components or devices to be attached by means of a bolt or pin. The eye may be forged, welded, or nonwelded.

Eye socket An appliance that provides for the attachment of a threaded bolt or rod to the bolt or rod of another component or device.

Fabrication A term used to refer to a part constructed or manufactured out of standard parts or raw materials.

Fabricated steel part A component that is constructed from standard shapes of steel plate.

Fabricator A business engaged in the fabrication of parts.

Forged clevis A connector device, a clevis, that has been formed as one piece (i.e., forged).

Four-way brace An assembly consisting of lateral and longitudinal bracing that is designed to control back-and-forth movement in four directions.

Framing steel A structural steel member, normally less than 10 feet in length, used between existing members as a means of providing for the attachment of a hanger or support for a piping system.

Friction load The stress or loading put on a piping system as the result of frictional forces that exist between different surfaces that are in contact with each other, such as moving or sliding surfaces.

Galvanized A zinc coating applied to steel for protection from oxidation and other chemical actions.

Gang hanger A hanger assembly utilizing a common cross member to provide support for parallel runs or banks of piping.

Guide A device used to permit pipe movement in a predetermined direction while restraining movement in other directions.

Hanger A device that is suspended from a structure and used to carry or support a load.

Hanger assembly A general term used to describe a series of assembled components that make up a device that is connected to or suspended from a structure and is used to carry or support a load in tension or carry a load under compression. The device may be designed to prevent, resist, or limit movement, or it may be used to permit movement in a predetermined direction while restraining movement in other directions.

Hanger drawing See brace, hanger, or support drawing.

Hanger loads See pipe hanger loads.

Hanger rod Round steel bar, normally threaded, used to connect components for hangers and supports.

Heavy bracket A bracket used for the support of heavy loads. (See bracket.)

Hinged pipe clamp Also known as a split ring, it is a hinged attachment device that permits installation before or after piping is in place and is used primarily on noninsulated piping.

Horizontal traveler A hanger or support device that accommodates horizontal piping movement.

Hot-dip galvanized A corrosion protection coating of zinc applied to steel or other metals.

Hot elevation The mechanical drawing view of the piping system as it will appear in its full operating environment.

Hot hanger location The location of the pipe hangers, supports, and assemblies of the installed piping system in reference to the building's structure and structural elements within the operating environment.

Hot load The stress or loading put on a piping system as the result of a normal or steady-state operating environment. (See operating load.)

Hot setting The position at which a mechanical control device indicator, such as that on a spring hanger, is set to denote the proper operating position setting of the unit.

Hot shoe A T section hanger or support with integrated insulation that has been designed for hot temperature piping system application.

HVAC Heating, ventilation, and air-conditioning.

Hydraulic snubber See hydraulic sway brace.

Hydraulic sway brace A hydraulic cylinder or rotating vane device used for the control of shock or sway in piping systems, while allowing for normal thermal expansion.

Hydrostatic load The stress or loading put on a piping system as the result of hydrostatic testing. (See hydrostatic test load.)

Hydrostatic lock The condition wherein a supplemental restraint temporarily locks or holds in place moveable parts during a hydrostatic test. It often is used in conjunction with spring devices, such as a spring hanger, to provide for a fixed position enabling a load to be transferred to a supporting structure in a desired placement during construction or installation.

Hydrostatic test A preoperational test whereby the piping system is subjected to a pressurized fluid test in excess of the specified operational pressure to ensure the integrity of the system.

Hydrostatic test load The temporary loading condition consisting of the total load weight of the piping (gravitational load), insulation, and test fluid for piping systems subjected to hydrostatic tests.

Industrial piping system A piping system located in an industrial complex that generally includes fire protection, plumbing, heating, and cooling piping systems and also incorporates process, vacuum, air, steam, or chemical piping systems.

Insert An anchor device that is cast in place in a concrete structure and provides for a hanger, support, rod, or similar attachment. Inserts provide load assistance to a piping system and have nominal lateral adjustment.

Insert box See concrete insert.

Insert nut A female threaded anchor device that is locked into position as part of an insert and that receives a threaded rod or bolt.

Institutional piping system A piping system located in an institutional environment or building structure that generally includes fire protection, plumbing, heating, and cooling piping systems, as well as process, vacuum, air, or chemical gas piping systems.

Insulated pipe support A hanger or support with an integrated insulation insert designed for use with insulated pipe.

Insulation protection saddle A device used to prevent damage to the insulation on a pipe at the support point.

Integral attachment When connector pieces and devices have been welded together as hangers and supports or an assembly.

Intermediate anchor An attachment point used to control the distribution, loading, and movement on a flexible piping system.

Invert Drawing elevation view from the bottom or underneath.

Jacket A metal covering placed around the insulation on a pipe to protect it against damage.

Knee brace A diagonal structural member used to transfer load or provide stability.

Lateral brace A brace designed to restrain a piping system against transverse loads.

Lateral stability The state or degree of control of a piping system transverse to the run of the pipe.

Light bracket A bracket used for the support of light loads. (See bracket.)

Limit stop An internal device built into a mechanical device to prevent the overstressing of a spring coil, overtravel, or release of a load.

Liner Material placed between hangers, supports, or an assembly to protect a piping system from damage or other undesirable effects.

Load adjustment scale A scale used on a mechanical device to indicate the load adjustment.

Load bolt or pin A bolt or pin used to support the weight or load carried by a hanger or assembly.

Load coupling An adjustment device used to connect hanger and support components.

Load indicator A pointer, dial, or gauge for reading or determining the settings and changes of a device.

Load rated The rating of a particular size of component or assembly to withstand a specified force with a safety factor applied.

Load scale A measurement pointer, dial, or gauge attached to a device to provide a means of determining the static or dynamic aspects of a supported load.

Load variation The difference in the elevations at a support point between the time of installation (cold) and actual operating (hot) environment.

Load See pipe hanger load.

Location See pipe hanger location.

Lock up The operational period when a hydraulic, mechanical, or spring device used for the control of shock and sway in piping systems is actuated.

Longitudinal brace A brace designed to restrain a piping system against axial loads.

Lug A welded appliance to provide an attachment point to a structural member or piping.

Mechanical snubber See mechanical sway brace.

Mechanical sway brace A mechanical device used for the control of shock or sway in piping systems, while allowing for normal thermal expansion.

Medium bracket A bracket used for the support of moderate loads (See bracket.)

Metric hanger A hanger or support that conforms to metric measurements and, where appropriate, contains a metric threaded connection.

Mill galvanized A corrosion-protection coating of zinc applied at the point of fabrication.

Multiple support See gang hanger.

Negligible movement The calculated minimum movement at a support point for a portion of a piping system where there is an inherent flexibility of the piping system.

Nominal size The identified size, which may vary from the actual size.

Nonintegral attachment When connector pieces and devices do not require being welded together as hangers and supports or an assembly.

Nut, insert See insert nut.

Offset A relative displacement between a structural attachment point and a piping system that is incorporated into the design to accommodate movement.

Operating load The stress or loading put on a piping system as the result of a normal or steady-state operating environment.

OSHPD California Office of Statewide Health Planning and Development. OSHPD is essentially a service organization providing services that include the efficient processing of approvals for health facility construction. OSHPD is a national leader in seismic restraint guidelines and requirements.

Pipe attachment Any component or device used to connect a pipe to a hanger, support, or assembly.

Pipe brace See brace.

Pipe channel Conduit or channel that is cast in place within concrete structural elements and that provides for the passing through of pipe. It is placed horizontally throughout a concrete structure to facilitate future access.

Pipe clamp A bolted clamp attachment that connects a pipe to a hanger, support, assembly, or structural element.

Pipe clip An attachment appliance used to connect a pipe directly to a structural element, also referred to as a strap or pipe clamp.

Pipe covering protection saddle A protective covering used to prevent damage to insulation surrounding a pipe at hanger and support points.

Pipe elevations See design elevation, erected elevation, after cold pull elevation, and cold elevation.

Pipe hanger An appliance or device that is attached to or suspended from a structural element and that is used to support a piping system load in tension.

Pipe hanger assembly An assembly used for a piping system.

Pipe hanger drawing A mechanical drawing that details the elements and components of a piping system and incorporates a bill of material, load and movement data, location information, and both general and specific identification. (See also engineered drawing and semi-engineered drawing.)

Pipe hanger load See specific load types: cold load, deadweight load, design load, dynamic load, friction load, hot load, hydrostatic load, operating load, thrust load, seismic load, thermal load, trip-out load, wind load, and water hammer load.

Pipe hanger location See location types: cold hanger location and hot hanger location.

Pipe hanger plan and ***pipe hanger plan location*** The engineered design and elevations that fully detail the hangers, supports, and anchors of a piping system. Mechanical drawings include appropriate offsets as a result of movement and displacement expectations.

Pipe insulation shield A rigid insert appliance designed to protect pipe insulation passing through hangers, supports, and assemblies.

Pipe load See specific load types: cold load, deadweight load, design load, dynamic load, friction load, hot load, hydrostatic load, operating load, thrust load, seismic load, thermal load, trip-out load, wind load, and water hammer load.

Pipe opening An opening, conduit, or channel that is cast in place within concrete structural elements and that provides for the passing through of pipe. The most typical usage is for short vertical conduit in concrete slabs to eliminate the subsequent drilling of core holes.

Pipe rack A structural frame that is used to support piping systems. (See assembly.)

Pipe roll A pipe hanger or support that utilizes a roller or bearing device to provide the ability for lateral axial movement in a piping system.

Pipe saddle support A pipe support that utilizes a curved section for cradling the pipe.

Pipe shoe A hanger or support (typically T shaped) attached to the pipe to transmit the load or forces to adjacent structural elements.

Pipe size Reference to nominal pipe size, unless otherwise specified.

Pipe sleeve An opening, conduit, or channel that is cast in place within concrete structural elements and that provides for the passing through of pipe. The most typical usage is for short vertical conduit in concrete slabs to eliminate the subsequent drilling of core holes. However, conduit or channel may be placed horizontally throughout a concrete structure to facilitate future access.

Pipe sleeve, pipe sleeve hanger or support An appliance or device that surrounds a pipe and connects to a hanger or support to provide for alignment and limited movement.

Pipe slide A hanger or support that incorporates a slide plate to accommodate horizontal pipe movement.

Pipe strap An attachment appliance used to connect a pipe directly to a structural element. (See pipe clip and pipe clamp.)

Pipe support A device or stanchion by which a pipe is carried or supported from beneath. In this position, the pipe load is in compression.

Pipe system load See specific load types: cold load, deadweight load, design load, dynamic load, friction load, hot load, hydrostatic load, operating load, thrust load, seismic load, thermal load, trip-out load, wind load, and water hammer load.

Plate lug See lug.

Plating An electroplating process whereby a metallic coating (e.g., copper, chrome, or zinc) is deposited on a substrate.

Point loading The point of application of a load between two surfaces. It typically describes the load point between a curved and a flat surface.

Preset Prior installation adjustment of hangers, supports assemblies, equipment, and devices.

Protection saddle A saddle that provides a protective covering or coating to prevent damage to pipe or to the insulation surrounding a pipe at hanger and support points.

Protection shield An appliance, which may be rigid or flexible, designed to protect pipe or insulation at contact points with hangers and supports.

Random hanger A hanger or support that requires field fabrication and the exact location, shape, and type of which are left to the discretion of, and are to be determined by, the installer.

Reservoir An attachment or separate container used in conjunction with a fluid- (or gas-) using device (e.g., hydraulic) that provides a means to store or hold a supply of liquid (or gas) to provide for a reserve or otherwise ensure for an adequate or continuous supply of fluid (or gas).

Restraint Any appliance, device, or equipment that prevents, resists, or limits unplanned or random movement.

Restraining control device Any hydraulic, mechanical, spring, or other rigid or flexible hanger, support, or device used to control movement.

Resilient support A hanger, support, or device that provides for vertical, horizontal, lateral, or axial movement.

Retaining strap An appliance or device used in conjunction with clamps and other components to secure hangers and supports to structural elements.

Rigid sway brace Components added to a standard pipe support or hanger system to limit sway during movement such as a seismic event. The components include solid strut or pipe, pipe attachments, and attachment to the structure. Rigid bracing only requires one attachment per location because it works under tension and compression.

Rigid hanger A hanger or support that controls or limits vertical and horizontal movement.

Rigid support See rigid hanger.

Rigging Appliances and devices, including chain, rope, and cable, used to erect, support, and manipulate.

Ring band An appliance or device consisting of a strap (steel, plastic, or other material) formed in a circular shape with an attached knurled swivel nut used for vertical adjustment.

Riser An upright or vertical member, structural or otherwise.

Riser clamp An appliance or device used to provide connections to and support for upright or vertical members, structural or otherwise.

Riser hanger A hanger or support used in conjunction with a riser.

Rod A slender bar typically considered to have a circular cross section, available in a variety of materials. (See threaded rod.)

Rod coupling An appliance or device used to join two rods. (See threaded rod coupling.)

Rod hanger A hanger or support that has an integrated rod as part of its construction.

Rod stiffener An appliance or device used to provide additional rigidity to a rod.

Roll stand A pipe roll mounted on a stand and used for support.

Roll and plate A combination of a pipe roll and a slide plate used for minimal lateral and axial movement where minimal or no vertical adjustment is required.

Roll hanger An appliance or device that utilizes a pipe roll for lateral and axial movement when used to carry a load in suspension or tension.

Roll plate A flat appliance, typically a steel or alloy plate, that permits movement and/or facilitates a sliding motion. (See slide plate.)

Roll trapeze A combination device utilizing a pipe roll and a trapeze hanger.

Saddle A curved appliance or device designed to cradle a pipe and used in conjunction with a hanger or support.

Safety factor The ultimate strength of a material divided by the allowable stress. It also refers to the ultimate strength of a device divided by the rated capacity.

Scale plate A device attached to hangers, supports, and assemblies to detect changes in load or movement.

Seismic control device An appliance or device used to provide structural stability in the event of a change in the steady-state environment affecting a building's structure, such as would occur with a natural event such as an earthquake or other violent action.

Seismic load The temporary stress or loading put on a piping system as the result of a change in the steady-state environment affecting a building's structure, such as would occur with a natural event such as an earthquake or other violent action.

Semi-engineered drawing A mechanical drawing that details the elements and components of a piping system and incorporates a bill of material, load and movement data, and other general identification.

Semi-engineered hanger assembly A mechanical drawing that details the elements and components of a hanger assembly and incorporates a bill of material, load and movement data, and other general identification.

Service conditions Description of the operating environment and operating conditions, including operating pressures and temperatures.

Shear lug An appliance or device primarily to transfer axial stress (shear stress) and load to a support element.

Shield See protection shield.

Side beam bracket A bracket designed to be mounted in a vertical position by attachment to a structural element. This bracket provides mounting capability for a hanger or support.

Side beam clamp A beam clamp that provides for an off-center attachment to the structural element.

Significant movement The calculated movement at a proposed support point for a hanger or support.

Single acting A descriptor for a mechanical device that provides resistance in either tension or compression cycles, but not both. (See double acting.)

Single pipe roll A pipe roll used in a trapeze hanger.

Sleeper A horizontal support, usually located at grade.

Slide plate A flat appliance, typically a steel or alloy plate, which permits movement and/or facilitates a sliding motion.

Sliding support An appliance or device that provides for only frictional resistance to horizontal movement.

Slip fitting An appliance or device used to help align and provide for limited movement of a pipe. This device is used as an assembly component.

Snubber A hydraulic, mechanical, or spring device used for the control of shock and sway; a shock absorber.

Special component Any appliance or device that is designed and fabricated on an as-required basis.

Spider guide An appliance or device used with insulated piping for maintaining alignment during axial expansion and contraction cycles.

Split ring See hinged pipe clamp.

Spring cushion hanger A simple, noncalibrated, single-rod spring support used for providing a cushioning effect.

Spring cushion roll A pair of spring coils with retainers for use with a pipe roll.

Spring hanger An appliance or device using a spring or springs to permit vertical movement.

Spring snubber See spring sway brace.

Spring sway brace A spring device used for the control of vibration or shock or bracing against sway.

Stanchion A straight length of structural material used as a support in a vertical or upright position.

Stop An appliance or device used to limit movement in a specific direction.

Strap An attachment appliance used to connect a pipe directly to a structural element. (See pipe clip and pipe clamp.)

Stress analysis An analytical report that evaluates material, structural, or component stress levels.

Strip insert See continuous insert.

Structural attachment An appliance or device used to connect a hanger, support, or assembly to a structural element.

Strut A rigid tension/compression member.

Strut clamp An appliance or device used to secure a pipe to a strut.

Support A device that attaches to or rests on a structural element and is used to carry a load in compression.

Support drawing See brace, hanger, or support drawing.

Suspension hanger See pipe hanger.

Sway brace See lateral brace or restraining control device.

Swivel pipe ring See ring band.

Swivel turnbuckle An appliance or device that provides flexibility and linear adjustment capability used in conjunction with hangers and supports. (See turnbuckle.)

Thermal load The stress or loading put on or introduced to a piping system as the result of regular or abrupt changes in the steady-state temperature of the pipe contents or the surrounding environment.

Threaded rod A steel, alloy, plastic, or other material rod threaded along its full length. Threads may be rolled or cut.

Threaded rod coupling An appliance or device used to join two threaded rods.

Three-bolt pipe clamp A pipe clamp normally used for horizontal insulated piping that utilizes bolts to attach the clamp to the pipe and a separate load bolt to transfer the piping weight to the remainder of the pipe hanger assembly from a point outside the insulation (previously known as a double-bolt pipe clamp).

Top beam clamp A mechanical device used to connect, as a hanger or support, or used to hold part of a piping system to the top of a structural beam element (typically a steel beam). A clamp firmly holds multiple materials or devices together and does not require welding.

Thrust load The temporary stress or loading put on a piping system as the result of a change in the steady-state operating environment of the pipe contents as a result of regular or abrupt changes associated with equipment or mechanical devices such as the discharge from a safety valve, relief valve, pump failure, or failure of some other mechanical device or element.

Transverse brace See lateral brace.

Trapeze hanger A pipe hanger consisting of parallel vertical rods connected at their lower ends by a horizontal member that is suspended from a structural element. This type of hanger often is used when there is an overhead obstruction or where insufficient vertical space is available to accommodate a more traditional hanger or support.

Travel device A hanger or support device that accommodates piping movement.

Travel indicator See constant support hanger indicator and variable spring hanger indicator.

Travel scale A device attached to a spring unit to measure vertical movement.

Travel stop An appliance or device that temporarily locks moveable parts in a fixed position, enabling a load to be transferred to a supporting structural element during installation and testing phases.

Trip-out load The temporary stress or loading put on a piping system as the result of a change in the steady-state flow of the pipe contents as a result of the change associated with equipment or mechanical devices such as a turbine or pump.

Turnbuckle A device with one left-hand female threaded end and one right-hand female threaded end, used to join two threaded rods and provide linear adjustment.

Two-way brace A brace designed to control movement in two directions. (See lateral brace and longitudinal brace.)

U-bolt A U-shaped rod with threaded ends that fits around a pipe and is attached to a structural element or a supporting member.

Vapor barrier An uninterrupted, nonpermeable material used as a cover for insulated pipe to exclude moisture from the insulation.

Variability The load variation of a variable-spring hanger divided by the hot load expressed as a percentage.

Variable-spring hanger A spring coil device that produces varying support while permitting vertical movement.

Variable-spring hanger indicator A device attached to a variable-spring hanger that measures vertical pipe movement.

Velocity limited A term relating to snubbers in which velocity is the means of control.

Vibration control device An appliance used to reduce and/or control the transmission of vibration to structural elements.

Vibration isolation device See vibration control device.

Water hammer load The temporary stress or loading put on a piping system as the result of a change, abrupt or otherwise, in the steady-state flow of the pipe contents.

Welded beam attachment A U-shaped, flat-bar appliance, normally welded to a steel beam, used to connect a hanger, support, or assembly.

Welded pipe attachment The use of a weld to attach a pipe to a hanger, support, or assembly.

Weldless eye nut A forged steel appliance that provides an attachment point for a threaded hanger rod to a bolt or pin connection.

Wire hook A type of hanger or support that is simply a bent piece of heavy wire.

Wind load The temporary or steady-state stress or loading put on or added to a piping system as the result of a change of environmental conditions such as increased steady state or alternating air movement. Usually refers to piping systems in environmentally exposed conditions.

7 Vibration Isolation

In recent years, vibration and noise due to mechanical equipment have become critical issues, not only due to the life expectancy of the machinery itself, but also due to the educated demands of today's building tenants. In modern construction, one of the biggest battles during design is the allocation of adequate mechanical space. Pumps, compressors, and other associated equipment are sized larger to increase capacity and reduce cost, which means that greatly increased power input is being applied. While this is the ideal in practice, it presents a number of issues. In many buildings today, due to space requirements, equipment is placed near occupied space where such vibration disruption is unacceptable.

In the past, a very critical installation on an upper floor could be achieved by allowing not more than 10 percent vibration transmission. Thick concrete floors and walls in older buildings were stiff and could withstand and absorb such significant machinery vibration and noise. However, for the same amount of unbalance (keeping in mind new structures utilizing steel, pan-type floors, and curtain walls), doubling the equipment's revolutions per minute (rpm) quadruples the unbalanced force. Despite the efforts of equipment manufacturers to compensate for this through improved balance of rotating equipment, the net result is more vibration and noise generation.

Light structures having resonant frequencies that are readily excited by equipment vibration require a greater precision to the quality, engineered and installed, of design, reaping not more than a 1 percent or 2 percent transmissibility. For many buildings constructed today, people are not willing to tolerate vibration and noise. Installations that were satisfactory in the past are no longer acceptable by modern standards. Noise levels now must be controlled to the extent that equipment noise does not add to the noise level of any building area.

These more sophisticated tenants are much more inclined to understand the problematic issues behind noted building deficiencies. Furthermore, tests have been conducted to establish acceptable noise criteria for different types of use. These noise criteria (NC) curves take into consideration an individual's sensitivity to both the loudness and frequency of noise. This studied criteria is very prevalent in more sensitive environments such as schools, hospitals, and performance venues where the disturbance hinders the acceptable environment. A similar criterion in vibration analysis shows that in certain facilities a dramatic effect on the neurological path-fire of tenants occurs due to such disturbance.

In summary, more larger and higher-speed machines are installed higher in lighter structures, disturbing more sophisticated tenants than ever before. The only acceptable solution is to analyze the structure and equipment, not just as individual pieces, but as a total system. Every element must be carefully considered to ensure a completely satisfactory job. It is impossible to separate vibration and noise problems, but a more conscientious approach must be taken to eliminate the greater issues that have always existed.

DEFINITIONS

Following are a few definitions for the factors found in vibration isolation theory formulas.

Vibration isolator Placed between the equipment or machinery and the building structure, a pliant, or resilient, material (i.e., cork, elastomers, neoprene rubber, steel spring isolators) used to create a low, natural frequency support system for the equipment.

Static deflection (d) How much the isolator deflects under the weight of the equipment.

Transmissibility Also known as frequency or efficiency quotient (Eq) the ratio (f_d/f_n) of the maximum force to the supporting structure, due to the vibration of a machine, to the maximum machine force.

Percent transmissibility (T) The percentage of the maximum force given to the building's structure through the isolators.

Natural frequency (f_n) When compressed and released rapidly, the frequency at which the vibration isolator naturally oscillates.

Disturbing frequency (f_d) Generated by the equipment, the lowest frequency of vibration.)

Resonant amplification The occurrence of the natural frequency of the isolators (f_n) and the disturbing frequency (f_d) equaling one another.

Damping Essentially acts as the brakes for equipment mounted on isolators by reducing or stopping motion through friction or viscous resistance.

THEORY OF VIBRATION CONTROL

A very simple equation applies to determining the transmission of steady-state vibration, the constantly repeating sinusoidal wave form of vibration generated by such equipment as compressors, engines, and pumps:

Equation 7-1

$$T = \frac{F_t}{F_d} = \frac{1}{(f_d/f_n)^2 - 1}$$

where

T = Transmissibility
F_t = Force transmitted through the resilient mountings
F_d = Unbalanced force acting on the resiliently supported system
f_d = Frequency of disturbing vibration, cycles per minute (cpm [hertz, Hz])
f_n = Natural frequency of the resiliently mounted system, cpm (Hz)

This equation is exact for steel springs because they have straight-line load deflection characteristics and negligible damping. When the equation is used for organic materials, the following corrections normally give conservative results: For rubber and neoprene, use 50 percent of the static deflection when calculating f_n. For cork, use f_n equal to one and one-half times the natural frequency determined by actual test.

The natural frequency of the resiliently mounted system (f_n) can be calculated using the following equation:

Equation 7-2

$$f_n = \frac{188}{(1/d)^{½}}$$

where

d = Static deflection of the resilient mounting, inches (millimeters)

When using Equation 7-2 in international standard (SI) units, the 188 multiplying factor should be changed to 947.5. The static deflection can be obtained from the expression:

Equation 7-3

$$d = \frac{W}{k}$$

where

W = Weight on the mounting, pounds (kilograms)
k = Stiffness factor of the mounting of deflection, pounds per inch (kg/mm)

The natural frequency (f_n) of a resiliently mounted system is the frequency at which it will oscillate by itself if a force is exerted on the system and then released. This can be illustrated by suspending a weight from a very long rubber band. The longer the rubber band, the more deflection the weight produces in it. If the weight is then pulled down slightly by hand and released, it will oscillate up and down at the natural frequency of the system. The more deflection in the system, the lower its natural frequency. The importance of this can be seen by examining Equation 7-1 rewritten in the following form:

Equation 7-4

$$F_t = F_d \left[\frac{1}{(f_d/f_n)^2 - 1} \right]$$

A system may have up to six natural frequencies. In the practical selection of machine mountings, if the vertical natural frequency of the system is made low enough for a low transmissibility, the horizontal and rotational natural frequencies generally will be lower than the vertical and can be disregarded, except on machines with very large horizontal, unbalanced forces or with large unbalanced moments, such as horizontal compressors and large two-, three-, and five-cylinder engines.

Obviously, the transmitted force (F_t) should be minimized. Since the disturbing force (F_d) is a function of the machine characteristics and cannot be reduced, except by dynamic balancing of the machine—or

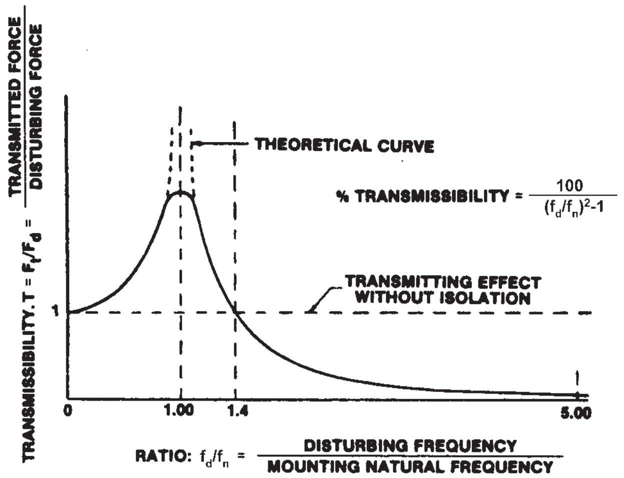


Figure 7-1 Transmissibility vs. Frequency Ratio

Note: This curve applies to steel spring isolators and other materials with very little damping.

Here are typical problems which can be solved with this calculator.

NATURAL FREQUENCY AND SPRING DEFLECTION — What natural frequency and spring deflection are required to isolate a disturbing frequency of 600 CPM with a transmissibility of 10%?

Answer: Vertical line from 600 on f_D scale intersects 10% transmissibility diagonal line at A. Horizontal line from A intersects f_N scale at 180 CPM and δ scale at 1.1" deflection.

SPRING CONSTANT — What spring constant is required to give a deflection of 1.1" for a load of 300 lbs.?

Answer: Horizontal line from 1.1" on δ scale intersects 300 lbs. weight diagonal line at B. Vertical line from B intersects K scale at 280 LBS. PER INCH.

SPRING DEFLECTION AND NATURAL FREQUENCY — What deflection and natural frequency are obtained with a 300 lb. load on a spring whose constant is 280 lbs. per inch?

Answer: Vertical line from 280 on K scale intersects 300 lbs. weight diagonal line at B. Horizontal line from B intersects δ scale at 1.1" deflection and f_N scale at 180 CPM.

TRANSMISSIBILITY — What is the transmissibility of a system having a natural frequency of 180 CPM and being disturbed by vibrations of 600 CPM frequency?

Answer: Vertical line from 600 on f_D scale, and horizontal line from 180 on f_N scale intersects at A on 10% transmissibility diagonal scale.

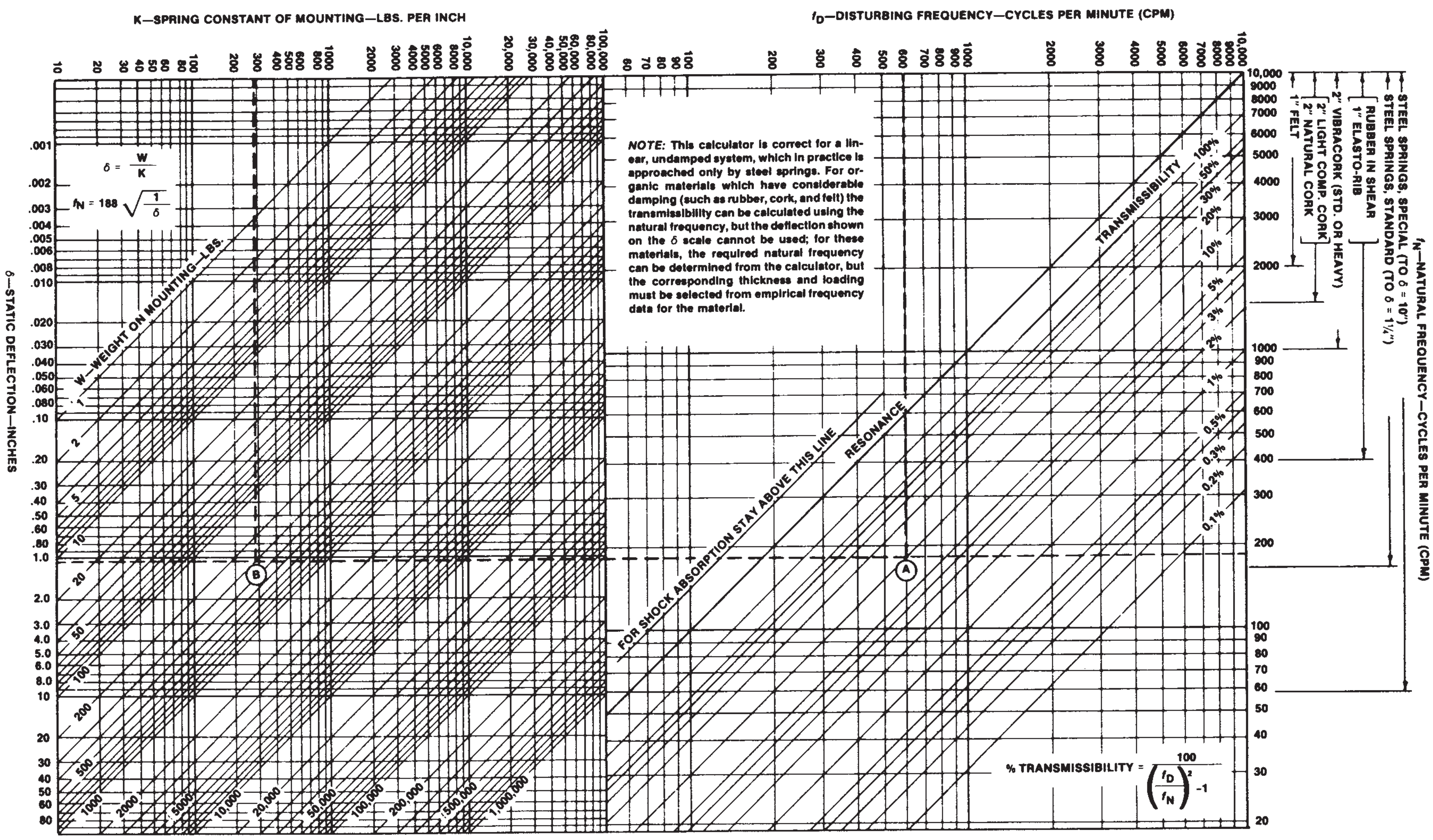


Figure 7-2 Calculator for Vibration Isolation

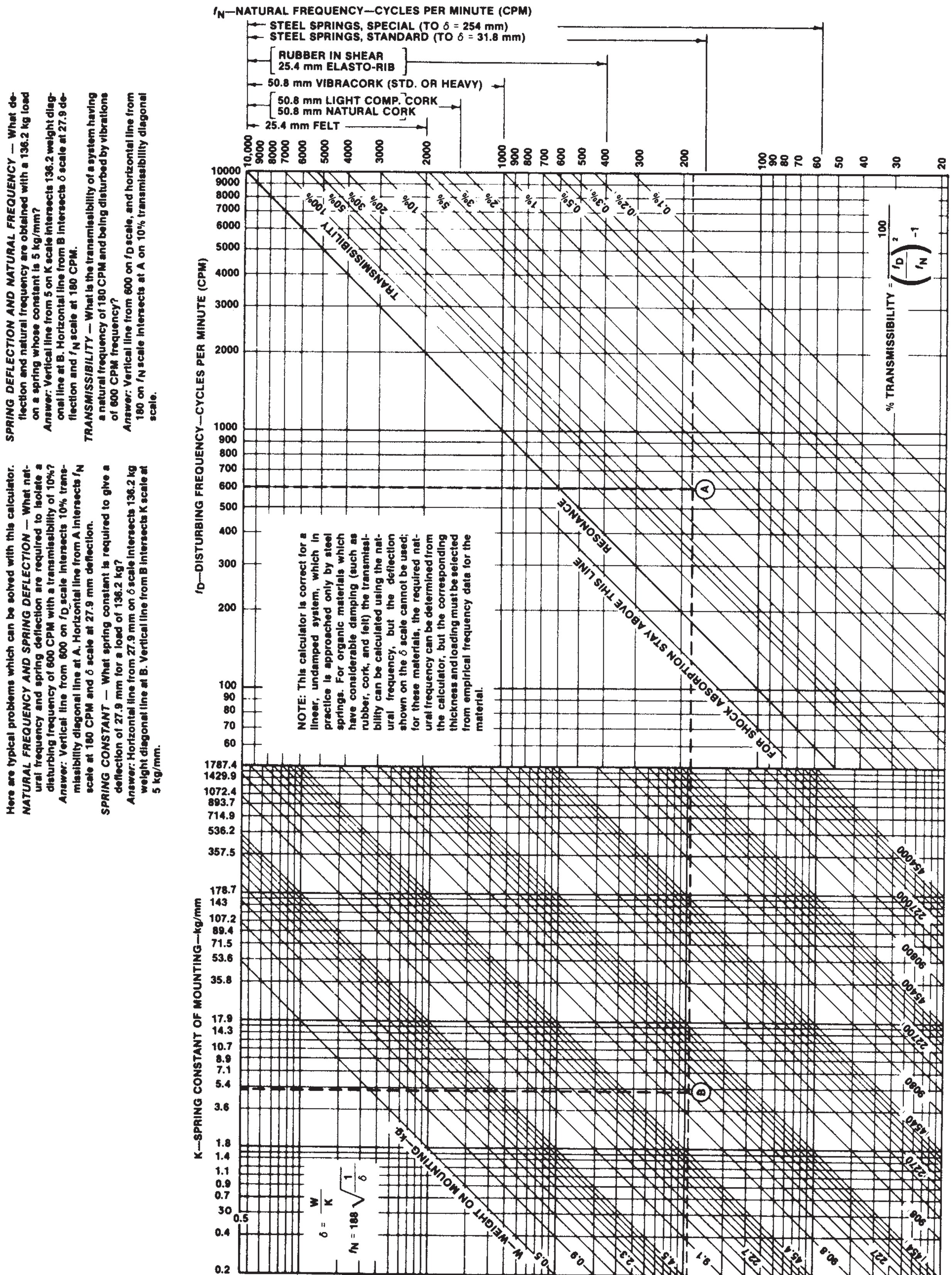


Figure 7-2(M) Calculator for Vibration Isolation

by reducing the operating speed, which is seldom practical—the transmitted force can be reduced only by minimizing the function $1/[(f_d/f_n)^2 - 1]$.

This can be accomplished only by increasing the frequency ratio (f_d/f_n). However, since the disturbing frequency (f_d) is fixed for any given machine and is a function of the rpm, it seldom can be changed. The only remaining variable is the mounting natural frequency (f_n). Reducing f_n by increasing the static deflection of the resilient mountings reduces the vibration transmission. This explains why the efficiency of machinery mountings increases as their resiliency and deflection increase.

Figure 7-1 shows the effect of varying frequency ratios on the transmissibility. Note that for f_d/f_n less than 2, the use of mountings actually increases the transmissibility above what would result if no isolation were used and the machine were bolted down solidly. In fact, if careless selection results in a mounting with the natural frequency equal to or nearly equal to the disturbing frequency, a very serious condition called "resonance" occurs. In Equation 7-4, the denominator of the transmissibility function becomes zero, and the transmitted force (f_t) theoretically becomes infinite. As the ratio f_d/f_n increases beyond 2, the resilient mountings reduce the transmitted force.

Figure 7-2 shows a chart that can be used to select the proper resilient mountings when the following job characteristics are known: weight per mounting, disturbing frequency, and design transmissibility. The chart shows the limitations of the various types of isolation materials, data that is particularly helpful in selecting the proper media.

TYPES OF VIBRATION AND SHOCK MOUNTINGS

Cork

Cork is the original vibration and noise isolation material and has been used for this purpose for at least 100 years. The most widely used form of cork today is compressed cork, which is made of pure granules of cork without any foreign binder and compressed and baked under pressure with accurately controlled density. Cork can be used directly under machines, but its widest applications are under concrete foundations (see Figure 7-3). It is not affected by oils, acids normally encountered, or temperatures between 0°F and 200°F (-17.8°C and 93.3°C) and does not rot under continuous cycles of moistening and dryness. However, it is attacked by strong alkaline solutions.

Cork under concrete foundations still giving good service after 20 years indicates that the material has a long, useful life when properly applied. Cork is fairly good as a low-frequency shock absorber, but its use as a vibration isolator is limited to frequencies above 1,800 cpm. Cork has good sound insulation characteristics. Because of the large amount of damping in cork, the natural frequency cannot be computed from the static deflection and must be determined in tests by vibrating the cork under different loads to find the resonance frequency, which establishes the natural frequency of the material. The limiting values for cork given in Figure 7-2 were determined in this manner.

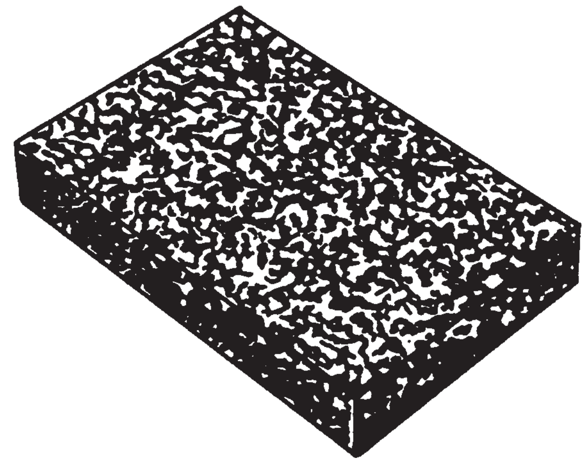


Figure 7-3 Typical Cork

Elastomers and Neoprene Rubber

Elastomers having very good sound insulation characteristics are acceptable for low-frequency shock absorption and are useful as vibration isolators for frequencies above 1,200 cpm. Static deflection typical to elastomers is from 0.05 inch to 0.15 inch (1 mm to 4 mm). Typical elastomer mountings are illustrated in Figure 7-4. The temperature range of natural rubber is 50°F to 150°F (10°C to 65.6°C), and that of neoprene is 0°F to 200°F (-17.8°C to 93.3°C).

Neoprene rubber is recommended for applications with continuous exposure to oil. Special elastomer compounds are available to meet conditions beyond those cited. Elastomers tend to lose resiliency as they age. The useful life of elastomer mountings is about seven years under nonimpact applications and about five years under impact applications, though they retain their sound insulation value for much longer. Individual molded elastomer mountings generally are economical only with light- and medium-weight machines, since heavier capacity mountings approach the cost of the more efficient steel spring isolators. Pad-type elastomer isolation has no such limitations.

Steel Spring Isolators

Steel spring isolators provide the most efficient method of isolating vibration and shock, approaching 100 percent effectiveness. The higher efficiency is due to the greater deflections they provide. Standard steel spring isolators, such as those shown in Figure 7-5, provide deflections up to 5 inches (127 mm) compared to about ½ inch (12.7 mm) maximum for rubber

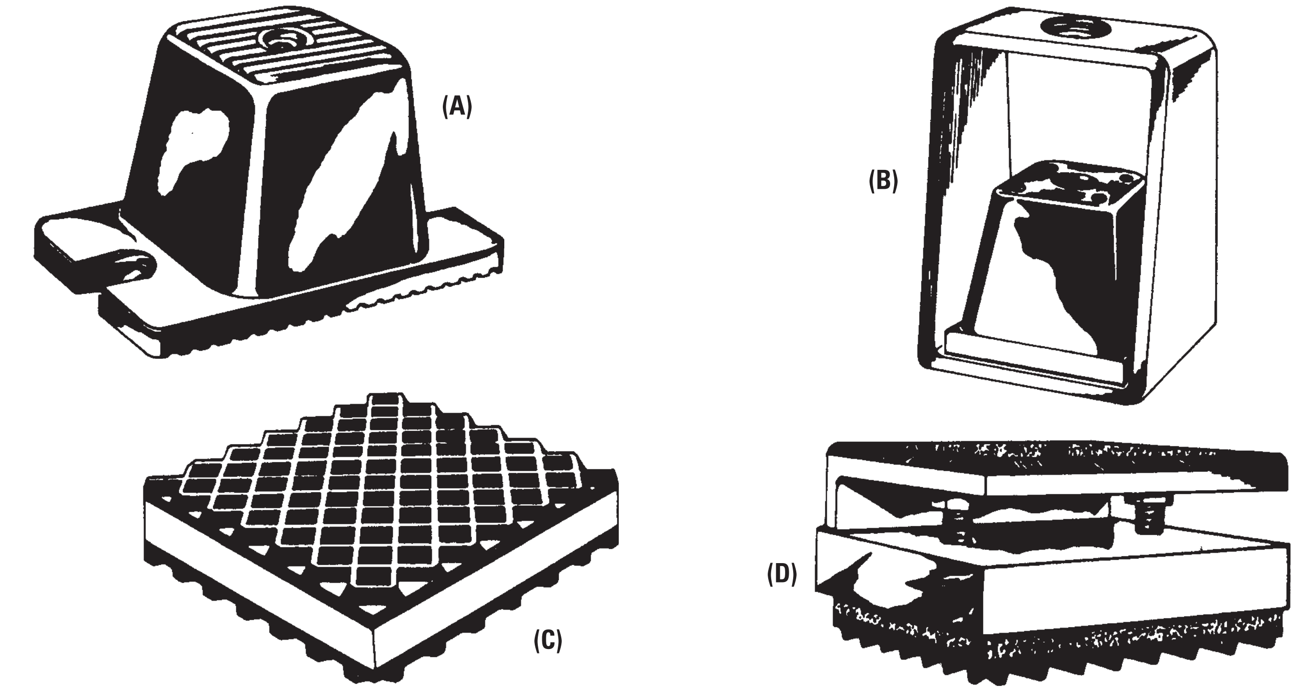


Figure 7-4 Typical Elastomer and Elastomer-cork Mountings: (A) Compression and Shear Elastomer Floor Mountings Provide Up to ½ in. (12.7 mm) Deflection; (B) Elastomer Hangers for Suspended Equipment and Piping; (C) Elastomer/Cork Mountings Combine Characteristics of These Two Materials, Provide Nonskid Surface, which Eliminates Bolting Machine Down; (D) Elastomer/Cork Mounting with Built-in Leveling Screw.

and other materials. Special steel spring isolators can provide deflections up to 10 inches (254 mm). Since the performance of steel springs follows the vibration control equations very closely, their performance can be predetermined very accurately, eliminating costly trial and error, which is sometimes necessary in other materials.

Steel spring isolators are available in static deflections from 0.75 inch to 6.0 in (19 to 152 mm), yielding natural frequencies from 4 Hz to 1.3 Hz with open steel spring isolators. (Restrained spring isolators have different capacity levels than open steel spring.) Most steel spring isolators are equipped with built-in leveling bolts, which eliminate the need for shims when installing machinery. The more rugged construction possible in steel spring isolators provides for a long life, usually equal to that of the machine itself. Since high-frequency noises sometimes tend to bypass steel springs, rubber sound isolation pads usually are used under spring isolators to stop such transmission into the floor on critical installations.

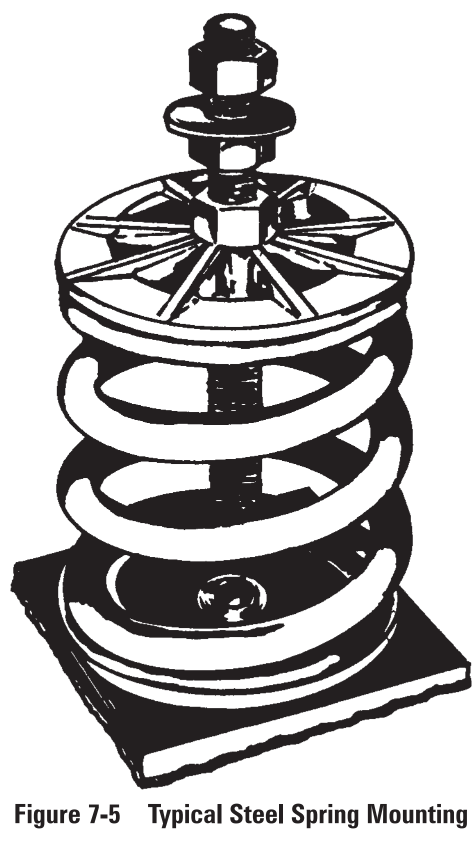


Figure 7-5 Typical Steel Spring Mounting

Table 7-1 tabulates the useful ranges of cork, rubber, and steel springs for different equipment speeds.

APPLICATIONS

Properly designed mountings now permit installation of the heaviest mechanical equipment in penthouses and on roofs directly over offices and sleeping areas. Such upper-floor installations permit certain operating economies and release valuable basement space for garaging automobiles. However, when heavy machinery is installed on upper floors, great care must be used to prevent vibration transmission, which often shows up many floors below when a wall, ceiling, or even a lighting fixture has the same natural frequency as the disturbing vibration. The result of such resonance vibration is a very annoying noise.

Efficient mountings permit lighter, more economical construction of new buildings and

Table 7-1 The Relative Effectiveness of Steel Springs, Rubber, and Cork in the Various Speed Ranges

Range	RPM	Springs	Rubber	Cork
Low	Up to 1200	Required	Not recommended	Unsuitable except for shock[a]
Medium	1200–1800	Excellent	Fair	Not recommended
High	Over 1800	Excellent	Good	Fair to good for critical jobs

[a] For noncritical installations only; otherwise, springs are recommended.

prevent difficulties when machinery is installed on concrete-filled, ribbed, metal deck floors. They also permit installation of heavy machinery in old buildings that were not originally designed to accommodate such equipment.

Vibration and noise transmission through piping is a serious problem. When compressors are installed on resilient mountings, provision should be made for flexibility in the discharge and intake piping to reduce vibration transmission. This can be accomplished either through the use of flexible metallic hose (which must be of adequate length and very carefully installed in strict accordance with the manufacturer's specifications) or by providing for flexibility in the piping itself. This often is accomplished by running the piping for a distance equal to 15 pipe diameters, both vertically and horizontally, before attaching the piping to the structure. Additional protection is provided by suspending the piping from the building on resilient mountings.

Effective vibration control for machines is usually quite inexpensive, seldom exceeding 3 percent of the equipment cost. In many cases, resilient mountings pay for themselves immediately by eliminating special machinery foundations or the need to bolt equipment to the floor. It is much cheaper to prevent vibration and structural noise transmission by installing mountings when the equipment is installed than it is to go back later and try to correct a faulty installation. Resilient machinery mountings should not be considered a panacea for noise transmission problems. They have a definite use in the overall solution of noise problems, and their intelligent use can produce gratifying results at low cost.

8 Grease Interceptors

The purpose of a grease interceptor is to intercept and collect grease from a commercial or institutional kitchen's wastewater passing through the device, thereby preventing deposition of pipe-clogging grease in the sanitary drainage system and ensuring a free flow at all times. Grease interceptors are installed in locations where liquid wastes contain grease. These devices are required to receive the drainage from fixtures and equipment with grease-laden wastes located in food preparation facilities such as restaurants, hotel kitchens, hospitals, school kitchens, bars, factory cafeterias, and clubs. Fixtures and equipment shall include pot sinks, soup kettles or similar devices, wok stations, floor drains or sinks into which kettles are drained, automatic hood wash units, pre-rinse sinks, and dishwashers without grinders. Residential dwellings seldom discharge grease in such quantities as to warrant a grease interceptor.

Historically, grease interceptors came in two types. The first type (covered by Plumbing and Drainage Institute [PDI] G101: *Testing and Rating Procedure for Grease Interceptors)* generally was referred to as a grease trap. These are prefabricated steel manufactured units, predominately located indoors at a centralized location in proximity to the fixtures served or at the discharging fixture point of use. They are relatively compact in size and utilize hydraulic flow action, internal baffling, air entrainment, and a difference in specific gravity between water and FOG (fats, oils, and grease) for the separation and retention of FOG from the fixture waste stream. These units now are classified as hydromechanical grease interceptors, or HGIs.

The second type generally was referred to as a grease interceptor. These are engineered, prefabricated, or field-formed concrete-constructed units that typically are located outside due to their large size and receive FOG discharge waste from all required fixtures within a given facility. These units essentially utilize gravity flow and retention time as the primary means of separating FOG from the facility waste stream prior to entering the municipal drainage system. These units now are classified as gravity grease interceptors, or GGIs.

Presently, all FOG retention and removal equipment is categorized as hydromechanical grease interceptors (HGIs), gravity grease interceptors (GGIs), grease removal devices (GRDs), and FOG disposal systems (FDSs). HGIs, GRDs, and FDSs are designed and tested in conformance with nationally recognized standards. The standard for the design and construction of gravity grease interceptors is IAPMO/ANSI Z1001: *Prefabricated Gravity Grease Interceptors,* published by the International Association of Plumbing and Mechanical Officials (IAPMO) and the American National Standards Institute (ANSI).

PRINCIPLE OF OPERATION

Most currently available grease interceptors operate on the principle of separation by flotation alone (gravity grease interceptor) or fluid mechanical forces in conjunction with flotation (hydromechanical grease interceptor).

The relationship in Equation 8-3, which identifies the principal of separation in a gravity grease interceptor, has been verified by a number of investigators for spheres and fluids of various types.

An examination of this equation shows that the vertical velocity of a grease globule in water depends on the density and diameter of the globule, the density and viscosity of the water, and the temperature of the water and FOG material. Specifically, the grease globule's vertical velocity is highly dependent on the globule's diameter, with small globules rising much more slowly than larger ones. Thus, the larger the globule, the faster the rate of separation.

The performance of the system depends on the difference between the specific gravity of the water and that of the grease. The closer the specific gravity of the grease is to that of the water, the slower the globules will rise. The greater the density difference between the grease and water, the faster the rate of separation.

Since the grease globules' rise rate is inversely proportional to the viscosity of the wastewater, the less viscous the carrier fluid, the faster the rate of separation and vice versa. Grease globules rise more slowly at lower temperatures and more rapidly at higher temperatures. Grease, especially when hot or warm, has less drag, is lighter than water, and does not mix well with water. The final velocity for a spherical particle, known as its floating velocity, may be calculated using Newton's equation for the frictional drag with the driving force, shown in Equation 8-1.

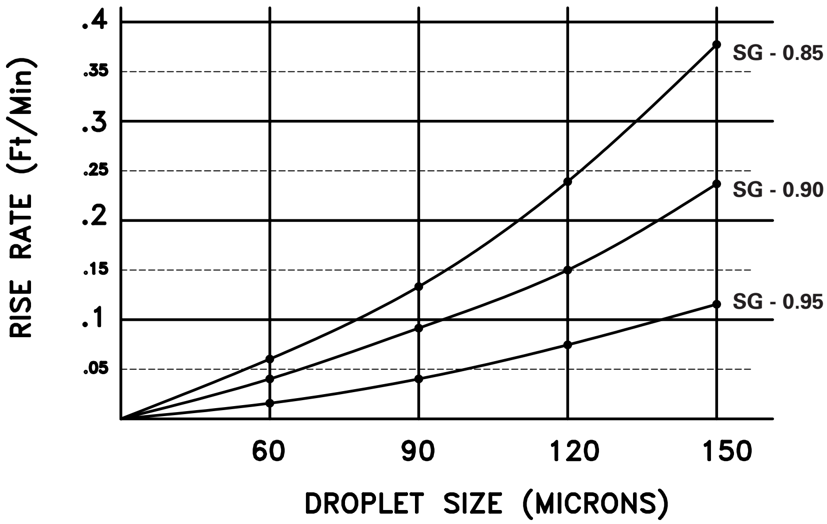


Figure 8-1 Rising and Settling Rates in Still Water

Equation 8-1

$$\frac{C_d\, A\, p\, v^2}{2} = (p_1 - p)\, g\, V$$

This yields the following mathematical relationship:

Equation 8-2

$$v = \sqrt{\frac{4}{3}\,\frac{g}{C_d}\,\frac{p_1 - p}{p} D}$$

where

C_d = Drag coefficient number
A = Projected area of the particle, $pD^2/4$ for a sphere
v = Relative velocity between the particle and the fluid
p = Mass density of the fluid
p_1 = Mass density of the particle
g = Gravitational constant, 32.2 ft/s/s
D = Diameter of the particle
V = Volume of the particle, $13pr^3$ for a sphere (r = radius of the particle)

Experimental values of the drag coefficient number have been correlated with the Reynolds number, a dimensionless term expressing the ratio of inertia and viscous forces. The expression for the Reynolds number, R = r v D/m, contains, in addition to the parameters defined above, the absolute viscosity. The drag coefficient has been demonstrated to equal 24/R (Stokes' law). When this value is substituted for C_d in Equation 8-2, the result is the following (Reynolds number < 1):

Equation 8-3

$$v = \frac{g\,(p_1 - p)\, D^2}{18m}$$

Note: Equation 8-2 applies to particles with diameters 0.4 inch (10 millimeters) or smaller and involving Reynolds numbers less than 1. For larger diameters, there is a transition region; thereafter, Newton's law applies.

The effect of shape irregularity is most pronounced as the floating velocity increases. Since grease particles that need to be removed in sanitary drainage systems have slow floating velocities, particle irregularity is of small importance.

Figure 8-1 shows the settling velocities of discrete spherical particles in still water. The heavy lines are for settling values computed using Equation 8-3 and for drag coefficients depending on the Reynolds number. Below a Reynolds number of 1, the settlement is according to Stokes' law. As noted above, as particle sizes and Reynolds numbers increase, there is first a transition stage, and then Newton's law applies. At water temperatures other than 50°F (10°C), the ratio of the settling velocities to those at 50°F (10°C) is approximately (T + 10)/60, where T is the water temperature in degrees Fahrenheit (degrees Celsius). Sand grains and heavy floc particles settle in the transition region; however, most of the particles significant in the investigation of water treatment settle well within the Stokes' law region. Particles with irregular shapes settle somewhat more slowly than spheres of equivalent volume. If the volumetric concentration of the suspended particles exceeds about 1 percent, the settling is hindered to the extent that the velocities are reduced by 10 percent or more.

Flotation is the opposite of settling insofar as the densities and particle sizes are known.

Retention Period

The retention period (P) is the theoretical time that the water is held in the grease interceptor. The volume of the tank for the required retention period can be computed as follows:

Equation 8-4

$$V = \frac{QP}{7.48}$$

As an example of the use of Equation 8-4, for a retention period (P) equal to two minutes and a flow rate (Q) of 35 gallons per minute (gpm), the tank volume is:

$$V = \frac{35 \times 2}{7.48} = 9.36 \text{ ft}^3$$

Retention periods should be based on peak flows. In International Standard (SI) units, the denominator in Equation 8-4 becomes approximately unity (1).

Flow-through Period

The actual time required for the water to flow through an existing tank is called the flow-through period. How closely this flow-through period approximates the retention period depends on the tank. A well-designed tank should provide a flow-through period of at least equal to the required retention period.

Factors Affecting Flotation in the Ideal Basin

When designing the ideal separation basin, four parameters dictate effective FOG removal from the water: grease/oil droplet size distribution, droplet velocity, grease/oil concentration, and the condition of the grease/oil as it enters the basin. Grease/oil can be present in five basic forms: oil-coated solids, free oil, mechanically emulsified, chemically emulsified, and dissolved. When designing the ideal basin, consider only free grease/oil.

The ideal separation basin is one that has no turbulence, short-circuiting, or eddies. The flow through the basin is laminar and distributed uniformly throughout the basin's cross-sectional area. The surface-loading rate is equal to the overflow rate. Free oil is separated due to the difference in specific gravity between the grease/oil globule and the water. Other factors affecting the design of an ideal basin are influent concentration and temperature.

It is important to evaluate and quantify a basin design both analytically and hydraulically. Figure 8-2 shows a cross-section of a basin chamber. The basin chamber is divided into two zones: liquid treatment zone and surface-loading area (grease/oil mat). The mat zone is that portion of the basin where the separated grease/oil is stored. L is the length of the chamber or basin, and D is the liquid depth or the maximum distance the design grease/oil globule must rise to reach the grease mat. Vh is the horizontal velocity of the water, and Vt is the vertical rise rate of the design grease/oil globule.

As noted, the separation of grease/oil from water by gravity differential can be expressed mathematically by the use of Stokes' law. Stokes' law can be used to calculate the rise rate of any grease/oil globule on the basis of its size and density and the density and viscosity of water. (See Figure 8-1 for the rise rate versus globule size at a fixed design temperature.)

The primary function of a grease interceptor is to separate free-floating FOG from the wastewater. Such a unit does not separate soluble substances, and it does not break emulsions. Therefore, it never should be specified for these purposes. However, like any settling facility, the interceptor presents an environment in which suspended solids are settled coincident with the separation of the FOG in the influent.

The ability of an interceptor to perform its primary function depends on a number of factors. These include the type and state of FOG in the waste flow, the characteristics of the carrier stream, and the design and size of the unit. Due to the reliance on gravity differential phenomena, there is a practical limitation to interceptor effectiveness. In terms of grease/oil globule size, an interceptor will be effective over a globule diameter range having a lower limit of 0.015 centimeter (150 microns).

Gravity separation permits the removal of particles that exhibit densities different from their carrier fluid. Separation is accomplished by detaining the flow stream for a sufficient time to permit particles to separate out. Separation, or retention, time (T) is the theoretical time that the water is held in the basin. A basin must be designed such that even if the grease/oil globule enters the chamber at the worst possible location (at the bottom), there will be enough time for the globule to rise the distance needed for capture. (See Figure 8-3.) If the grease/oil globule rate of rise (Vt)

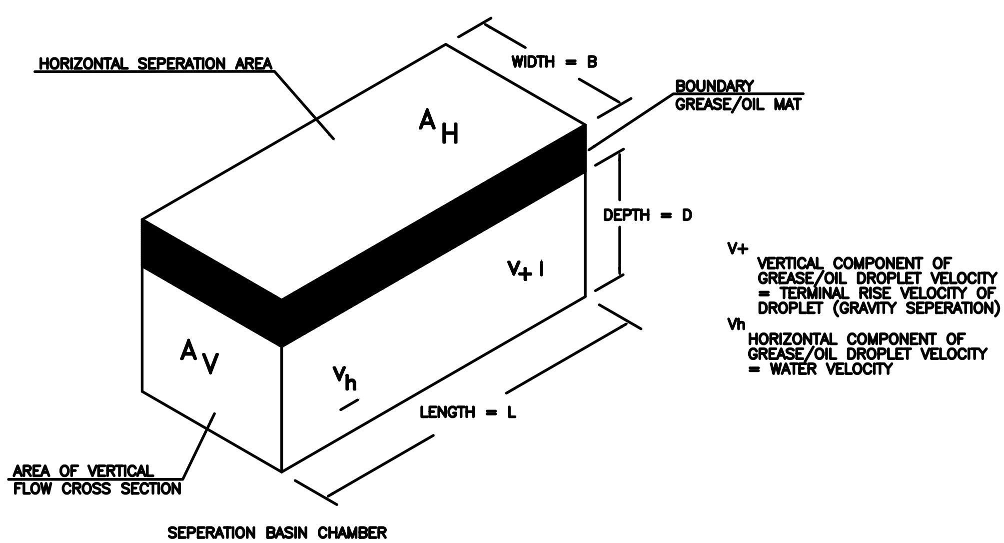


Figure 8-2 Cross-section of a Grease Interceptor Chamber

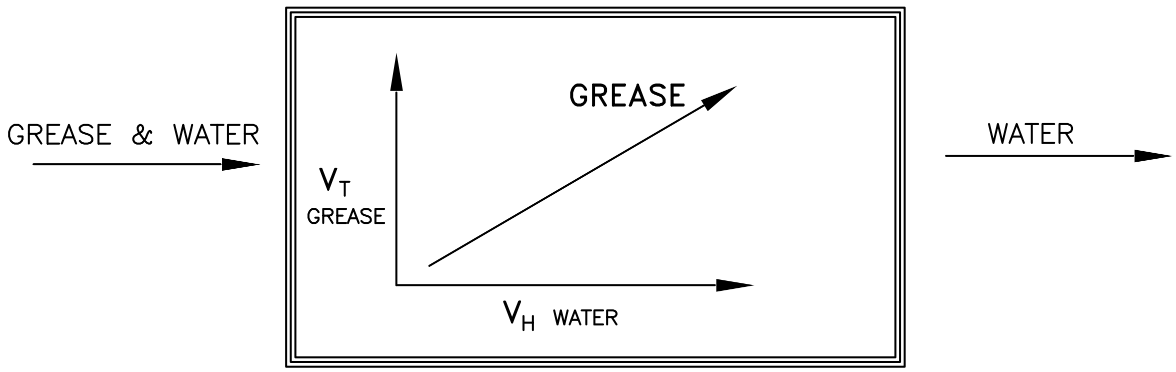


Figure 8-3 Trajectory Diagram

exceeds the retention time required for separation, the basin will experience pass-through or short-circuiting. Retention time can be expressed as:

Equation 8-5

$$V = QT$$

where
V = Volume of basin
Q = Design flow
T = Retention time

As previously noted, particles that rise to the surface of a liquid are said to possess rise rates, while particles that settle to the bottom exhibit settling rates. Both types obey Stokes' Law, which establishes the theoretical terminal velocities of the rising and/or settling particles. This basic principle governing the separation of oil from water by gravity differential may be expressed mathematically. With a value of 0.015 centimeter for the diameter (D) of the globule, the rate of rise of oil globules in wastewater may be expressed in feet per minute as:

Equation 8-6

$$Vt = \frac{0.0241\ (Sw - So)}{u}$$

where
Vt = Rate of rise of oil globule (0.015 centimeter in diameter) in wastewater, feet per minute
Sw = Specific gravity of wastewater at design temperature of flow
So = Specific gravity of oil in wastewater at design temperature of flow
u = Absolute viscosity of wastewater at design temperature, poises

This is an expression of Stokes' law for terminal velocity of spheres in a liquid medium that is applicable to the rate of rise of oil globules or the rate of settling of suspended solids.

An examination of this law discloses:

- The larger the particles, the faster the rate of separation.
- The greater the density differences between the particle and carrier fluid, the faster the rate of separation.
- The less viscous the carrier fluid, the faster the rate of separation and vice versa.

GREASE INTERCEPTOR DESIGN EXAMPLE

The following example illustrates the application of the above equations for the design of a grease interceptor.

Data

Without additional data describing the distribution of oil droplets and their diameters within a representative wastewater sample, it is not possible to quantitatively predict the effect that increased interceptor size or reduced flow and subsequent increased retention time within the grease interceptor will have on the effluent concentration of the interceptor. However, experimental research on oil droplet rise time (see Table 8-1) illustrates the effect that increased interceptor size or reduced flow and subsequent increased retention time within the grease interceptor will have on oil droplet removal.

An examination of Table 8-1 enables the designer to at least be able to predict the effect of increased interceptor size or reduced flow and subsequent increased retention time within the grease interceptor on oil droplet removal.

If you follow this logic, you can improve the grease interceptor by increasing the interceptor volume or reducing flow and subsequently lowering horizontal velocity and increasing retention time within the grease interceptor.

Other data is as follows:

- Specific gravity of grease/oil in wastewater: 0.90 (average)
- Temperature of wastewater and oil mixture: 68°F (average)
- Rate of rise of oil globules in wastewater:

Table 8-1 Droplet Rise Time

Travel Time for 3-inch Distance at 688°F (hr:min:sec)	
Droplet Diameter (microns)	**Oil (rise time) SG 0.85**
300	0:00:12
150	0:00:42
125	0:01:00
90	0:01:54
60	0:04:12
50	0:06:18
40	0:09:36
30	0:17:24
20	0:38:46
15	1:08:54
10	2:35:02
5	10:02:09
1	258:23:53
Droplet Diameter (microns)	**Oil (rise time) SG 0.90**
300	0:00:15
150	0:01:03
125	0:01:27
90	0:02:54
60	0:06:36
50	0:09:18
40	0:14:24
30	0:25:48
20	0:58:08
15	1:43:22
10	3:52:33
5	15:30:14
1	387:35:49

$$Vt = \frac{0.0241\ (Sw - So)}{u}$$

- Dimensions of typical 20-gpm capacity grease interceptor:

  Capacity: 21.33 gallons

  Dimensions: 22 inches long, 14 inches wide, 20 inches high

  Fluid level: 16 inches

  Flow rate: 20 gpm

  Inlet/outlet: 2 inches

- Grease interceptors are to operate when completely full and when the interceptor is in a horizontal position.
- Inlet and outlet pipes are running full, and the interceptor is fully charged.
- Grease/oil globules must rise a minimum distance of 3 inches from a point at the bottom of the inlet head of the interceptor to a point directly below the interceptor effluent outlet.

Solution

1. Determine the rate of rise of oil globules: 150 micron = 0:01:03
2. Determine the wastewater flow rate through a 20-gpm capacity grease interceptor:

   Vh = L/T = 1.83 ft^2/1.03 min = 1.776 ft/min

   Wetted cross-sectional area of the separation basin: W × H = 14 in. × 16 in. = 224 $in.^2 \times 6.944 \times 10^{-3}$ = 1.55 ft^2

   Wastewater flow rate: 1.55 ft^2 × 1.776 ft/min = 2.76 ft^3/min × 7.48 = 20.66 gal/min

The example proves the critical elements in designing the ideal basin. Grease/oil droplet size and velocity determine the minimum outlet elevation needed to capture the targeted grease/oil globule. This also establishes retention time as a key element in the design of a basin.

The hydraulic environment of the separation chamber of the grease interceptor induces the separation of grease/oil and the deposition of solids. Stokes' law governs the rise and fall rates of an oil droplet or solid particle in the fluid stream.

The principles of flotation discussed above are applicable strictly to particles that are separate and distinct. If the wastewater mixture contains variously sized grease/oil droplets and solid particles distributed throughout the mixture, each droplet will (in accordance with Stokes' law) rise toward the surface or fall to the bottom at a rate depending on its own diameter.

In strong concentrations of very small particles, as in turbid waters, hindered flotation takes place. This condition means that the faster-rising particles collide with the slower-rising particles with more or less agglomeration due to adhesion. The resulting larger particles float still faster. These coalesce into even larger droplets with an even higher rate of rise. The odds of such a collision depend on the droplet size distribution and the quantity of droplets in the mixture. This condition is particularly noticeable where the suspended particles are highly flocculent (i.e., composed of masses of very finely divided material). Therefore, a tank that is deep enough to permit agglomeration will have a blanket (or mass) of flocculent material receiving the suspended solids from the material rising from below or from the currents passing through it. Thus, the tank will lose masses of the agglomerated solids to the storage space above.

While varying flotation rates among the particles are probably the most important factor in agglomeration, the varying liquid velocities throughout the tank have a similar effect, causing fast-moving particles to collide with slower-moving particles. Since flocculation can be assumed to continue throughout the entire flotation period, the amount of flocculation depends on the detention period. Accordingly, with a given overflow rate, a tank of considerable depth should be more efficient than a shallow unit. On the other hand, a decrease in the overflow rate might have the same effect. A flotation test might determine the point of agglomeration for a known water sample.

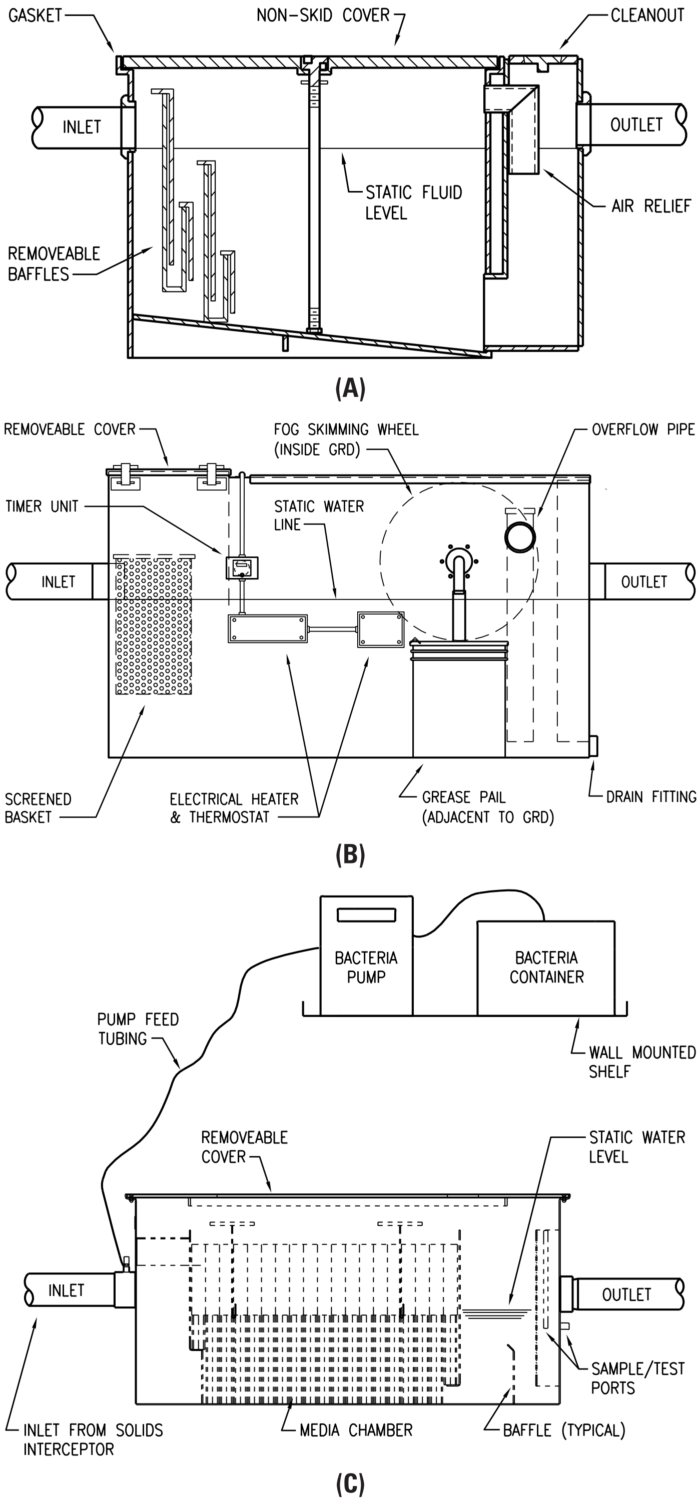


Figure 8-4 (A) Hydromechanical Grease Interceptor (B) Timer-controlled Grease Removal Device (C) FOG Disposal System

PRACTICAL DESIGN

While acquaintance with the theory of flotation is important to the engineer, several factors have prevented the direct application of this theory to the design of grease interceptors. Some turbulence is unavoidable at the inlet end of the tank. This effect is greatly reduced by good inlet design (including baffling) that distributes the influent as uniformly as practicable over the cross-section of the tank. There is also some interference with the streamline flow at the outlet, but this condition is less pronounced than the inlet turbulence and is reduced only by using overflow weirs or baffles. Density currents are caused by differences in the temperature, the density of the incoming wastewater, and the interceptor's contents. Incoming water has more suspended matter than the partially clarified contents of the tank. Therefore, there is a tendency for the influent to form a relatively rapid current along the bottom of the tank, which even may extend to the outlet. This condition is known as short-circuiting and occurs even with a uniform collection at the outlet end.

Flocculation of suspended solids has been mentioned. Its effects, however, are difficult to predict.

In general, the engineer depends on experience as well as the code requirements of the various local health departments for the preferred retention and overflow rates. Length, width, depth, and inlet and outlet details enter into the design of a grease interceptor. Of these items, depth already has been discussed as having some effect on the tank's efficiency. A smaller depth gives a shorter path for the rising particle to settle, which gives the basin a greater efficiency as the surface-loading rates match the overflow rates based on a given retention time. The tank's inlets and outlets require careful consideration by the designer. The ideal inlet reduces the inlet velocity to prevent the pronounced currents toward the outlet, distributes the inlet water as uniformly as practical over the cross-section of the tank, and mixes the inlet water with the water already in the tank to prevent the entering water from short-circuiting toward the outlet.

HYDROMECHANICAL GREASE INTERCEPTORS

For over a hundred years, grease interceptors have been used in plumbing drainage systems to prevent grease accumulations from clogging interconnecting sanitary piping and sewer lines. However, it wasn't until 1949 that a comprehensive standard for the basic testing and rating requirements for hydromechanical grease interceptors was developed. This standard is known as PDI G101. It has been widely recognized and is referenced in most plumbing codes, replicated in American Society of Mechanical Engineer (ASME) A112.14.3: *Grease Interceptors,* referred to in manufacturers' literature information, and included in the basic testing and rating requirement of Military Specification MIL-T-18361. A specifying engineer or purchaser of a hydromechanical grease interceptor can be assured that the interceptor will perform as intended when it has been tested, rated, and certified in conformance with PDI G101, ASME A112.14.3, and ASME A112.14.4: *Grease Removal Devices*.

Conventional manually operated hydromechanical interceptors are extremely popular and generally available up to 100-gpm (6.31-liters-per-second [L/s]) rated flow capacity for most applications. (See Figure 8-4(A).) For flow rates above 100 gpm (6.31 L/s), large capacity units up to 500 gpm (31.5 L/s) commonly are used. The internal designs of these devices are similar. The inlet baffles, usually available in various styles and arrangements, act to ensure at least a 90 percent efficiency of grease removal through the HGI, per PDI G101 standard testing requirements for units of 100 gpm and less. Care should be taken to avoid long runs of pipe between the source and the interceptor to avoid FOG accumulation and mechanical emulsification prior to entering the interceptor.

Grease removal from manually operated hydromechanical grease interceptors typically is performed by opening the access cover and manually skimming the accumulated grease from the interior water surface (along with the removal of a perforated filter screen for cleaning if so equipped).

Semiautomatic Units

These units are typically a hydromechanical interceptor design, with FOG accumulation on the surface of the water inside the interceptor. However, these types of HGIs are not used as widely as they once were due in part to advances in grease retention equipment technology. In addition, the FOG removal process involves the running of hot water through the interceptor to raise the water level and force the FOG into the draw-off recovery cone or pyramid and then out through the attached draw-off hose to a FOG disposal container until the running water becomes clear. As compared to the operational qualities of the interceptor types and technologies currently available, this process is wasteful of potable water at a time when water conservation should be of legitimate concern to the plumbing engineer, especially in certain areas of the country where the cost of water may be at a premium for a facility owner.

GREASE REMOVAL DEVICES

Grease removal devices are typically hydromechanical interceptors that incorporate automatic, electrically powered skimming devices within their design. The two basic variations of this type of interceptor are timer-controlled units and sensor-controlled units.

Timer-controlled Units

In such units, FOG is separated by gravity flotation in the conventional manner, at which point the accumulated FOG is skimmed from the surface of the water in the interceptor by a powered skimming device and activated by a timer on a time- or event-controlled basis. (See Figure 8-4(B).)

The skimmed FOG essentially is scraped or wiped from the skimmer surface and directed into a trough, from which it drains through a small pipe from the interceptor into a disposal container located adjacent to the interceptor. Most GRDs are fitted with an electric immersion heater to elevate the temperature in the interceptor to maintain the contained FOG in a liquid state for skimming purposes.

A variation of this type of interceptor utilizes a FOG removal pump that is positioned in a tray inside the interceptor and controlled from a wall unit that contains a timer device. The pump is attached to a small translucent tank with a drain outlet that is located adjacent to the interceptor.

To operate these units, a timer is set to turn on the skimmer or FOG removal pump within a selected time period. In a short time, the accumulated FOG is drained into the adjacent container, to be disposed of in a proper manner.

Sensor-controlled Units

These interceptors employ computer-controlled sensors or probes, which sense the presence of FOG and automatically initiate the draw-off cycle at a predetermined percentage level of the interceptor's rated capacity. FOG then is drawn from the top of the FOG layer in the interceptor. The draw-off cycle continues until the presence of water is detected by the sensor, which stops the cycle to ensure that only water-free FOG is recovered. If required, an immersion heater is activated automatically at the onset of the draw-off cycle to liquefy FOG in the interceptor. In addition, if either the unit's grease collection reservoir (where the recovered grease is stored pending removal) or the interceptor itself is near capacity with potential overloading sensed, warning measures and unit shutdown are activated automatically.

When GRDs are considered for installation, the manufacturer should be consulted regarding electrical, service, and maintenance requirements. The plumbing engineer must coordinate these requirements with the appropriate trades to ensure a proper installation. Furthermore, owing to these requirements, it is essential that those responsible for operating GRDs be trained thoroughly in their operation.

FOG DISPOSAL SYSTEMS

A FOG disposal system is very similar to a hydromechanical interceptor in its operation. However, in addition to reducing FOG in effluent by separation, it automatically reduces FOG in effluent by mass and volume reduction, without the use of internal mechanical devices or manual FOG removal. This system is specifically engineered, and one type is configured to contain microorganisms that are used to oxidize FOG within the interceptor to permanently convert the FOG material into the by-products of digestion, a process otherwise referred to as bioremediation. It should be noted that this is also the same process used by municipal wastewater treatment plants. Other FOG disposal systems utilize thermal or chemical methods of oxidation.

Figure 8-4(A) is an example of a bioremediation type of interceptor. The interceptor is divided into two main chambers, separated by baffles at the inlet and outlet sides. The baffle located at the inlet side of the interceptor acts to distribute the inflow evenly across the horizontal dimension of the interceptor. However, unlike conventional HGIs, a media chamber is its main compartment, which contains a coalescing media that is engineered to cause FOG to rise along the vertical surfaces of the media structure where it comes into contact with microorganisms inhabiting a biofilm attached to the media. A wall-mounted shelf located above the interceptor supports a metering pump, timer, controls, and a bottle filled with a bacteria culture provided by the system manufacturer.

As the FOG material collects in the biofilm, bacteria from the culture bottle (injected by the metering pump) break the bonds between fatty acids and glycerol and then the bonds between the hydrogen, carbon, and oxygen atoms of both, thereby reducing FOG volume. Drainage continues through the media chamber around the outlet baffle, where it then is discharged to the sanitary system.

Though FOG disposal systems significantly reduce the need for manual FOG removal or the handling of mechanically removed FOG materials, the need for monitoring effluent quality, routine maintenance to remove undigested materials, and inspections to ensure all components are clean and functioning properly are required and should be performed on a regular basis.

Furthermore, it is essential that the plumbing engineer coordinate all electrical and equipment space allocation requirements with the appropriate trades to allow for proper installation and functioning of a FOG disposal system.

GRAVITY GREASE INTERCEPTORS

Gravity grease interceptors commonly are made of 4-inch (101.6-mm) minimum thickness concrete walls, with interior concrete barriers that act to sectionalize the interior into multiple chambers that dampen flow and retain FOG by flotation. Figure 8-5(A) shows a typical installation. However, standards allow other materials such as fiberglass, plastic, and protected steel. Generally, these units are used outside buildings as inground installations rather than as inside systems adjacent to or within kitchen areas. These units

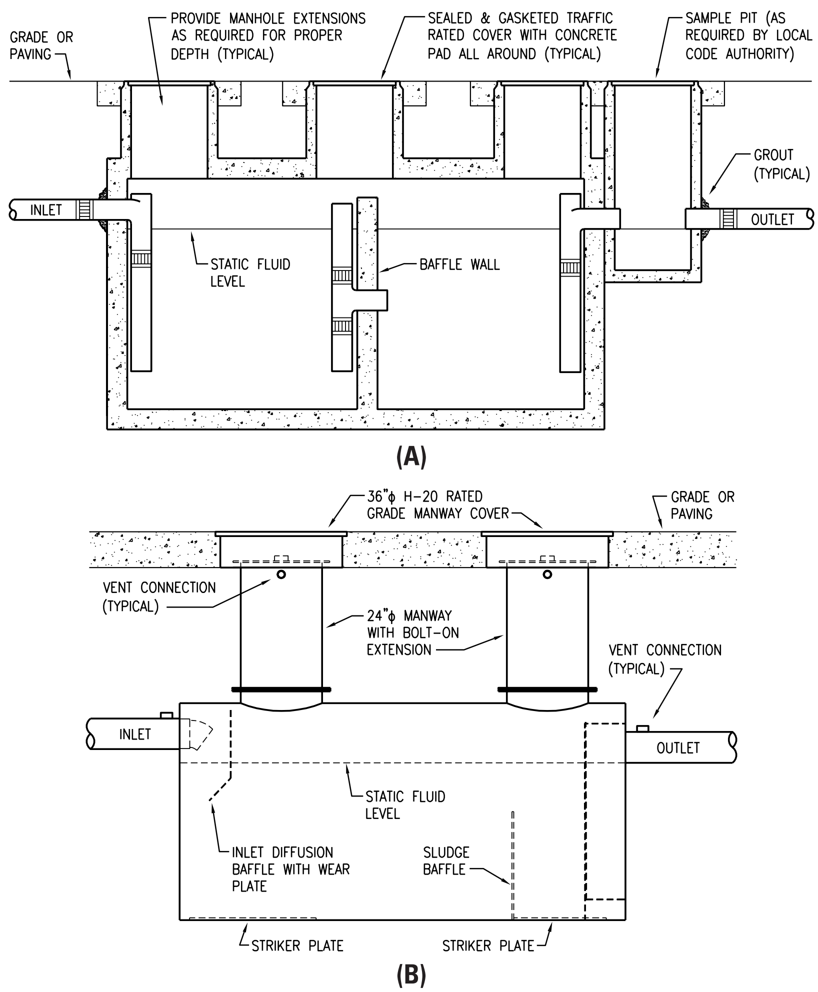


Figure 8-5 (A) Gravity Grease Interceptor (B) Passive, Tank-type Grease Interceptor

generally do not include the draw-off or flow-control arrangements common to hydromechanical units. The unit should be installed as close to the source of FOG as possible. If this cannot be achieved due to field conditions or other site constraints, a heat trace system can be installed along the drain piping that is routed to the inlet side of the GGI to help keep the temperature of the FOG-laden waste from solidifying before it enters the interceptor. Increasing the slope of the drain piping to the interceptor also can be considered in lieu of heat tracing where allowable by local codes and authorities having jurisdiction.

If a unit is located in a traffic area, care must be taken to ensure that the access covers are capable of withstanding any possible traffic load. It is also important that the interceptor be located in such a way as to allow an easy cleanout procedure.

Prefabricated GGIs also tend to be internally and externally configured with unique, pre-installed features designed to meet the local jurisdictional requirements of any given project location. The plumbing engineer must verify the local jurisdictional requirements to which these units must conform to ensure proper unit selection.

Field-formed Concrete Units

Field-formed concrete gravity grease interceptors are basically identical to the prefabricated units as described above, with the exception that they usually are constructed at the project site. Though likely more expensive to install than a prefabricated unit, one reason for its installation could be unique project site constraints. For example, a GGI may need to be installed in a very tight area, too close to existing property lines or adjacent structures to allow hoisting equipment the necessary access to an excavated area that otherwise would be sufficient for a standard prefabricated GGI installation.

Following is a list of recommended installation provisions for prefabricated and field-formed GGIs located outside a building.

- The unit should be installed as close to the source of FOG as possible. If this cannot be achieved due to field conditions or other site constraints, a heat trace system can be installed along the drain piping that is routed to the inlet side of the GGI.
- The influent should enter the unit at a location below the normal water level or near the bottom of the GGI to keep the surface as still as possible.
- The inlet and the outlet of the unit should be provided with cleanouts for unplugging both the sewers and the dip pipes.
- The effluent should be drawn from near the bottom of the unit, via a dip pipe, to remove as much floatable grease and solids as possible.
- A large manhole, or removable slab, should be provided for access to all chambers of the grease interceptor for complete cleaning of both the floatable and the settleable solids.
- The top, or cover, should be gas-tight and capable of withstanding traffic weight.
- A difference in elevation between the inlet and the outlet of 3 inches to 6 inches (76.2 mm to 152.4 mm) should be provided to ensure a flow through the grease interceptor during surge conditions without the waste backing up in the inlet sewer. As the grease begins to accumulate, the top of the grease layer will begin to rise above the normal water level at a distance of approximately 1 inch (25.4 mm) for each 9 inches (228.6 mm) of grease thickness.
- After installation, testing of the GGI for leakage should be a specification requirement prior to final acceptance.

In addition to concrete GGIs, gravity grease interceptors in the form of prefabricated round, cylindrical protected steel tanks are also available. (See Figure 8-5(B).) These units often are referred to as passive grease interceptors, but they fall into the same category as gravity grease interceptors because they operate in virtually the same manner. Interceptors of this type are available with single and multiple chambers (depending on local jurisdictional requirements), with internal baffles, vent connections, and manhole extensions as required to allow for proper operation. They also are manufactured in single- and double-wall construction and can be incorporated with steam or electric heating systems to help facilitate FOG separation and extraction from the unit.

Protected steel tank GGIs are built to Underwriters Laboratories (UL) specifications for structural and corrosion protection for both the interior and the exterior of the interceptor. The exterior corrosion protection is a two-part, polyurethane, high-build coating with interior coating options of polyurethane, epoxy, or proprietary coatings (depending on influent wastewater temperature, wastewater characteristics, etc.). When protected steel tank GGIs are considered for installation, the manufacturer should be consulted regarding venting and hold-down requirements for buoyancy considerations.

EQUIPMENT SUMMARY

It is important for the plumbing engineer to understand that the topic of FOG retention and removal is a continuing and ever-changing evolution of both technology and the latest equipment available at the time. Types of interceptors currently on the market (such as the FOG disposal system and protected steel tank GGIs mentioned) may be proprietary in nature and may include features specifically inherent to one particular manufacturer. The purpose of the equipment descriptions contained in this chapter is to expose the reader to the basic types of FOG treatment equipment presently available as they currently are defined and listed within model codes. The text is not intended to imply that any one particular type of device is superior to another for a given application. That being the case, the plumbing engineer must exercise care when proposing to specify FOG treatment equipment that could be considered proprietary, in conjunction with a government-controlled or publicly funded project that may prohibit the specifying of such equipment due to a lack of competition by other manufacturers.

APPLICATIONS

Most local administrative authorities require in their jurisdictions' codes that spent water from food service fixtures and equipment producing large amounts of FOG discharge into an approved interceptor before entering the municipality's sanitary drainage system. These requirements (generally code and pretreatment regulations, with pretreatment coordinators having the final word) can include multi-compartment pot sinks, pre-rinse sinks, kettles, and wok stations, as well as area floor drains, grease-extracting hoods installed over frying or other grease-producing equipment, and dishwashing equipment.

If floor drains are connected to the interceptor, the engineer must give special consideration to other adjacent fixtures that may be connected to a common line with a floor drain upstream of the interceptor. Unless flow control devices are used on high-volume fixtures or multiple fixtures flowing upstream of the floor drain connection, flooding of the floor drain can occur. A common misapplication is the installation of a flow control device at the inlet to the interceptor that may restrict high-volume fixture discharge into the interceptor, but floods the floor drain(s) on the common branch. Floor drains connected to an interceptor require a recessed (beneath the floor) interceptor design.

An acceptable design concept is to locate the interceptor as close to the grease-producing fixtures as possible. Under-the-counter or above-slab interceptor installations are often possible adjacent to the grease-producing fixtures. This type of arrangement often avoids the individual venting of the fixtures, with a common vent and trap downstream of the grease interceptor serving to vent the fixtures and the grease interceptor together. Therefore, a p-trap is not required on the fixture outlet. However, provided this particular arrangement is allowed by governing codes and local jurisdictions, special attention should be paid to air inlet sources for the air-injected flow control if no p-trap is attached to the fixture outlet to avoid circuiting the building vent to the fixture.

The location of a grease interceptor far from the fixtures it serves allows the grease to cool and solidify in the waste lines upstream of the grease interceptor, causing clogging conditions or requiring more frequent rodding-out of the waste lines. However, a heat trace system can be installed along the main waste line that is routed to the inlet side of the interceptor to help keep the temperature of the FOG-laden waste from solidifying before it enters the interceptor. Long horizontal and vertical runs also can cause mechanical emulsification of entrained FOG such that it is not easily separated.

Some practical considerations are also important if an interceptor is to be located near the fixtures it serves. If the interceptor is an under-the-counter, above-the-slab device, the engineer should leave enough space above the cover to allow the complete cleaning and FOG removal from the unit.

Some ordinances also require that interceptors not be installed where the surrounding temperatures under normal operating conditions are less than 40°F (4.4°C).

Some administrative authorities prohibit the discharge of food waste disposers through HGIs and GRDs because of the clogging effect of ground-up particles. Other jurisdictions allow this setup, provided that a solids interceptor or strainer basket is installed upstream of these devices to remove any food particulates prior to entering the interceptor. It is recommended that food waste disposers be connected to HGIs and GRDs (in conjunction with a solids strainer) when allowed by the authority having jurisdiction due to the fact that disposer waste discharge is a prime carrier of FOG-laden material.

The same situation is similar with respect to dishwashers. Some administrative authorities prohibit the discharge of dishwasher waste to HGIs and GRDs, while other jurisdictions allow it, provided that the dishwashers are without pre-rinse sinks. It is recommended that dishwashers not be connected to HGIs or GRDs. Although the high discharge waste temperature from a dishwasher may be beneficial to the FOG separation process by helping to maintain the FOG in a liquid state, the detergents used in dishwashing equipment can enter these types of devices and inhibit their ability to separate FOG altogether. This allows FOG to pass through the device where it eventually can revert to its original state and cause problems within the municipal sanitary system.

FLOW CONTROL

Flow control devices are best located at the outlet of the fixtures they serve. However, a few precautions are necessary for the proper application of flow control devices. The engineer should be sure that enough vertical space is available if the flow control device is an angle pattern with a horizontal inlet and a vertical outlet. A common difficulty encountered is the lack of available height for an above-slab grease interceptor adjacent to the fixture served when the vertical height needed for the drain outlet elbow, pipe slope on the waste arm from the fixture, vertical outlet flow control fitting, and height from the grease interceptor inlet to the floor are all compensated.

The air intake (vent) for the flow control fitting may terminate under the sink as high as possible to prevent overflow or terminate in a return bend at the same height on the outside of the building. When the fixture is individually trapped and back-vented, air intake may intersect the vent stack. All installation recommendations are subject to the approval of the code authority. The air intake allows air to be drawn into the flow control downstream of the orifice baffle, thereby promoting air-entrained flow at the interceptor's rated capacity. The air entrained through the flow control also may aid the flotation process by providing a lifting effect for the rising grease. Flow control fittings are not common for floor drains or for fixtures that would flood if their waste discharge was restricted (such as a grease-extracting hood during its flushing cycle). It is particularly important to install the grease interceptor near the grease-discharging fixture when flow control devices are used because of the lower flow in the waste line downstream of the flow control device. Such flow may not be enough to ensure self-cleaning velocities of 3 feet per second (fps) (0.9 meters per second [m/s]).

GUIDELINES FOR SIZING

The following recommended sizing procedure for grease interceptors may be used by the engineer as a general guideline for the selection of these units. The engineer should always consult the local administrative authorities regarding variations in the allowable drain-down times acceptable under the approved codes. Calculation details and explanations of the decision-making processes have been included in full in the examples as an aid to the engineer using these guidelines in specific situations.

Example 8-1

Assume an HGI or a GRD for a single-fixture installation with no flow control. Size the grease interceptor for a three-compartment pot (scullery) sink, with each compartment 18 × 24 × 12 inches (457.2 mm × 609.6 mm × 304.8 mm)

1. Determine the sink volume.

   Cubic contents of one sink compartment = $18 \times 24 \times 12 = 5{,}184$ in.^{3}

   Cubic contents of the three sink compartments = $3 \times 5{,}184 = 15{,}552$ in.^{3}

   Contents expressed in gallons = 15,552 in.$^3/231 = 67.3$ gallons

   [Contents expressed in liters = $457.2 \times 609.6 \times 304.8 = 84.95 \times 10^6$ mm^3 = 8.49×10^4 mL

   $3 \times 8.49 \times 10^4 = 25.44 \times 10^4$ mL = 254.4 L]

2. Add the total potable water supply that could be discharged independent of a fixture calculated above, including manufacturer-rated appliances such as water wash exhaust hoods and disposers (if allowed to discharge to the interceptor).

3. Determine the fixture load. A sink (or fixture) seldom is filled to the brim, and dishes, pots, or pans displace approximately 25 percent of the water. Therefore, 75 percent of the actual fixture capacity should be used to establish the drainage load.

   0.75×67.3 gal = 50.8 gal

   [$0.75 \times 254.4 = 190.8$ L]

4. Calculate the flow rate based on drain time, typically one minute or two minutes. The flow rates are calculated using the following equation:

   $$\frac{\text{Drainage load, in gallons (L)}}{\text{Drainage load, in minutes (s)}}$$

   Therefore, the flow rate for this example would be as follows: 50 gpm (3.15 L/s) for one-minute drainage or 25 gpm (1.58 L/s) for two-minute drainage.

5. Select the interceptor. Choose between a hydromechanical interceptor with a rated capacity of 50 gpm (3.15 L/s) for one-minute flow or 25 gpm (1.58 L/s) for two-minute flow, or a gravity interceptor with a capacity of 1,500 gallons (50-gpm flow rate × 30-minute detention time).

Local administrative authorities having jurisdiction should be consulted as they may dictate a specific formula or sizing criteria that would ultimately determine the specific flow parameters for which the interceptor could be selected. It is extremely important that the plumbing engineer determine not only the governing model code requirements regarding specific interceptor criteria, but also local jurisdictional requirements promulgated by the pretreatment authority since they sometimes contradict each other, especially where local jurisdictions adopt certain amendments and regulations that may supersede any model code requirements.

Grease extraction water-washed hood equipment may be used. It should be noted that while these systems are used in some cases, grease hoods that incorporate troughs that entrap grease, which are sloped to drip cups at the ends of the hood, are used quite prevalently. These cup drains are removed by hand, and the FOG material contained is disposed of in a proper manner and never discharges to the interceptor. It is important that the plumbing engineer verify which types of systems will be used with respect to grease hood equipment prior to the selection of the interceptor so that the proper capacity can be determined.

It also should be noted that the phrase “sizing an interceptor” is used throughout the industry quite loosely. However, grease interceptors are not sized. They are selected based on specific flow parameters and requirements as determined by the plumbing engineer during the design process for each individual facility. Furthermore, the design flow rates and pipe sizing criteria for food preparation facilities should not be determined by using the fixture unit method typically used for other types of facilities due to the fact that the probability of simultaneous use factors associated with fixture unit values do not apply in food preparation facilities where increased and continuous flow rates are encountered. Also, the facility determines the peak flows used to select the proper interceptor for the intended application, not the other way around (i.e., a single facility does not discharge at a multitude of different flow rates dependant on which particular type of interceptor is being considered for installation.)

Lastly, in certain projects the plumbing engineer may be called on to select an interceptor in which the flow rates for a facility are not readily quantifiable at the time of design, such as for a future expansion, restaurant, or food court area within a new development. In this case, tables or formulas can be used in an effort to help quantify the maximum flow rate that will be encountered for a specific pipe size at a given slope and velocity that ultimately discharges to the interceptor. This information can be used to select the proper interceptor capacity for the intended flow rates anticipated.

CODE REQUIREMENTS

The necessity for the plumbing engineer to verify all state and local jurisdictional requirements prior to the start of any food service facility design cannot be emphasized enough. Although state and model plumbing codes provide information with respect to interceptor requirements and regulations, local health departments and administrative authorities having jurisdiction have likely established their own set of guidelines and requirements for an interceptor on a specific project and, therefore, also should be consulted at the start of the design. It is up to the plumbing engineer to pull together the various agency requirements in an effort to design a code-compliant system, while incorporating any additional governing requirements and regulations.

The following model plumbing codes should be viewed for provisions regarding interceptors:

- Uniform Plumbing Code
- International Plumbing Code
- National Standard Plumbing Code

Following are itemized lists incorporating the major provisions of the model plumbing codes reviewed and are included herein as an abbreviated design guide for the engineer when specifying sizing. It is important to review the applicable code in effect in the area for any variation from this generalized list.

Summary of Uniform Plumbing Code Requirements for Interceptors

1. Grease interceptors are not required in individual dwelling units or residential dwellings.
2. Water closets, urinals, and other plumbing fixtures conveying human waste shall not drain into or through any interceptor.
3. Each fixture discharging into an interceptor shall be individually trapped and vented in an approved manner.
4. Grease waste lines leading from floor drains, floor sinks, and other fixtures or equipment in serving establishments such as restaurants, cafes, lunch counters, cafeterias, bars, clubs, hotels, hospitals, sanitariums, factory or school kitchens, or other establishments where grease may be introduced into the drainage or sewage system shall be connected through an approved interceptor.
5. Unless specifically required or permitted by the authority having jurisdiction, no food waste disposal unit or dishwasher shall be connected to or discharge into any grease interceptor. Commercial food waste disposers shall be permitted to discharge directly into the building drainage system.
6. The waste discharge from a dishwasher may be drained into the sanitary waste system through a gravity grease interceptor when approved by the authority having jurisdiction.
7. Flow control devices are required at the drain outlet of each grease-producing fixture connected to a hydromechanical grease

interceptor. Flow control devices having adjustable (or removable) parts are prohibited. The flow control device shall be located such that no system vent shall be between the flow control and the interceptor inlet. (Exception: Listed grease interceptors with integral flow controls or restricting devices shall be installed in an accessible location in accordance with the manufacturer's instructions).

8. A vent shall be installed downstream of hydromechanical grease interceptors.
9. The grease collected from a grease interceptor must not be introduced into any drainage piping or public or private sewer.
10. Each gravity grease interceptor shall be so installed and connected that it shall be at all times easily accessible for inspection, cleaning, and removal of intercepted grease. No gravity grease interceptor shall be installed in any part of a building where food is handled.
11. Gravity grease interceptors shall be placed as practical to the fixtures they serve.
12. Each business establishment for which a gravity grease interceptor is required shall have an interceptor that shall serve only that establishment unless otherwise approved by the authority having jurisdiction.
13. Gravity grease interceptors shall be located so as to be readily accessible to the equipment required for maintenance and designed to retain grease until accumulations can be removed by pumping the interceptor.

Summary of International Plumbing Code Requirements for Hydromechanical Grease Interceptors

1. Grease interceptors are not required in individual dwelling units or private living quarters.
2. A grease interceptor or automatic grease removal device shall be required to receive the drainage from fixtures and equipment with grease-laden waste located in food preparation areas such as restaurants, hotel kitchens, hospitals, school kitchens, bars, factory cafeterias, and clubs. The fixtures include pre-rinse sinks, soup kettles or similar devices, wok stations, floor drains or sinks to which kettles are drained, automatic hood wash units, and dishwashers without pre-rinse sinks.
3. Where food waste disposal units are connected to grease interceptors, a solids interceptor shall separate the discharge before connecting to the interceptor. Solids interceptors and grease interceptors shall be sized and rated for the discharge of the food waste grinder.
4. Grease interceptors shall be equipped with devices to control the rate of water flow so that the water flow does not exceed the rated flow. The flow control device shall be vented and terminate not less than 6 inches above the flood rim level or be installed in accordance with manufacturer's instructions.
5. Hydromechanical grease interceptors shall have the minimum grease retention capacity for the flow-through rates indicated in Table 8-2.

Table 8-2 Minimum Grease Retention Capacity

Total Flow-through Rating (gpm)	Grease Retention Capacity (pounds)
4	8
6	12
7	14
9	18
10	20
12	24
14	28
15	30
18	36
20	40
25	50
35	70
50	100
75	150
100	200

OPERATION AND MAINTENANCE

Operational methods can create problems for the engineer even if all the design techniques for grease interceptors presented have been observed. Failing to scrape dinner plates and other food waste-bearing utensils into the food waste disposer prior to loading them into dishwasher racks means that the liquid waste discharged from the dishwasher to the grease interceptor also carries solid food particles into the grease interceptor unit. The grease interceptor is not a food waste disposer.

Another common problem is insufficient grease removals. The period between removals differs for each interceptor type and is best left to the experience of licensed professional cleaning services. However, if the flow rate of the unit is constantly exceeded (no flow control) with high-temperature water, such as a heavy discharge from a dishwasher, the grease in the unit may periodically be liquefied and washed into the drainage system downstream of the grease interceptor. In this case, the operator or cleaning service may never realize that the unit needs cleaning because it never reaches its grease storage capacity. The difficulty is that when the temperature of the grease/water mixture finally cools in the drainage system downstream of the grease interceptor, clogging ultimately occurs.

Adequate maintenance is critical to an efficient grease interceptor installation. One of the most common problems is the disposal of the accumulated grease. The grease removed must be disposed of in various ways depending on local requirements. Grease should not be poured down any other drain or in any sewer line or buried in the ground. It should be disposed of via garbage pickup or some similar approved operation.

ECONOMICS

Broadly speaking, a single grease interceptor is more economical than a multiple interceptor installation for any given grease waste system. The length and cost of the grease waste piping to transport waste to a single large interceptor must be compared to the cost of short lengths and more than one unit.

RESOURCES

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9 Cross-connection Control

Keeping a fluid isolated in a complex piping network in a modern building may seem like a straightforward proposition. However, such efforts fall short unless all details are addressed thoroughly. Plumbing conveys one of society's most cherished commodity, safe water, to be used for personal hygiene and consumption, for industry, for medical care, and for landscape irrigation. Thus, a clear and distinct barrier between potable water and pollution, toxic substances, or disease-causing microbes is required. Good plumbing practices also call for similar controls related to graywater.

HYDROSTATIC FUNDAMENTALS

A cross-connection in plumbing is the point in the water supply where the water purity level is no longer known because of the transition from an enclosed streamline of water to another surface, basin, drain system, pipe system, or other piping beyond the control of the water purveyor. The point is not necessarily a hard-piped connection. Rather, because of the nature of fluid mechanics, it includes situations where the end of a water supply pipe is suspended below the rim of a fixture or floor drain. A cross-connection control (CCC) is a piping design or device together with frequent monitoring to prevent a reverse flow of water at the cross-connection. A cross-connection hazard is relative to the nature of the contaminants likely to be present in the environment of the cross-connection. Examples of potential cross-connections include plumbing fixtures, hose bibbs, appliance connections, hydronic water supply connections, fire sprinkler and standpipe water supply connections, water supply connection to industrial processes, laundries, medical equipment, food service equipment, HVAC equipment, swimming pool water makeup, water treatment backwash, trap primers, irrigation taps, dispensers that dilute their product with water, pressure-relief valve discharge piping, and drain-flushing water supply.

The fundamentals of hydrostatics are essential to understanding the hazards and control of cross-connections. That is, the pressure at any point in a static condition of a water supply system is a function only of the water's depth. This relationship is understood by considering that at any point, the weight of water above it is the product of its volume and its specific weight. Specific weight is similar to density; however, it is defined as weight per unit volume rather than mass per unit volume. Like density, it varies slightly with temperature.

To derive the pressure relationship in a hydrostatic fluid, consider the volume of the fluid at a given depth and a horizontal area at that depth. The pressure is the weight divided by the area. Hence,

$$p = W/A = h \times A \times w/A, \text{ or}$$

Equation 9-1

$$p = h \times w$$

or

$$p = h \times 62.4/144 = 0.433h$$

$$[p = h \times 1 \times 9.81 = 9.81h]$$

where

p = Static gauge pressure, pounds per square inch (psi [kilopascals, or kPa])
W = Weight, pounds (N)
A = Area, square inch (square meter)
w = Specific weight of water, pounds per cubic feet (N/m^3)
h = Static head, feet (meters)

For absolute pressure in a water supply, the local atmospheric pressure is added to the gauge pressure. For example, in Figure 9-1, the pressure at the top of the column is found from $p = (0.433)(-23) + 14.7 = 4.73$ $[(9.81)(-7.0) + 100 = 31.2]$. Note that atmospheric pressure is not constant. Rather, it varies with the weather, geographic location, and the effects of HVAC systems.

Hydrodynamics, or additional forces related to momentum from moving water, affects the magnitude of a reverse flow and the transient nature of a flow demand. Pressure reversals at booster pump inlets and circulator pump inlets may cause other hydrodynamic

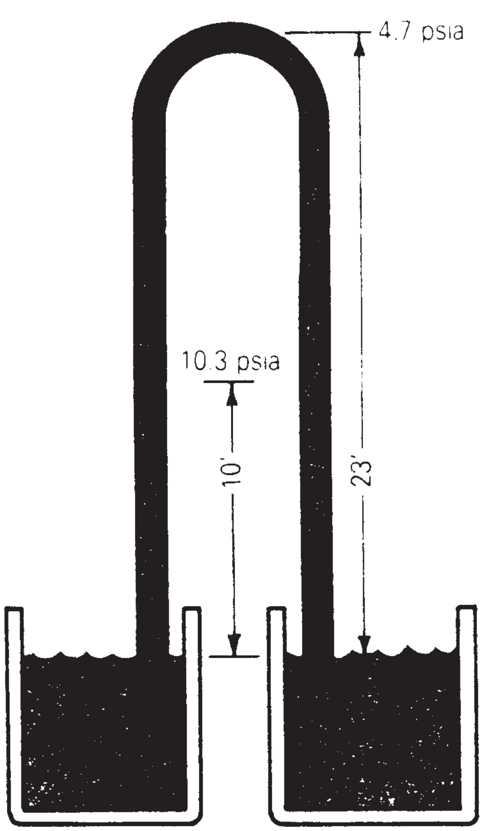


Figure 9-1 Hydrostatics Showing Reduced Absolute Pressure in a Siphon

issues. These pressure effects are superimposed on hydrostatic pressures. Nonetheless, impending reversals generally are affected by hydrostatics only.

As an example, consider a 100-foot (30.5-m) tall water supply riser pipe with 20 pounds per square inch gauge (psig) (138 kPa) at its top. From Equation 9-1, the pressure at the base of the riser will be 63.3 psig (436 kPa). If an event causes a 30-psig (207-kPa) pressure loss, the pressure at the top fixture will be -10 psig (-69 kPa gauge) or 4.7 pounds per square inch absolute (psia) (32 kPa absolute). This vacuum will remain in the piping until any faucet, flush valve, or other valve is opened on the riser.

CAUSES OF REVERSE FLOW

Preventing pollution or a contaminant from inadvertently entering the water supply applies to a potable water supply, to other water supplies, and between varying water supplies. An example of a varying water supply is a municipality and the water supply of a vehicle.

A general water supply is represented in Figure 9-2. Although it shows four endpoints and various pipes between them, expanding it to any number of endpoints with any arrangement of pipes can illustrate a general water supply of any type. The elevation and length of any pipe can vary. Hence, the

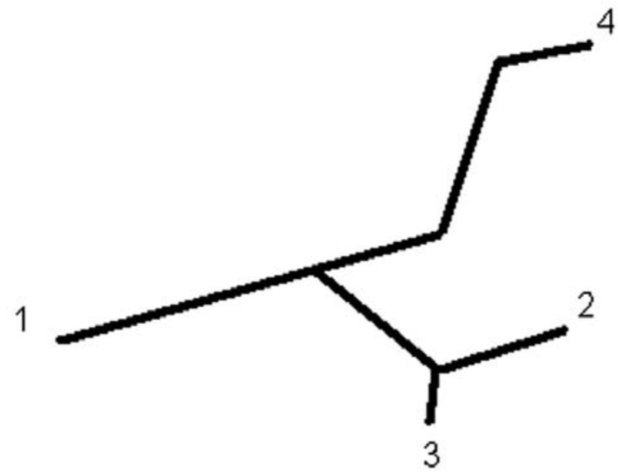


Figure 9-2 Pipe Network With Four Endpoints

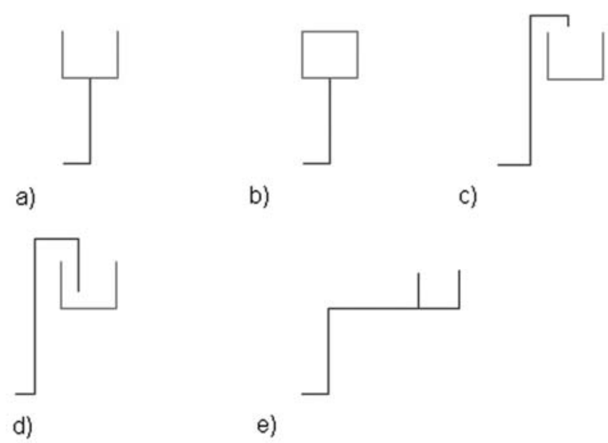


Figure 9-3 Five Typical Plumbing Details Without Cross-connection Control

network of pipes may represent a small network, such as a residence or a vehicle, or it may represent a large network, such as a building complex or a major city. At each endpoint in a plumbing water supply, any of five general details, such as shown in Figure 9-3, may be connected. Elevation is represented in the vertical direction in each of these recognizable details. However, for illustration purposes, no CCC is included. An example of the first detail is a water storage tank with an open or vented top, such as a city water tower; of the second is a pressure vessel such as a boiler; of the third is a plumbing basin; of the fourth is a hose immersed in a plumbing basin or a supply to a water closet with a flushometer; and of the fifth is a fire suppression system or a hydronic system. Other examples of Figure 9-3(e) are a connection point for process piping, for a vehicle, or for a building's water distribution in contrast to the street distribution.

Lastly, to include a pump anywhere in a network, an elevated reservoir can illustrate the effect of a pump. The pump's discharge head is equivalent to the surface elevation level of the reservoir relative to the piping system discharge level.

All discussions of CCC include identification of back-pressure and back-siphonage. The maximum back-pressure at the base of the riser in Figure 9-3(a), for a reservoir other than the normal water supply, occurs if the tank shown is filled to its rim or overflow outlet. Back-pressure can be defined as the pressure at a point in a water supply system that exists if the normal water supply is cut off or eliminated. In Figure 9-3(d), flow from the basin may occur if the water supply is cut off or eliminated and if the water elevation is near or above the pipe outlet. This reverse flow, or siphon action, is caused by atmospheric pressure against the free surface of the water in the basin. Recall that a siphon can be defined as a bent tube full of water between two reservoirs under atmospheric pressure so that flow takes place despite the barrier between them. Back-siphonage is defined as an unintended siphon situation in a water supply with the source reservoir being a fixture or other source with an unknown level of contamination.

In a network, when the law of hydrostatics is generally applied to the reservoir with the highest elevation, the network's pressure distribution is identifiable, and the direction of flow can be known through general fluid mechanics. In an ideal case, the presence of that reservoir generally keeps the direction of flow in a favorable direction. However, the connection of a supply reservoir is vulnerable to any cause for a pressure interruption, and the normal network pressure distribution may be disturbed. For example, when a valve anywhere in a general system isolates a part of the system away from the supply reservoir, another part of the isolated section may become the water source, such as any fixture, equipment, or connected system. As an example in Figure 9-2 with endpoint 2 being the city water supply, consider that endpoint 4 is a closed-loop ethylene glycol system on a roof. If the city supply is cut off, the glycol may freely feed into endpoints 1 and 3.

Other pressure interruptions include broken pipes, broken outlets, air lock, pressure caused by thermal energy sources, malfunctioning pumps, malfunctioning pressure-reducing valves, and uncommon water discharges such as a major firefighting event. Several specific instances of mishaps are described in Appendix 9-G.

Because it cannot be predicted where a valve may close or where another type of pressure interruption may occur, each water connection point becomes a potential point for reverse flow. Thus, every fixture, every connected piece of equipment, and every connected non-plumbing system becomes a point of reverse flow. Containers of any liquid that receive water from a hose or even a spout of inadequate elevation potentially may flow in a reverse direction. Submerged irrigation systems or yard hydrants with a submerged drain point potentially may flow soil contaminants into the water supply system. Hence, the safety of a water supply distribution depends on effective control at each connection point. The safety is not ensured if the effectiveness of one point is unknown despite the investment of controls at all other points. One example of a cross-connection catastrophe occurred in Chicago in 1933 from defective fixtures and piping. As a result, 1,409 individuals contracted amoebic dysentery, which caused 98 deaths.

Further, control methods today do not detect or remove the presence of contaminants. A control device added to hot water piping supplying a laboratory will not be effective if the circulation return brings contaminated hot water out of the laboratory.

A manually closed water supply valve is not considered a cross-connection control, even if the valve is bubble-tight and well supervised. Ordinary check valves also are not considered a cross-connection control. The history of such good intentions for equipment connections or water fill into processing operations has not been sufficiently effective as compared to cross-connection control.

In addition, as a measure of containment, a control device in the water service is a primary candidate to isolate a hazard within a building. However, its function is to preserve the safety of adjacent buildings and not the building itself. That is, reverse flows may occur within a building having only containment cross-connection control. Its occupants remain at risk even though the neighborhood is otherwise protected.

HAZARDS IN WATER DISTRIBUTION

A hazard exists in a water supply system if a risk may occur and if the probability of occurrence is beyond the impossible. The various pressure interruptions previously described do not occur frequently, but they happen and often without warning. Hence, the probability cannot be discounted even if an occurrence is uncommon, especially in large networks. Risks are more common since they are associated with every plumbing fixture, many types of equipment, and various connections with non-plumbing systems. The nature of the risk ranges from mere objections such as water color or odor to varying exposure levels of nuclear, chemical, or biological material. The varying level further ranges from imperceptible to mildly toxic to generally lethal in healthy adults. A risky material generally is referred to as a contaminant. Appendix 9-E presents a list of contaminants and maximum concentration levels as mandated by the U.S. Safe Drinking Water Act of 1974.

Control Paradox

A paradox exists in a water supply. That is, reverse flows rarely happen, yet they are dangerous. While fire prevention is generally respected, cross-connection control is poorly understood. It often is regarded as superfluous. Further, well-intentioned users often tamper with these controls. The hazard escapes notice because the pressure rarely is interrupted and the potential source of a contaminant may not always be present at a perceptively dangerous level. For example, a disconnected vacuum breaker at a mop basin fitted with a detergent dispenser generally will not flow into the building supply until a pressure interruption occurs, and then the effect of consuming contaminated water may be only mild for occupants on floors below the offending mop basin. However, another example may include hospital patients and more toxic chemicals.

Table 9-1 Air Gap Standards

Applications	Standard
Air gap	ANSI/ASME A112.1.2: Air Gaps in Plumbing Systems
Air gap fitting	ANSI/ASME A112.1.3: Air Gap Fittings for Use with Plumbing Fixtures, Appliances, and Appurtenances
Water closet flush tank ball cock	ASSE 1002: Performance Requirements for Anti-siphon Fill Valves for Water Closet Tanks
Commercial dishwasher	ASSE 1004: Backflow Prevention Requirements for Commercial Dishwashing Machines
Residential dishwasher	ASSE 1006: Performance Requirements for Residential Use Dishwashers
Residential clothes washer	ASSE 1007: Performance Requirements for Home Laundry Equipment

Classification of Hazards

Since risks can be ranked from those that are likely to be unsafe to those rarely unsafe, the CCC industry has developed two broad classifications. Examples of each are presented in Appendix 9-D. Less capital generally is invested in CCC where the hazard is low.

CONTROL TECHNIQUES

Control to prevent reverse flow is achieved by techniques such as certain piping designs and installation of control devices. If no mechanical moving parts exist, the control can be regarded as passive. Effective operation is more inherent, but limitations warrant other controls. If there are moving parts, the control can be regarded as active.

Passive Techniques

Examples of a passive control include air gaps and barometric loops. An air gap is regarded as effective if the outlet of the flow discharge is adequately

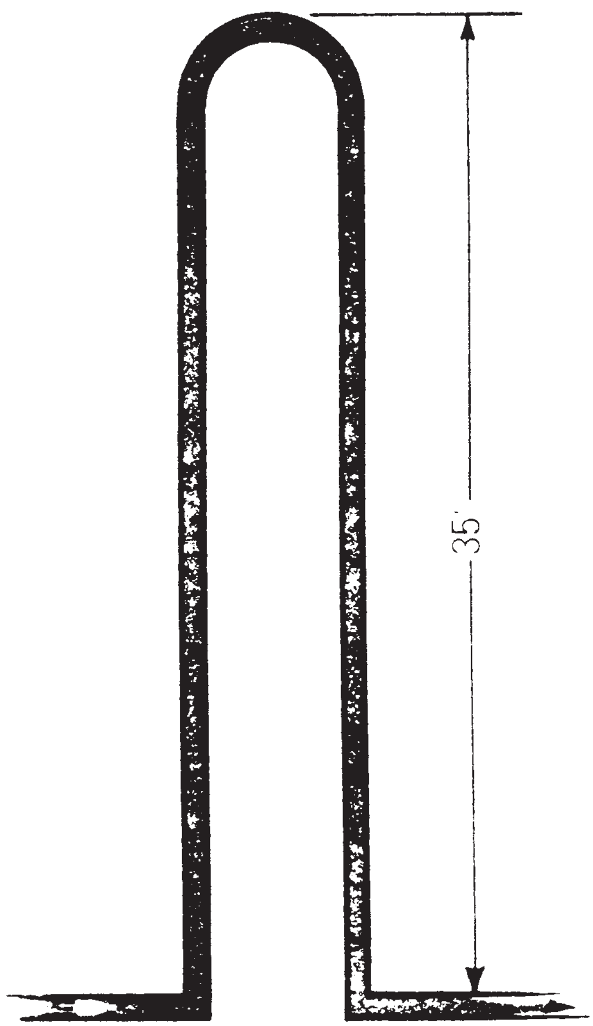


Figure 9-4 Siphon Sufficiently High to Create a Barometric Loop

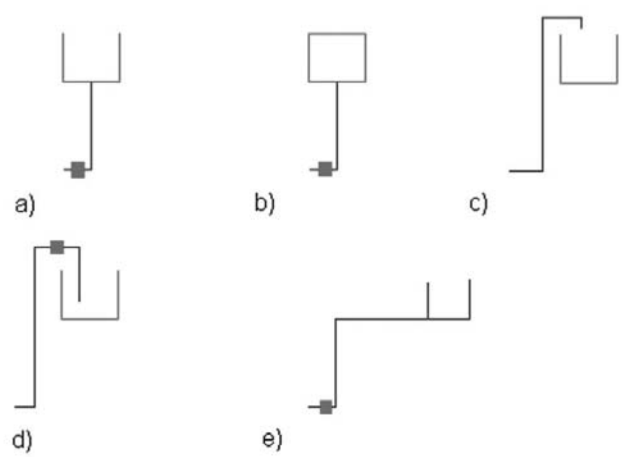


Figure 9-5 Five Typical Plumbing Details With Cross-connection Control

Table 9-2 Types of Back-pressure Backflow Preventer

Description	Alternate Description	Application	ASSE Reference
Dual-check valve with atmospheric vent	Intermediate atmospheric	Low hazard	1012
Reduced-pressure principle	Reduced-pressure zone	High hazard	1013
Dual-check valve with atmospheric vent	Intermediate atmospheric	Carbonated beverage	1022
Reduced-pressure principle detector assembly	Reduced-pressure zone	Fire protection	1047

above the rim of the receiving basin, generally twice the diameter of the outlet. Requirements vary with plumbing codes. Some codes expand the distance to three times the diameter if the outlet is close to the basin wall. Other standards regard the valve seat as being the relevant diameter. Still other standards explore the adequacy of overflow pipework as establishing the flood level elevation. In modern plumbing, faucet spout outlets invariably discharge through an air gap positioned above the flood level rim of all plumbing fixtures.

The theory of operation of an air gap is that, with an excessively short vertical distance, a vacuum in the water supply draws room air, which also captures water from the surface of a full basin. The vacuum can be imagined by visualizing water in a riser pipe rapidly dropping. The void above this falling water produces vacuum until the fall becomes complete. Another situation is when a valve in the water supply is opened after the vacuum has occurred because of lost pressure in the water supply moments earlier.

Table 9-3 Types of Vacuum Breakers

Description	Application	ASSE Reference
Pipe applied	Mop basin, indoor hose	1001
Hose connection	Indoor hose	1011
Hose connection	Handheld shower	1014
Frost resistant	Wall hydrant	1019
Pressure-type	Turf irrigation	1020
Pressure flush	Flushometer	1037
Spill resistant	High hazard	1056

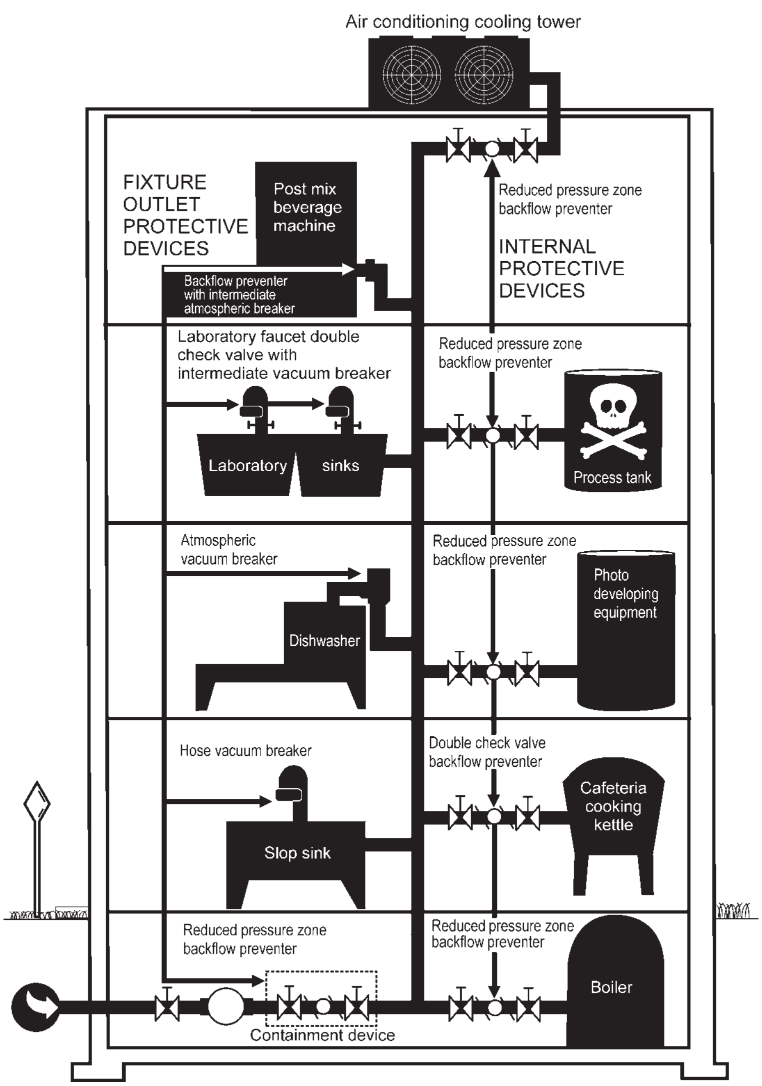


Figure 9-6 Example of Cross-connection Controls in a Building

Other provisions of acceptable industry standards include recognition of overflow pipes in water closet tanks and diverter hoses such as in food sprayers on kitchen sinks. Table 9-1 lists several air gap standards for various applications.

The design of a barometric loop requires part of the upstream supply pipe to be adequately above the receiving basin. The minimum height is derived from Equation 9-1. For an atmospheric pressure of 31 inches (788 millimeters) of mercury, h = 35.1 feet (10.8 m). The technique, shown in Figure 9-4, is effective because the room's atmospheric pressure is not sufficient to push a column of water up that much elevation.

Active Techniques

Mechanisms in a device of an active control prevent reverse flows either by allowing flow in one direction only or by opening the pipe to atmospheric pressure. The former generally is categorized as a back-pressure backflow preventer, and it generally uses discs that lift from seats for normal flow. The latter is generally a vacuum breaker, and it has greater application restrictions. Examples of locating back-pressure backflow preventers that are required for effective cross-connection control in Figure 9-3(a), (b), and (e) are shown with a small square in corresponding applications in Figure 9-5(a), (b), and (e). The hydrostatic pressure of the water downstream from the backflow preventer must be resisted by the active control in the event of water supply pressure failure.

A device of either broad category uses a specially designed, fabricated, tested, and certified assembly. For high hazard applications, the assembly often includes the supply and discharge valves and some testing ports. For various applications, Tables 9-2 and 9-3 list several back-pressure backflow preventer standards and vacuum breaker standards respectively. Figure 9-6 shows several backflow preventers as isolation at fixtures and equipment as well as hazard containment at the water service.

A hybrid of passive and active control is the break tank. Consisting of a vented tank, an inlet pipe with an air gap, and a pump at the discharge, a break tank provides effective control for any application ranging from an equipment connection to the water service of an entire building. Its initial cost and operating cost are obviously greater than with other controls.

Types of back-pressure backflow preventers include double-check valve assemblies, reduced-pressure principle backflow preventers, and dual checks with atmospheric vents. Types of vacuum breakers include atmospheric, pressure, spill-resistant, hose connection, and flush valve.

Double-check Valve Assembly

This control with its two check valves, supply valves, and testing ports can effectively isolate a water supply from a low hazard system such as fire standpipe and sprinkler systems. The design includes springs and resilient seats. (See Figure 9-7.) Some large models, called detector assemblies, include small bypass systems of equivalent components with a meter added. The meter provides monitoring of small water usages associated with quarterly testing of the fire sprinkler system.

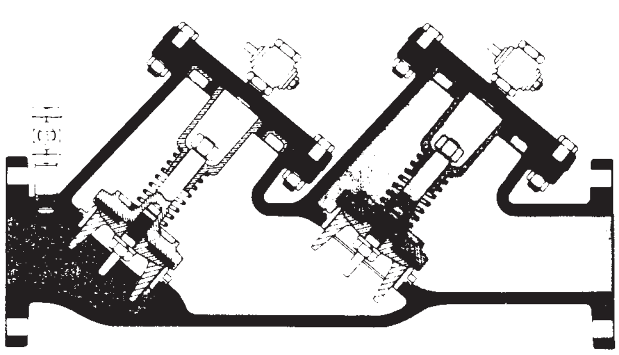


Figure 9-7 Double-check Valve

A small version of a double-check for containment CCC has been developed for residential water services.

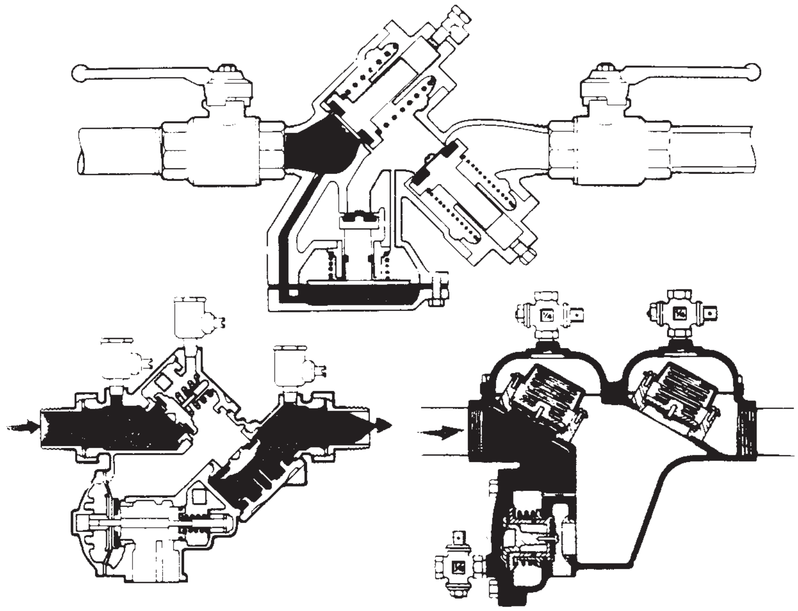


Figure 9-8 Reduced-pressure Principle Backflow Preventer

Reduced-pressure Principle Backflow Preventer

This control is similar to the double-check valve but employs added features for isolating a water supply from a high hazard. An alternate name is reduced-pressure zone backflow preventer. (See Figure 9-8.) A heavier spring is used on the upstream check valve, which causes a pronounced pressure drop for all portions of the piping system downstream. A relief port between the check valves opens to atmosphere and is controlled by a diaphragm. Each side of the diaphragm is ported to each side of the upstream check valve. A rated spring is placed on one side of the diaphragm. If the expected pressure drop across the upstream check valve does not occur, the spring favors opening the relief port. This circumstance occurs if the downstream equipment or piping has excessive pressure. It also occurs if the upstream check valve fails or if the water supply is lost. Effective protection requires periodic testing and an air gap at the relief port. Like the double-check valve detector assembly, this backflow preventer is available as a detector assembly.

Dual Check with Atmospheric Vent

This control is similar to the reduced-pressure principle type, but the diaphragm design is replaced with a piston combined with the downstream check valve. (See Figure 9-9.) It effectively isolates a water supply from a low hazard such as beverage machines and

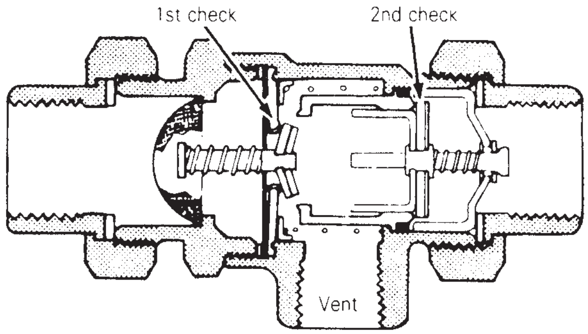


Figure 9-9 Dual-check with Atmospheric Vent

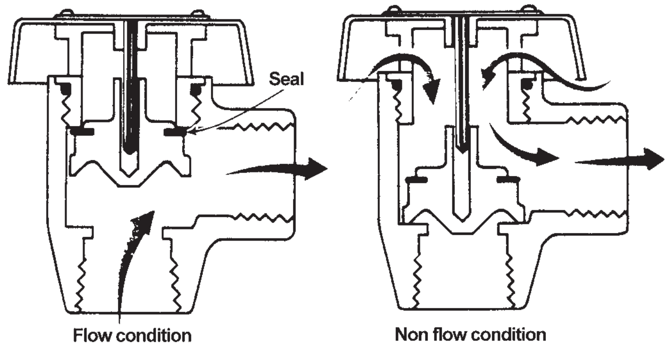


Figure 9-10 Atmospheric Vacuum Breaker

equipment with nontoxic additives. The function of its design is not sufficiently precise for high hazards. The relief port is generally hard-piped with its air gap located remotely at a similar or lower elevation.

A vacuum breaker is of a simpler design, but it is elevation sensitive for effective isolation of a hazard. Permitted maximum back-pressure ranges from 4.3 psig (29.7 kPa) down to zero depending on the type.

Atmospheric Vacuum Breaker

This control, with a single moving disc, can effectively isolate a water supply from a low hazard system. Without this control in Figure 9-3(d), a reverse flow will occur from the basin if the fluid level in the basin is near or above the pipe discharge, the water supply pressure is lost, and the highest elevation of the piping above the fluid level is less than for a barometric loop. The reverse flow, referred to as back-siphonage, is caused by atmospheric pressure against the surface of the fluid, which pushes the fluid up the normal discharge pipe and down into the water supply. Static pressure for any point in the basin and in the pipe, after discounting pipe friction, is a function only of elevation. Above the fluid surface elevation, this pressure is less than atmospheric; that is, it is a vacuum. The reverse flow therefore is stopped if the vacuum is relieved by opening the pipe to atmosphere. Figure 9-10 illustrates the vent port and the disc that closes under normal pressure.

Pressure-type Vacuum Breaker

This control is similar to the atmospheric vacuum breaker but employs one or two independent spring-loaded check valves, supply valves, and testing ports. It is used for isolating a water supply from a high hazard system.

Spill-resistant Vacuum Breaker

This control is similar to the pressure-type vacuum breaker, but it employs a diaphragm joined to the vacuum breaker disc. It is used for isolating a water supply from a high hazard system and eliminates splashing from the vent port.

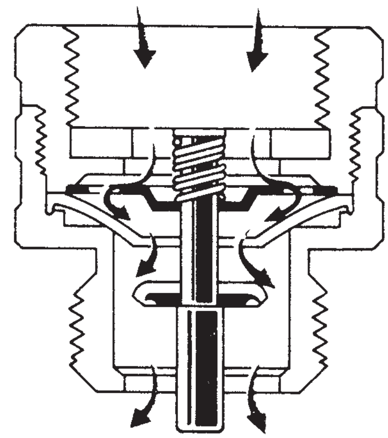


Figure 9-11 Hose Connection Vacuum Breaker

Hose Connection Vacuum Breaker

This control is similar to the atmospheric vacuum breaker in function but varies in design and application. The disc is more elastic, has a pair of sliced cuts in the center, and deforms with the presence of water supply pressure to allow the water to pass through the cuts. (See Figure 9-11.) The deformation also blocks the vent port. A more advanced form employs two discs, and the design allows performance testing.

Flush Valve Vacuum Breaker

This control is similar to the hose connection vacuum breaker in function but varies somewhat in the design of the elastic part.

INSTALLATIONS

All cross-connection controls require space, and the active controls require service access. In addition, an air gap cannot be confined to a sealed space or to a sub-grade location, and it requires periodic access for inspection. A vacuum breaker may fail to open if it is placed in a ventilation hood or sealed space. A backflow preventer is limited to certain orientations.

If a water supply cannot be interrupted for the routine testing of a control device, a pair of such devices is recommended. Some manufacturers have reduced the laying length of backflow preventers in their design. Backflow preventers with relief ports cannot be placed in a sub-grade structure that is subject to flooding because the air gap will potentially be submerged. Thus, backflow preventers for water services are located in buildings and above grade outdoors. Where required for climatic reasons, heated enclosures commonly are provided. Features include an adequate opening for the relief port flow and large access provisions.

Manufacturers of reduced-pressure principle backflow preventers recommend an inline strainer upstream of the backflow preventer and a drain valve permanently mounted at the strainer's upstream side. Periodic flushing of the screen and upstream piping should include brisk opening and closing to jar potential debris and flush it away before it could enter the backflow preventer. Manufacturers also have incorporated flow sensors and alarm devices that can provide warnings of malfunctions.

If special tools are required to service and maintain an active control device, the specification should require the tools to be furnished with and permanently secured to the device.

Installation Shortfalls

Though relatively simple, air gaps have some shortfalls. Namely, the structure of the outlet must be sufficiently robust to withstand abuse while maintaining the gap. The general openings around the air gap must not be covered. The rim of the basin must be wide enough to capture attendant splashing that occurs from fast discharges. The nature of the rim must be adequately recognized so that the gap is measured from a valid elevation. That is, if the top edge of the basin is not practical, the invert of a side outlet may be regarded as the valid elevation. Similarly, the rim of a standpipe inside the basin may be regarded as the valid elevation. In either design, the overflow and downstream piping must be evaluated to consider if it will handle the greatest inlet flow likely to occur. A common design of potable water filling a tank through an air gap that is below the tank rim but where the tank has an overflow standpipe is the design found in water closet tanks. The generous standpipe empties into the closet bowl so that the air gap is never compromised.

Vacuum breakers have several shortfalls. A valve downstream of the vacuum breaker will send shock waves through the vacuum breaker every time the valve closes. This causes the disc to drop during the percussion of the shock wave, which momentarily opens the vent port, allowing a minute amount of water to escape. The design of vacuum breakers is sensitive to the elevation of the breaker relative to the elevation of the water in the basin. A vacuum breaker mounted too low may allow back-siphonage because the vacuum is too low for the disc to respond.

Back-pressure backflow preventers have several shortfalls. A floor drain or indirect waste receptor is required, which complicates its installation, especially in renovation work and for water services. An air gap is required for the relief port, which has its own set of shortfalls. For the reduced-pressure principle backflow preventer, its shortfall includes high first cost and added cost for annual testing. Its testing disrupts a water service. In addition, it requires space for its large size and its accessibility requirement. Another hazard exists with this backflow preventer in fire protection supply because of the additional pressure drop in the water supply in contrast with a single check valve. Lastly, the public's perception of backflow preventers is mired by confusing regulations, misunderstandings when they fail, and modifications of the air gap when nuisance splashing occurs.

Existing water distribution systems and connection points commonly have installation faults. These range from submerged inlets in fixtures or tanks, direct connections to equipment or the sanitary drain system, tape wrapped around air gaps to limit splashing, and the discharge of relief pipes below floor drain rims.

Flood Hazard

Reduced-pressure principle backflow preventers represent a significant flood hazard during low flow conditions if the upstream check has a slight leak because the pressure will equalize, which opens the relief not to the mere back-pressure but to the supply pressure.

Break Tank

In addition to noise, energy consumption, and maintenance, break tanks allow the opportunity for microbial growths. Chlorine eventually dissipates in the open air above the water level if consumption is modest. Lastly, an obstructed overflow pipe may render the air gap ineffective.

Splashing

The vent openings of active devices and air gaps are prone to splashing and nuisance wet floors. Each drain with its rim above the floor should be accompanied with a nearby floor drain or indirect waste drain.

QUALITY CONTROL

Product Standards and Listings

For quality assurance in cross-connection control, standard design and device testing have been part of the manufacturing and sale of active control devices. In addition, the product is furnished with an identifying label of the standard, and the model number is furnished in a list that is published by a recognized agency.

Field Testing

Frequent testing provides additional quality assurance, such as upon installation, upon repairs, and annually.

Tests for a pressure-type vacuum breaker and a spill-resistant vacuum breaker include observing the opening of the air-inlet disc and verification of the check valve(s). That is, the disc shall open at a gauge reading of not less than 1 psig (6.90 kPa), for a pressure gauge mounted on the vacuum breaker body. With downstream piping open and a sight glass, open to atmosphere at its top and mounted upstream of the check valve and purged of air, open and then close the supply valve when 42 inches (1,070 mm) of water are in the sight glass. The water level in the sight glass of a properly functioning device will drop as water escapes past the check valve, but it will not drop lower than 28 inches (710 mm) above its connection point.

Tests for a reduced-pressure principle backflow preventer include verification of each check valve, the downstream shutoff valve, and operation of the relief valve. That is, on a properly functioning device with all air purged, upstream pressure is deliberately applied downstream of the second check valve, and the pressure differential across it is held when the downstream shutoff is both open and closed. In the next test, a pressure differential is observed across the upstream check valve. A defect in the check valve seat will prevent a differential from being held. In the last test, a bypass on the test instrument is opened slowly to begin equalizing pressure across this check valve, and the pressure differential, for a properly functioning device, is noted as not being less than 3 psi (20.7 kPa) when flow is first observed from the relief port.

Regulatory Requirements

Authorities having jurisdiction create and enforce legally binding regulations regarding the applications of cross-connection control, the standards and listings for passive and active controls, and the types and frequencies of field testing. The authority may require evidence of field testing by keeping an installation record of each testable device and all tests of the device.

Authorities having jurisdiction typically are water purveyors, plumbing regulation officials, health department officials, or various qualified agents in contract with government regulators. Regulations of cross-connection control are generally part of a plumbing code, but they may be published by a local health department or as the requirements of a municipal water service connection.

GLOSSARY

Absolute pressure The sum of the indicated gauge pressure and the atmospheric local pressure. Hence, gauge pressure plus atmospheric pressure equals absolute pressure.

Air gap A separation between the free-flowing discharge end of a water pipe or faucet and the flood level rim of a plumbing fixture, tank, or any other reservoir open to the atmosphere. Generally, to be acceptable, the vertical separation between the discharge end of the pipe and the upper rim of the receptacle should be at least twice the diameter of the pipe, and the separation must be a minimum of 1 inch (25.4 mm).

Air gap, critical The air gap for impending reverse flow under laboratory conditions with still water, with the water valve fully open and one-half atmospheric pressure within the supply pipe.

Air gap, minimum required The critical air gap with an additional amount. It is selected based on the effective opening and the distance of the outlet from a nearby wall.

Atmospheric pressure Equal to 14.7 psig (101 kPa) at sea level.

Atmospheric vacuum breaker A device that contains a moving float check and an internal air passage. Air is allowed to enter the passage when gauge pressure is zero or less. The device should not be installed with shutoff valves downstream. The device typically is applied to protect against low-hazard back-siphonage.

Backflow An unwanted flow reversal.

Backflow preventer A device that prevents backflow. The device should comply with one or more recognized national standards, such as those of the American Society of Sanitary Engineering, American Water Works Association, or University of Southern California Foundation for Cross-connection Control and Hydraulic Research, and with the requirements of the local regulatory agency.

Back-pressure backflow A backflow caused by pressure that exceeds the incoming water supply pressure.

Back-siphonage backflow A backflow that occurs when the pressure in the water piping falls to less than the local atmospheric pressure.

Containment A means of cross-connection control that requires the installation of a back-pressure backflow preventer in the water service.

Contaminant A substance that impairs the quality of the water to a degree that it creates a serious health hazard to the public, leading to poisoning or to the spread of disease.

Cross-connection A connection or potential connection that unintentionally joins two separate piping systems, one containing potable water and the other containing pollution or a contaminant.

Cross-connection control Active or passive controls that automatically prevent backflow. Such controls include active and passive devices, or other design techniques; standardized designs, testing, and labeling; and frequent site surveys and field testing of mechanical devices.

Cross-connection control program A program consisting of both containment and point-of-use fixture or equipment isolation. The containment program requires a control installed at the point where water leaves the water purveyor's system and enters the consumer side of the water meter. The isolation program requires an ongoing survey to ensure that there have been no alterations, changes, or additions to the system that may have created or recreated a hazardous condition. Isolation protects occupants as well as the public.

Double-check valve assembly A device that consists of two independently acting spring-loaded check valves. They typically are supplied with test cocks and shutoff valves on the inlet and outlet to facilitate testing and maintenance. The device protects against both back-pressure and back-siphonage backflow; however, it should be installed only for low-hazard applications.

Effective opening The diameter or equivalent diameter of the least cross-sectional area of a faucet or similar point at a water discharge through an air gap. For faucets, it is usually the diameter of the seat of the faucet valve.

Fixture isolation The cross-connection control at a fixture or piece of equipment.

Flood level rim The elevation at which water overflows from its receptacle or basin.

Flushometer valve A mechanism energized by water pressure that allows a measured volume of water for the purpose of flushing a fixture.

Free water surface A free water surface whose pressure against it is equal to the local atmospheric pressure.

Indirect waste pipe A drainpipe that flows into a drain system via an air gap above a receptacle, interceptor, vented trap, or vented and trapped fixture.

Joint responsibility The responsibility shared by the purveyor of water and the building owner for ensuring and maintaining the safety of potable water. The purveyor is responsible for protecting their water supply from hazards that originate from a building. The owner is responsible for ensuring that the building's system complies with the plumbing code or, if no code exists or is enforced, within reasonable industry standards. The owner is also responsible for the ongoing testing and maintenance of backflow devices that are required to protect the potable water supply.

Negligent act An act that results from a failure to exercise reasonable care to prevent foreseeable backflow incidents from occurring or when another problem is created when correcting a potential problem. For example, if a closed system is created by requiring a containment device without considering how such a device will alter the hydrodynamics within the system, and this causes the rupture of a vessel such as a water heater, this could be considered negligent.

Plumbing code A legal minimum requirement for the safe installation, maintenance, and repair of a plumbing system, including the water supply system. When there is no applicable code, good plumbing practice should be applied by following reasonable industry standards.

Pollutant A foreign substance that, if permitted to get into the public water system, will degrade the water's quality so as to constitute a moderate hazard or to impair the usefulness or quality of the water to a degree that is not an actual hazard to public health but adversely and unreasonably affects the water for domestic use.

Potable water Water that is furnished by the water purveyor with an implied warranty that it is safe to drink. The public is allowed to make the assumption that it is safe to drink by the water purveyor or regulatory agency having jurisdiction.

Pressure-type vacuum breaker A device that contains two independently operating valves, a spring-loaded check valve, and a spring-loaded air inlet valve. The device has test cocks for inline testing and two tightly sealing shutoff valves to facilitate maintenance and testing. It is used only to protect against back-siphonage.

Professional An individual who, because of his or her training and experience is held to a higher standard than an untrained person. The professional is exposed to a liability for their actions or inaction.

Reasonable care Working to standards that are known and accepted by the industry and applying those standards in a practical way to prevent injury or harm via predictable and foreseeable circumstances.

Reduced-pressure principle backflow preventer A device consisting of two separate and independently acting spring-loaded check valves, with a differential pressure-relief valve situated between the check valves. Since water always flows from a zone of high pressure to a zone of low pressure, this device is designed to maintain a higher pressure on the supply side of the backflow preventer than is found downstream of the first check valve. This ensures the prevention of backflow. An artificial zone of reduced pressure across the check valve is created by torsion on the check valve spring. Pressure on the inlet side of the device is intended to remain a minimum of 2 psi (13.8 kPa) higher than the pressure in the reduced-pressure zone. If the pressure in the zone increases to within 2 psi (13.8 kPa) of the supply pressure, the relief valve will open to atmosphere to ensure that the differential is maintained. These devices are designed to be inline, testable, and maintainable. They are equipped with test cocks and inlet and outlet shutoff valves to facilitate testing and maintenance. The device should be installed in an accessible location and orientation that allows testing and maintenance. This device provides effective high-hazard protection against both back-pressure and back-siphonage backflow.

Special tool A tool peculiar to a specific device and necessary for the service and maintenance of that device.

Spill-resistant vacuum breaker A device containing one or two independently operated spring-loaded check valves and the independently operated spring-loaded air inlet valve mounted on a diaphragm that is located on the discharge side of the check or checks. The device includes tightly closing shutoff valves on each side of the check valves and properly located test cocks for device testing.

Survey A field inspection within and around a building, by a qualified professional, to identify and report cross-connections. Qualification of a professional, whether an engineer or licensed plumber, includes evidence of completion of an instructional course in cross-connection surveying.

Vacuum A pressure less than the local atmospheric pressure.

Vacuum breaker A device that prevents back-siphonage by allowing sufficient air to enter the water system so that backflow is prevented.

Water supply system A system of service and distribution piping, valves, and appurtenances to supply water in a building and its vicinity.

RESOURCES

Cross-connection Control Manual. U.S. Environmental Protection Agency. February 2003.

American Society of Sanitary Engineering (ASSE): www.asse-plumbing.org

American Water Works Association (AWWA): www.awwa.org

National Sanitation Foundation (NSF) International: www.nsf.org

University of Southern California (USC) Foundation for Cross-connection Control and Hydraulic Research: www.usc.edu/dept/fccchr/education.html

Washington Suburban Sanitary Commission (WSSC): www.wssc.dst.md.us

APPENDIX 9-A SAMPLE WATER DEPARTMENT CROSS-CONNECTION CONTROL PROGRAM/ORDINANCE

[WATER DEPARTMENT NAME] CROSS-CONNECTION CONTROL PROGRAM/ORDINANCE

I. Purpose

a. The purpose of this program/ordinance is to protect the public potable water supply served by the [ ] Water Department from the possibility of contamination or pollution by isolating, within its customers' internal distribution system, such contaminants or pollutants which could backflow or back-siphon into the public water system.

b. The purpose is to promote the elimination or control of existing cross-connections, actual or potential, between its customers' in-plant potable water system and nonpotable systems.

c. The purpose is to provide for the maintenance of a continuing program of cross-connection control, which will effectively prevent the contamination or pollution of all potable water systems by cross-connection.

d. The purpose does not include, nor prevent, cross-connection controls at fixtures, controls at equipment connections, and controls connected at other hazards. The program may be expanded to include a jurisdictional authority of the cross-connection controls at equipment connections and other hazardous connections of the building's water distribution so as to isolate such hazards from building occupants.

II. Authority

a. The Federal Safe Drinking Water Act of 1974, and the statutes of the State of [ ] Chapters [ ], the water purveyor has the primary responsibility for preventing water from unapproved sources, or any other substances, from entering the public potable water system.

b. [ ] Water Department, Rules and Regulations, adopted.

III. Responsibility

The Director of Municipal Services shall be responsible for the protection of the public potable water distribution system from contamination or pollution due to the backflow or back-siphonage of contaminants or pollutants through the water service connection. If, in the judgment of the Director of Municipal Services, an approved backflow device is required at the city's water service connection to any customer's premises, the Director, or his delegated agent, shall give notice in writing to said customer to install an approved cross-connection control device at each service connection to his premises. The customer shall, within 90 days, install such approved device, or devices, at his own expense, and failure or refusal or inability on the part of the customer to install said device or devices within 90 days shall constitute a ground for discontinuing water service to the premises until such device or devices have been properly installed.

IV. Definitions

a. Approved

Accepted by the Director of Municipal Services as meeting an applicable specification stated or cited in this regulation or as suitable for the proposed use.

b. Auxiliary Water Supply

Any water supply on or available to the premises other than the purveyor's approved public potable water supply.

c. *Backflow*

The flow of water or other liquids, mixtures or substances, under positive or reduced-pressure, in the distribution pipes of a potable water supply from any source other than its intended source.

d. *Backflow Preventer*

A device or means designed to prevent backflow or back-siphonage.

d.1. *Air Gap*

A physical separation sufficient to prevent backflow between the free-flowing discharge end of the potable water system and any other system. Physically defined as a distance equal to twice the diameter of the supply side pipe diameter but never less than 1 inch (25.4 mm).

d.2. *Atmospheric Vacuum Breaker*

A device that prevents back-siphonage by allowing sufficient air to enter the water system so that backflow is prevented.

d.3. *Barometric Loop*

A fabricated piping arrangement rising at least 35 feet at its topmost point above the highest fixture it supplies. It is utilized in water supply systems to protect against back-siphonage.

d.4. *Dual-check Valve Assembly*

An assembly of two independently operating spring-loaded check valves with tightly closing shutoff valves on each side of the check valves, plus properly located test cocks for the testing of each check valve.

d.5. *Double-check Valve with Intermediate Atmospheric Vent*

A device having two spring-loaded check valves separated by an atmospheric vent chamber.

d.6. ***Hose Bibb Vacuum Breaker***

A device that is permanently attached to a hose bibb and that acts as an atmospheric vacuum breaker.

d.7. ***Pressure-type Vacuum Breaker***

A device containing one or two independently operated spring-loaded check valves and an independently operated spring-loaded air inlet valve located on the discharge side of the check or checks. The device includes tightly closing shutoff valves on each side of the device and properly located test cocks for device testing.

d.8. ***Spill-resistant Vacuum Breaker***

A device containing one or two independently operated spring-loaded check valves and the independently operated spring-loaded air inlet valve mounted on a diaphragm that is located on the discharge side of the check or checks. The device includes tightly closing shutoff valves on each side of the device and properly located test cocks for device testing.

d.9. ***Reduced-pressure Principle Backflow Preventer***

An assembly consisting of two independently operating check valves with an automatically operating differential relief valve located between the two check valves, tightly closing shutoff valves on each side of the device, and properly located test cocks for device testing.

d.10. ***Residential Dual Check***

An assembly of two spring-loaded, independently operating check valves without tightly closing shutoff valves and test cocks. Generally, it is employed immediately downstream of a residential water meter to act as a containment device.

e. Back-pressure

A condition in which the owner's system pressure is greater than the supplier's system pressure.

f. Back-siphonage

A backflow that occurs when the pressure in the water piping falls to less than the local atmospheric pressure.

g. Commission

The State of [ ] Water Supply and Pollution Control Commission.

h. Containment

A method of cross-connection control in the water service.

i. Contaminant

A substance that impairs the quality of the water to a degree that it creates a serious health hazard to the public, leading to poisoning or the spread of disease.

j. Cross-connection

Any actual or potential connection between the public water supply and a source of contamination or pollution.

k. Department

City of [ ] Water Department.

l. Director of Municipal Services

The Director, or his delegated representative, in charge of the Department of Municipal Services is invested with the authority and responsibility for the implementation of a cross-connection control program and for the enforcement of the provisions of the Ordinance.

m. Fixture Isolation

A method of cross-connection control in which a backflow preventer is located to correct a cross-connection at a fixture location or equipment location. Such isolation may be in addition to containment.

n. Owner

Any person who has legal title to, or license to operate or habituate in, a property where a cross-connection inspection is to be made or in which a cross-connection is present.

o. Permit

A document issued by the Department that allows the use of a backflow preventer.

p. Person

Any individual, partnership, company, public or private corporation, political subdivision or agency of the State Department, agency or instrumentality of the United States, or any other legal entity.

q. Pollutant

A foreign substance that, if permitted to get into the public water system, will degrade its quality so as to constitute a moderate hazard or to impair the usefulness or quality of the water to a degree that is not an actual hazard to public health but adversely and unreasonably affects the water for domestic use.

r. Water Service Entrance

That point in the owner's water system beyond the sanitary control of the District; generally considered to be the outlet end of the water meter and always before any unprotected branch.

V. Administration

a. The Department will operate a cross-connection control program to include the keeping of necessary records that fulfill the requirements of the Commission's Cross-Connection Regulations and is approved by the Commission.

b. The Owner shall allow his property to be inspected for possible cross-connections and shall follow the provisions of the Department's program and the Commission's Regulations if a cross-connection is permitted.

c. If the Department requires that the public supply be protected by containment, the Owner shall be responsible for water quality beyond the outlet end of the containment device and should utilize fixture outlet protection for that purpose.

d. The Department may utilize public health officials, or personnel from the Department, or their delegated representatives, to assist in the survey of facilities and to assist in the selection of proper fixture outlet devices, and the proper installation of these devices.

VI. Requirements

a. Department

1. On new installations, the Department will provide on-site evaluation and/or inspection of plans in order to review the type of backflow preventer, if any, that will be required and will issue a permit.
2. For premises existing prior to the start of this program, the Department will perform evaluations and inspections of plans and/or premises and inform the owner by letter of any corrective action deemed necessary, the method of achieving the correction, and the time allowed for the correction to be made. Ordinarily, 90 days will be allowed, depending upon the degree of hazard involved and the history of the device(s) in question.
3. The Department will not allow any cross-connection to remain unless it is protected by an approved backflow preventer for which a permit has been issued and which will be regularly tested to ensure satisfactory operation.
4. The Department shall inform the Owner, by letter, of any failure to comply by the time of the first re-inspection. The Department will allow an additional 15 days for the correction. In the event the Owner fails to comply with the necessary correction by the time of the second re-inspection, the Department will inform the Owner, by letter, that the water service to the Owner's premises will be terminated within a period not to exceed five days. In the event that the Owner informs the Department of extenuating circumstances as to why the correction has not been made, a time extension may be granted by the Department but in no case will exceed an additional 30 days.
5. If the Department determines at any time that a serious threat to the public health exists, the water service will be terminated immediately.
6. The Department shall have, on file, a list of private contractors who are certified backflow device testers. All charges for these tests will be paid by the Owner of the building or property.
7. The Department will begin inspections to determine the nature of existing hazards, following the approval of this program by the Commission, during the calendar year [ ]. Initial focus will be on high-hazard industries and commercial premises.

b. Non-residential Owner

1. The Owner shall be responsible for the elimination or protection of all cross-connections on his premises.
2. The Owner, after having been informed by a letter from the Department, shall, at his expense, install, maintain, and test, or have tested, any and all backflow preventers on his premises.
3. The Owner shall correct any malfunction of the backflow preventer that is revealed by periodic testing.
4. The Owner shall inform the Department of any proposed or modified cross-connections and also any existing cross-connections of which the Owner is aware but have not been found by the Department.
5. The Owner shall not install a bypass around any backflow preventer unless there is a backflow preventer of the same type on the bypass. Owners who cannot shut down operation for testing of the device(s) must supply additional devices necessary to allow testing to take place.
6. The Owner shall install backflow preventers in a manner approved by the Department.
7. The Owner shall install only backflow preventers approved by the Department or the Commission.
8. Any Owner having a private well or other private water source, must have a permit if the well or source is cross-connected to the Department's system. Permission to cross-connect may be denied by the Department. The Owner may be required to install a backflow preventer at the service entrance if a private water source is maintained, even if it is not cross-connected to the Department's system.

9. In the event the Owner installs plumbing to provide potable water for domestic purposes that are on the Department's side of the backflow preventer, such plumbing must have its own backflow preventer installed.
10. The Owner shall be responsible for the payment of all fees for permits and annual or semiannual device testing. For devices that failed to operate correctly, the Owner shall be responsible for the payment of retesting and subsequent inspections.
11. The Department strongly recommends that all new retrofit installations of reduced-pressure principle devices and double-check valve backflow preventers include the installation of strainers located immediately upstream of the backflow device. However, the use of strainers may not be acceptable by the fire protection authority having jurisdiction. The installation of strainers will preclude the fouling of backflow devices due to both foreseen and unforeseen circumstances occurring to the water supply system such as water main repairs, water main breaks, fires, periodic cleaning, and flushing of mains. These occurrences may stir up debris within the water main that will cause fouling of backflow preventers.

c. Residential Owner

Effective the date of the acceptance of this Cross-Connection Control Program for the Town of [ ], all new residential buildings will be required to install a residential dual-check device immediately downstream of the water meter. Installation of this residential dual-check device on a retrofit basis on existing service lines will be instituted at a time and at a potential cost to the homeowner as deemed necessary by the Department.

The Owner must be aware that installation of a residential dual-check valve results in a potential closed plumbing system within his residence. As such, provisions may have to be made by the Owner to provide for thermal expansion within his closed loop system, i.e., the installation of thermal expansion devices and/or pressure-relief valves.

VII. DEGREE OF HAZARD

The Department recognizes the threat to the public water system arising from cross-connections. All threats shall be classified by degree of hazard and shall require the installation of approved cross-connection control devices.

VIII. PERMITS

The Department shall not permit a cross-connection within the public water supply system unless it is considered necessary and that it cannot be eliminated.

a. Cross-connection permits that are required for each cross-connection control device are obtained from the Department. A fee of $[XX.XX] will be charged for the initial permit and $[XX.XX] for the renewal of each permit.
b. Permits shall be renewed every [ ] year(s) and are nontransferable. Permits are subject to revocation and become immediately revoked if the Owner should so change the type of cross-connection or degree of hazard associated with the service.
c. A permit is not required when fixture isolation is achieved with the utilization of a nontestable backflow preventer.

IX. EXISTING IN-USE CROSS-CONNECTION CONTROL DEVICES

Any existing backflow preventer shall be allowed by the Department to continue in service unless the degree of hazard is such as to supersede the effectiveness of the present backflow preventer, or result in an unreasonable risk to the public health. Where the degree of hazard has increased, as in the case of a residential installation converting to a business establishment, any existing backflow preventer must be upgraded to a reduced-pressure principle device, or a reduced-pressure principle device must be installed in the event that no backflow device was present.

X. PERIODIC TESTING

a. Reduced-pressure principle backflow devices, double-check valve devices, pressure-type vacuum breakers, and spill-resistant vacuum breakers shall be tested and inspected at least semiannually or as required by the administrative authority.
b. Periodic testing shall be performed by the Department's certified tester or his delegated representative. This testing shall be done at the Owner's expense.
c. The testing shall be conducted during the Department's regular business hours. Exceptions to this, when at the request of the Owner, may require additional charges to cover the increased costs to the Department.
d. Any backflow preventer that fails during a periodic test shall be repaired or replaced. When repairs are necessary, upon completion of the repair, the device shall be retested at the Owner's expense to ensure correct operation. High-hazard situations shall not be allowed to continue unprotected if the backflow preventer fails the test and cannot be repaired immediately. In other situations, a compliance date of not more than 30 days after the test date will be established. The Owner is responsible for spare parts, repair tools, or a replacement device. Parallel installation of two

devices is an effective means of the Owner ensuring uninterrupted water service during testing or the repair of devices and is strongly recommended when the owner desires such continuity.

e. Cross-connection control devices shall be tested more frequently than specified in item a above in cases where there is a history of test failures and the Department feels that, due to the degree of hazard involved, additional testing is warranted. Cost of the additional tests shall be borne by the Owner.

XI. RECORDS AND REPORTS

a. Records

The Department will initiate and maintain the following:

1. Master files on customer cross-connection tests and/or inspections
2. Master files on cross-connection permits
3. Copies of permits and permit applications
4. Copies of lists and summaries supplied to the Commission

b. Reports

The Department shall submit the following to the Commission:

1. Initial listing of low-hazard cross-connections to the State
2. Initial listing of high-hazard cross-connections to the State
3. Annual update lists of items 1 and 2 above
4. Annual summary of cross-connection inspections to the State

XII. FEES AND CHARGES

The Department will publish a list of fees or charges for the following services or permits:

a. Testing fees

b. Retesting fees

c. Fee for reinspection

d. Charges for after-hours inspections or tests

APPENDIX 9-B PLUMBING SYSTEM HAZARDS

DIRECT CONNECTIONS

Description

Air-conditioning, air washer
Air-conditioning, chilled water
Air-conditioning, condenser water
Air line
Aspirator, laboratory
Aspirator, medical
Aspirator, herbicide and fertilizer sprayer
Autoclave and sterilizer
Auxiliary system, industrial
Auxiliary system, surface water
Auxiliary system, unapproved well supply
Boiler system
Chemical feeder, pot type
Chlorinator
Coffee urn
Cooling system
Dishwasher
Fire standpipe
Fire sprinkler system
Fountain, ornamental
Hydraulic equipment
Laboratory equipment
Lubrication, pump bearings
Photostat equipment
Plumber's friend, pneumatic
Pump, pneumatic ejector
Pump, prime line
Pump, water-operated ejector
Sewer, sanitary
Sewer, storm
Swimming pool or spa equipment

POTENTIAL SUBMERGED INLETS

Description

Baptismal font
Bathtub
Bedpan washer, flushing rim
Bidet
Brine tank
Cooling tower
Cuspidor
Drinking fountain
Floor drain, flushing rim
Garbage can washer
Ice maker
Laboratory sink, serrated nozzle
Laundry machine
Lavatory
Lawn sprinkler system
Photo laboratory sink
Sewer flushing manhole
Slop sink, flushing rim

Slop sink, threaded supply
Steam table
Urinal, siphon jet blowout
Vegetable peeler
Water closet, flush tank, ball cock
Water closet, flush valve, siphon jet

APPENDIX 9-C AMERICAN WATER WORKS ASSOCIATION STATEMENT OF POLICY

The American Water Works Association recognizes that the water purveyor has a responsibility to provide its customers at the service connection with water that is safe under all foreseeable circumstances. Thus, in the exercise of this responsibility, the water purveyor must take reasonable precaution to protect the community distribution system from the hazards originating on the premises of its customers that may degrade the water in the community distribution system.

Cross-connection control and plumbing inspections on the premises of water customers are regulatory in nature and should be handled through the rules, regulations, and recommendations of the health authority or the plumbing code enforcement agencies having jurisdiction. The water purveyor, however, should be aware of any situation requiring inspection and/or reinspection necessary to detect hazardous conditions resulting from cross-connections. If, in the opinion of the utility, effective measures consistent with the degree of hazard have not been taken by the regulatory agency, the water purveyor should take such measures as he deems necessary to ensure that the community distribution system is protected from contamination. Such action would include the installation of a cross-connection control device, consistent with the degree of hazard at the service connection or discontinuance of the service.

In addition, customer use of the water from the community distribution system for cooling or other purposes within the customer's system and later return of the water to the community distribution system is not acceptable and is opposed by AWWA.

APPENDIX 9-D APPLICATION OF CROSS-CONNECTION CONTROL DEVICES

Standard	Device or Method	Type of Protection[a]	Hazard	Installation Dimensions and Position	Pressure Condition[b]	Comments	Use
ANSI A 112.2.1	Air Gap	BS and BP	High	Twice effective opening; not less than 1 inch above flood rim level	C		Lavatory, sink or bathtub spouts, Residential dishwasher (ASSE 1006) and clothes washers (ASSE 1007)
ASSE 1001	Pipe-applied vacuum breaker	BS	Low	6 inches above highest outlet; vertical position only	I		Goosenecks and appliances not subject to back pressure or continuous pressure
ASSE 1011	Hose bibb vacuum breaker	BS	Low	Locked on hose bibb threads; at least 6 inches above grade	I	Freeze-resistant type required	Hose bibbs, hydrants, and sillcocks
ASSE 1012[c]	Dual-check valve with atmospheric vent	BS and BP	Low to moderate	Any position; drain piped to floor	C	Air gap required on vent outlet; vent piped to suitable drain	Residential boilers, spas, hot tubs, and swimming pool feedlines, sterilizers; food processing equipment; photo lab equipment; hospital equipment; commercial dishwashers; water-cooled HVAC; landscape hose bibb; washdown racks; makeup water to heat pumps
ASSE 1013	Reduced-pressure zone backflow preventer	BS and BP	High	Inside building: 18–48 inches (centerline to floor); outside building: 18–24 inches (centerline to floor); horizontal only	C	Testing annually (minimum); Overhaul five years (minimum); drain	Chemical tanks; submerged coils; treatment plants; solar systems; chilled water; heat exchangers; cooling towers; lawn irrigation (Type II); hospital equipment; commercial boilers, swimming pools, and spas; fire sprinkler (high hazard as determined by commission)
ASSE 1015	Dual-check valve assembly	BS and BP	Low	Inside and outside building: 18–24 inches (centerline to floor); horizontal only; 60 inches required above device for testing	C	Testing annually (minimum); overhaul five years (minimum)	Fire sprinkler systems (Type II low hazard); washdown racks; large pressure cookers and steamers
ASSE 1020	Pressure-type vacuum breaker	BS	High	12–60 inches above highest outlet; vertical only	C	Testing annually (minimum); overhaul five years (minimum)	Degreasers; laboratories; photo tanks; Type I lawn sprinkler systems and swimming pools (must be located outdoors)
ASSE 1024[c]	Dual-check valve	BS and BP	Low	Any position	C		Fire sprinkler systems (Type I building); outside drinking fountains; automatic grease recovery device
ASSE 1035	Atmospheric	BS	Low	6 inches above flood level per manufacturer	I/C		Chemical faucets; ice makers; dental chairs; miscellaneous faucet applications; soft drink, coffee, and other beverage dispensers; hose sprays on faucets not meeting standards
ASSE 1056	Spill-resistant indoor vacuum breaker	BS	High	12–60 inches above highest outlet; vertical only	C	Testing annually (minimum); overhaul five years (minimum)	Degreasers; laboratories; photo tanks; Type I lawn sprinkler systems and swimming pools (must be located outdoors)

[a] BS = Back-siphonage; BP = Back-pressure

[b] I = Intermittent; C = Continuous

[c] A tab shall be affixed to all ASSE 1012 and 1024 devices indicating installation date and the following statement: "FOR OPTIMUM PERFORMANCE AND SAFETY, IT IS RECOMMENDED THAT THIS DEVICE BE REPLACED EVERY FIVE (5) YEARS."

APPENDIX 9-E SAFE DRINKING WATER ACT MAXIMUM CONTAMINANT LEVELS

Primary Contaminants	Maximum Containment Level (MCL)
Metals	
Arsenic	0.05 mg/L
Baruim	2.0 mg/L
Cadmium	0.005 mg/L
Chromium	0.1 mg/L
Copper	1.3 mg/L
Lead[a]	0.015 mg/L
Mercury	0.002 mg/L
Selenium	0.05 mg/L
Nonmetals	
Fluoride	4.0 mg/L
Nitrate	10.0 mg/L
Volatile Organic Chemicals	
Total trihalomethanes	0.10 mg/L
Benzene	0.005 mg/L
Vinyl chloride	0.002 mg/L
Carbon tetrachloride	0.005 mg/L
1,2-dichloroethane	0.005 mg/L
Trichloroethylene (TCE)	0.005 mg/L
1,4-dichlorobenzene	0.075 mg/L
1,1-dichloroethylene	0.007 mg/L
1,1,1-trichloroethane	0.2 mg/L
o-dichlorobenzene	0.6 mg/L
cis- 1,2-dichloroethylene	0.07 mg/L
trans- 1,2-dichloroethylene	0.1 mg/L
1,2-dichloropropane	0.005 mg/L
Ethylbenzene	0.7 mg/L
Monochlorobenzene	0.1 mg/L
Styrene	0.1 mg/L
Toluene	1.0 mg/L
Xylenes	10.0 mg/L
Tetrachloroethylene	0.005 mg/L
Herbicides, Pesticides, PCBs	
Chlordane	0.002 mg/L
Endrin	0.0002 mg/L
Heptachlor	0.0004 mg/L
Hexachlorobenzene	0.001 mg/L
Lindane	0.0002 mg/L
Methoxychlor	0.04 mg/L

Primary Contaminants	Maximum Containment Level (MCL)
Toxaphene	0.003 mg/L
PCBs	0.0005 mg/L
2,4-D	0.07 mg/L
2,4,5-TP Silvex	0.05 mg/L
Alachlor	0.002 mg/L
Atrazine	0.003 mg/L
Carbofuran	0.04 mg/L
1,2-dibromo-3-chloropropane (DBCP)	0.0002 mg/L
Ethylene dibromide (EDB)	0.00005 mg/L
Heptachlor epoxide	0.0002 mg/L
Phenols	
Pentachlorophenol	0.001 mg/L
Physical Parameters	
Turbidity (in turbidity units)	5 TU
Radioactivity	15 picocuries
Microbiology	
Coliform bacteria	0 per 100 mL
Secondary Contaminants	
Iron	0.3 mg/L
Manganese	0.05 mg/L
Zinc	5.0 mg/L
Chloride	250 mg/L
Sulfate	250 mg/L
Total dissolved solids	500 mg/L
Color	15 units
Corrosivity	none
Foaming agents	0.5 mg/L
Odor	3 T.O.N.
pH	6.5–8.5

Note: For these purposes, mg/L = milligrams per liter; ppm = parts per million; 1 ppm = 1,000 ppb; ppb = parts per billion; μg/L = micrograms per liter

[a] Level that requires action

APPENDIX 9-F INDEX OF WATER TREATMENT EQUIPMENT/WATER PROBLEMS

	Problem and/or Pollutant																																						
Equipment Options [a]	Aluminum	Arsenic	Asbestos	Barium	Cadmium	Chloride	Chlorine [b]	Chromium	Color	Copper	Endrin	Fluroide	Giardia Cysts	Hardness	Iron (Fe2)	Iron (Fe3)	Lead [c]	Lindane	Manganese	Mercury	Methoxychlor	Nitrate	Particulates	Pesticides, Herbicides, PCBs	Radium	Radon	Selenium	Silver	Sulfate	Tannic Acids	Taste & Odor	Total Dissolved Solids	Total Trihalomethanes (TTHMs)	Toxaphene	Turbidity	VOCs	Zinc	2,4–D	2,4,5–TP Silvex
Carbon							•		•		•						•	•			•			•		•				•	•		•	•	•	•		•	•
Filtration			•						•				•		•								•												•				
Reverse osmosis	•	•	•	•	•	•	•	•	•	•		•	•	•	•	•	•		•	•		•	•		•		•	•	•			•			•		•		
Distillation	•	•		•	•	•		•		•		•	•	•	•	•	•		•	•		•	•		•		•	•	•	•		•			•		•		
Cation exchange					•	•				•				•	•				•						•														
Mineral bed															•																								
Activated alumina		•										•					•										•												
Anion exchange							•															•							•										

[a] Some equipment may reduce additional contaminants because of its unique design and/or combinations of technology. Ask for proof of performance.
[b] Not all reverse osmosis units are effective for chlorine reduction. Ask for proof of performance.
[c] Not all carbon units are effective for lead reduction. Ask for proof of performance.

APPENDIX 9-G CASE STUDIES OF CROSS-CONTAMINATION

The following documentation outlines cases of cross-connection incidents registered with the EPA that illustrate and emphasize how actual cross-connections have compromised and continue to compromise drinking water quality and public health.

HUMAN BLOOD IN WATER SUPPLY

Health department officials cut off the water supply to a funeral home located in a large city after it was determined that human blood had contaminated the freshwater supply. City water and plumbing officials said they did not think that the blood contamination had spread beyond the building; however, inspectors were sent into the neighborhood to check for possible contamination. The chief plumbing inspector had received a telephone call advising that blood was coming from drinking fountains within the building. Plumbing and county health department officials and inspectors went to the scene and found evidence that the blood had been circulating in the water system within the building. They immediately ordered the building cut off from the water system at the meter.

Investigation revealed that the funeral home had been using a hydraulic aspirator to drain fluids from human remains as part of the embalming process. The aspirator directly connected to the water supply system at a faucet outlet located on a sink in the preparation (embalming) room. Water flow through the aspirator created suction that was utilized to draw body fluids through a hose and needle attached to the suction side of the aspirator.

The contamination of the funeral home's potable water supply was caused by a combination of low water pressure in conjunction with the simultaneous use of the aspirator. Instead of the body fluids flowing into the sanitary system drain, they were drawn in the opposite direction into the potable water supply of the funeral home.

CHEMICAL BURN IN THE SHOWER

A resident of a small town in Alabama jumped into the shower at 5 a.m., and when he got out his body was covered with tiny blisters. "The more I rubbed it, the worse it got," the 60-year-old resident said. "It looked like someone took a blow torch and singed me." He and several other residents received medical treatment at the emergency room of the local hospital after it was discovered that the water system was contaminated with sodium hydroxide, a strong caustic solution. One resident claimed that the water "bubbled up and looked like Alka-Seltzer. I stuck my hand under the faucet and some blisters came up." One neighbor's head was covered with blisters after she washed her hair, and others complained of burned throats or mouths after drinking the water.

The incident began after an 8-inch water main that fed the town broke and was repaired. While repairing the water main, one workman suffered leg burns from a chemical in the water and required medical treatment. Measurements of the pH of the water were as high as 13 in some sections of the pipe.

Investigation into the cause of the problem led to a nearby chemical company that distributes chemicals such as sodium hydroxide as a possible source of the contamination. The sodium hydroxide was brought to the plant in liquid form in bulk tanker trucks, transferred to a holding tank, and then dumped into 55-gallon drums. When the water main broke, a truck driver was adding water from the bottom of the tank truck instead of the top, and sodium hydroxide back-siphoned into the water main.

PROPANE GAS IN WATER SUPPLY

Hundreds of people were evacuated from their homes and businesses on an August afternoon as a result of propane entering a city's water supply system. Fires were reported in two homes, and the town water supply was contaminated. One five-room residence was gutted by a blaze resulting from propane gas "bubbling and hissing" from a bathroom toilet. In another home, a washing machine explosion blew a woman against a wall. Residents throughout the area reported hissing, bubbling noises coming from washing machines, sinks, and toilets. Faucets sputtered out small streams of water mixed with gas, and residents in the area were asked to evacuate their homes.

This near disaster occurred when the gas company initiated immediate repair procedures in one 30,000-gallon capacity liquid propane tank. To start the repair, the tank was purged of residual propane using water from one of two private fire hydrants located on the property. Water purging is the method of purging preferred over carbon dioxide, since it is more positive and floats out any sludge as well as any gas vapors. The purging consisted of hooking up a hose to one of the private fire hydrants located on the property and initiating flushing procedures.

Since the vapor pressure of the propane residual in the tank was 85 psi to 90 psi and the water pressure was only 65 psi to 70 psi, propane gas back-pressure backflowed into the water main. It was estimated that the gas flowed into the water mains for about 20 minutes and about 2,000 cubic feet of gas was involved. This was enough gas to fill approximately 1 mile of an 8-inch water main.

BOILER WATER ENTERS HIGH SCHOOL DRINKING WATER

A high school was closed for several days when a home economics teacher noticed that the water in the potable water system was yellow. City chemists determined that the samples taken contained levels of chromium as high as 700 parts per million, "astronomically higher than the accepted levels of 0.05 parts per million." The head chemist said that it was miraculous that no one was seriously injured or killed by the high levels of chromium. The chemical was identified as sodium dichromate, which is used in heating system boilers to inhibit corrosion of the metal parts.

No students or faculty were known to have consumed any water; however, area physicians and hospitals advised that if anyone had consumed those high levels of chromium, the symptoms would be nausea and burning of the mouth and throat. Fortunately, the home economics teacher, who saw the discolored water before school started, immediately covered all water fountains with towels so that no one would drink the water.

Investigation disclosed that chromium used in the heating system boilers to inhibit the corrosion of metal parts entered the potable water supply system as a result of backflow through leaking check valves on the boiler feed lines.

CARWASH WATER IN CITY MAIN

This carwash cross-connection and back-pressure incident resulted in backflow chemical contamination of approximately 100 square blocks of water mains. Because of the prompt response by the water department, a potentially hazardous water quality degradation problem was resolved without a recorded case of illness.

Numerous complaints of gray-green and "slippery" water were received by the water department from the same general area of town. A sample brought to the water department by a customer confirmed the reported problem, and preliminary analysis indicated contamination with what appeared to be a detergent solution. While emergency crews initiated flushing operations, further investigation within the contaminated area signaled that the problem probably was caused by a carwash or laundry because of the soapy nature of the contaminant.

The source was quickly narrowed down to a carwash, and the proprietor was very cooperative, admitting to the problem and explaining how it had occurred. On Saturday, a high-pressure pump had broken down at the carwash. This pump recycled reclaimed wash and rinse water and pumped it to the initial scrubbers of the carwash. A potable water connection is not normally made to the carwash's scrubber system. After the pump broke down, the carwash owner was able to continue operation by temporarily connecting a 2-inch hose section between the potable water supply within the carwash and the scrubber cycle piping.

On Monday, the owner repaired the high-pressure pump and resumed normal carwash operations. The 2-inch hose connection (cross-connection) was not removed. Because of the cross-connection, the newly repaired high-pressure pump promptly pumped a large quantity of the reclaimed wash/rinse water out of the carwash and into a 12-inch water main in the street. This in turn was delivered to the many residences and commercial establishments connected to the water main.

Within 24 hours of the incident, the owner of the carwash had installed a 2-inch reduced-pressure principle backflow preventer on his water service, and all carwash establishments in his town that used a wash water reclaim system were notified of the state requirement for cross-connection control.

SHIPYARD BACKFLOW CONTAMINATION

Water fountains at an East Coast shipyard were marked "No Drinking" as workers flushed the water lines to eliminate raw river water that had entered the shipyard following contamination from incorrectly connected water lines between ships at the pier and the shipyard. Some third shift employees drank the water before the pollution was discovered and later complained of stomach cramps and diarrhea.

The cause of the problem was a direct cross-connection between the on-board salt water fire protection water system and the freshwater connected to one of the ships at the dock. While the shipyard had been aware of the need for backflow protection at the dockside tie-up area, the device had not been delivered and installed prior to the time of the incident. As a result, the salt water on-board fire protection system, being at a greater pressure than the potable water supply, forced the salt water, through back-pressure, into the shipyard's potable water supply system.

Fortunately, a small demand for potable water at the time of the incident prevented widespread pollution in the shipyard and the surrounding areas.

HEXAVALENT CHROMIUM IN WATER SUPPLY

A well-meaning maintenance mechanic, attempting to correct a fogging lens in an overcooled laser machine, installed a tempering valve in the laser cooling line and inadvertently set the stage for a back-pressure backflow incident that resulted in hexavalent chromium contaminating the potable water of a large electronic manufacturing company employing 9,000 people. Quantities of 50 parts per million hexavalent chromium were found in the drinking water, which is sufficient to cause severe vomiting, diarrhea, and intestinal sickness.

Maintenance crews working during the plant shutdown were able to eliminate the cross-connection and thoroughly flush the potable water system, thereby preventing a serious health hazard from occurring.

The incident occurred as follows. Laser machine lenses were kept cool by circulating chilled water that came from a large refrigeration chiller. The water used in the chiller was treated with hexavalent chromium, a chemical additive used as an anticorrosive agent and an algicide. As a result, the chilled water presented a toxic, nonpotable substance unfit for human consumption but very acceptable for industrial process water. No health hazard was present as long as the piping was identified, kept separate from potable drinking water lines, and not cross-connected to the potable water supply.

A maintenance mechanic correctly reasoned that by adding a tempering valve to the chilled water line, he could heat up the water and eliminate fogging of the laser lenses resulting from the chilled water being too cold. The problem with the installation of the tempering valve was that a direct cross-connection was inadvertently made between the toxic chilled water and the potable drinking water system.

Periodic maintenance to the chiller was performed in the summer, requiring that an alternate chiller feed pump be temporarily installed. This replacement pump had an outlet pressure of 150 psi and promptly established an imbalance of pressure at the tempering valve, thereby over-pressurizing the 60-psi potable water supply. Back-pressure backflow resulted and pushed the toxic chilled water from the water heater and then into the plant's potable drinking water supply system. Yellowish-green water started pouring out of drinking fountains, the washroom, and all potable water outlets.

DIALYSIS MACHINE CONTAMINATION

Ethylene glycol, an antifreeze additive to air-conditioning cooling tower water, inadvertently entered the potable water supply system in a medical center, and two of six dialysis patients succumbed as a direct or indirect result of the contamination. The glycol was added to the air-conditioning water, and the glycol water mix was stored in a holding tank that was an integral part of the medical center's air-conditioning cooling system. Pressurized makeup water for the holding tank was supplied by a medical center potable water supply line and fed through a manually operated control valve. With this valve open, or partially open, potable makeup water flowed slowly into the

10 Water Treatment

Many types of possible pathogenic organisms can be found in source water. These include dissolved gases, suspended matter, undesirable minerals, pollutants, and organic matter. These substances can be separated into two general categories: chemical and biological. They generally require different methods of remediation. No single filtration or treatment process satisfies all water-conditioning requirements.

Surface water may contain more of these contaminants than groundwater, but groundwater, while likely to contain less pathogens than surface water, may contain dissolved minerals and have undesirable tastes and odors. Water provided by public and private utilities is regarded to be potable, or adequately pure for human consumption so long as it meets the standards of the U.S. Environmental Protection Agency's Safe Drinking Water Act and the local health official. However, such water still might contain some levels of pathogens and other undesirable components. Even if the water quality is not such that it would cause a specific health threat to the general public, it may not be suitable for buildings such as hospitals and nursing homes that house populations that may be more vulnerable. Moreover, it may not be pure enough for certain industrial, medical, or scientific purposes.

This chapter reviews the principles of basic water treatment, provides information on additional treatment (including a section on the selection and sizing of water softeners), and finally gives an overview of specialized treatment techniques. For the reader's reference, the common chemical compounds used in connection with water softeners are tabulated in Table 10-1.

Table 10-1 Chemical Names, Common Names and Formulas

Chemical Name	Common Name	Formula
Bicarbonate (ion)	—	HCO_3^-
Calcium (metal)	—	Ca^{2+}
Calcium bicarbonate	—	$Ca(HCO_3)_2$
Calcium carbonate	Chalk, limestone, marble	$CaCO_3$
Calcium hypochlorite	Bleaching powder, chloride of lime	$Ca(ClO)_2$
Chlorine (gas)	—	Cl_2
Calcium sulfate	—	$CaSO_4$
Calcium sulfate	Plaster of paris	$CaSO_4.½H_2O$
Calcium sulfate	Gypsum	$CaSO_4.2H_2O$
Carbon	Graphite	C
Carbonate (ion)	—	CO_3^{2-}
Carbon dioxide	—	CO_2
Ferric oxide	Burat ochre	Fe_2O_3
Ferruous carbonate	—	$FeCO_3$
Ferrous oxide	—	FeO
Hydrochloric acid	Muriatic acid	HCl
Hydrogen (ion)	—	H^+
Hydrogen (gas)	—	H_2
Hydrogen sulfide	—	H_2S
Iron (ferric ion)	—	Fe^{3+}
Iron (ferrous ion)	—	Fe^{2+}
Magnesium bicarbonate	—	$Mg(HCO_3)_2$
Magnesium carbonate	Magnesite	$MgCO_3$
Magnesium oxide	Magnesia	MgO
Magnesium sulfate	—	$MgSO_4$
Magnesium sulfate	Epsom salt	$MgSO_4.7H_2O$
Manganese (metal)	—	Mn
Methane	Marsh gas	CH_4
Nitrogen (gas)	—	N_2
Oxygen (gas)	—	O_2
Potassium (metal)	—	K
Potassium permanganate	Permanganate of potash	$KMnO_4$
Sodium (metal)	—	Na
Sodium bicarbonate	Baking soda, bicarbonate of soda	$NaHCO_3$
Sodium carbonate	Soda ash	Na_2CO_3
Sodium carbonate	Sal soda	$Na_2CO_3.10H_2O$
Sodium chloride	Salt	NaCl
Sodium hydroxide	Caustic soda, lye	NaOH
Sodium sulfate	Glauber's salt	$Na_2SO_4.10H_2O$
Sulfate (ion)	—	SO_4^{2-}
Sulfuric acid	Oil of vitrol	H_2SO_4
Water	—	H_2O

NEED AND PURPOSE FOR WATER TREATMENT

Damage by Untreated Water

Impure water damages piping and equipment by scoring, scaling, and corroding. Under certain conditions, water containing particles in suspension erodes the piping and scores moving parts. Water containing dissolved acidic chemicals in sufficient quantities dissolves the metal surfaces with which it comes in contact. Pitted pipe and tank walls are common manifestations of the phenomenon called corrosion.

Scaling occurs when calcium or magnesium compounds in the water (in a condition commonly known as water hardness) become separated from the water and adhere to the piping and equipment surfaces. This separation is usually induced by a rise in temperature (as these minerals become less soluble as the temperature increases). In addition to restricting flow, scaling causes damage to heat-transfer surfaces by decreasing heat-exchange capabilities. The result of this condition is the overheating of tubes, followed by failures and equipment damage.

Table 10-2 can be used to identify solutions to listed impurities and constituents found in water.

External and Internal Treatment

Changing the chemical composition of the water by means of mechanical devices (filters, softeners, demineralizers, deionizers, and reverse osmosis) is called external treatment because such treatment is outside the equipment into which the water flows. Neutralizing the objectionable constituents by adding chemicals to the water as it enters the equipment is referred to as internal treatment. Economic considerations usually govern the choice between the two methods.

Sometimes it is necessary to apply more than one technology. For instance, a water softener may be required to treat domestic water, but a reverse osmosis system may be needed before the water is sent to HVAC or medical equipment. Another example is the need for an iron prefilter to remove large iron particles to protect a reverse osmosis membrane, which would be damaged by the iron particles.

BASIC WATER TYPES

Following are the basic types of water.

- Raw water is received from a well, surface water, etc.
- Tower water is monitored and controlled for pH, algae, and total dissolved solids.
- Potable water is filtered, chlorinated, and/or otherwise treated to meet the local health department's standards for drinking water as well as the Safe Drinking Water Act.

Table 10-2 Water Treatment—Impurities and Constituents, Possible Effects and Suggested Treatments

	Possible Effects[a]							Treatment							
Constituents	Scale	Corrosion	Sludge	Foamin	Priming	Embritlement	None (Inert)	Setting, coagulation, filtration, evaporation	Setting, coagulation, filtration, evaporation, ion exchange	Softening by chemicals, ion exchange materials, evaporators	Softening by heaters, chemicals, ion exchange materials, evaporatiors	Neutralizing, followed by softening or evaporation	Evaporation and demineralization by ion-exchange material	De-aeration	Coagulation, filtration, evaporation
Suspended solids	X		X	X	X			X							
Silica — SiO_2	X								X						
Calcium carbonate — $CaCO_3$	X									X					
Calcium bicarbonate — $Ca(HCO_3)_2$	X										X				
Calcium Sulfate — $CaSO_4$	X	X								X					
Calcium chloride — $CaCl_2$	X									X					
Magnesium carbonate — $MgCO_3$	X									X					
Magnesium bicarbonate — $Mg(HCO_3)_2$	X									X					
Magnesium chloride — $MgCl_2$	X	X								X					
Free acids — HCl, H_2SO_4		X										X			
Sodium chloride — NaCl							X						X		
Sodium carbonate — Na_2CO_3				X	X	X							X		
Sodium bicarbonate — $NaHCO_3$				X	X	X							X		
Carbonic acid — H_2CO_3		X												X	
Oxygen — O_2		X												X	
Grease and oil		X	X	X	X										X
Organic matter and sewage		X	X	X	X										X

[a] The possibility of the effects will increase proportionately to an increase in the water temperature.

- Soft water meets additional requirements to reduce hardness.
- Deionized water is specified in ranges of conductivity.
- Purified water meets the requirements of the local health department as well as the Safe Drinking Water Act.
- Distilled water meets the requirements of the local health department as well as the Safe Drinking Water Act.
- Pure water is a relative term used to describe water mostly free from particulate matter and dissolved gases that may exist in the potable water supply. Pure water is generally required in pharmacies, central supply rooms, laboratories, and laboratory glassware-washing facilities. The two basic types of pure water are high-purity water, which is free from minerals, dissolved gases, and most particulate matter, and biopure water, which is free from particulate matter, minerals, bacteria, pyrogens, organic matter, and most dissolved gases.

Water purity is most easily measured as specific resistance in ohm-centimeters (Ω-cm) or expressed as parts per million (ppm) of ionized salt (NaCl). The theoretical maximum specific resistance of pure water is 18.3 megaohm-centimeters (MΩ-cm) at 25°C, a purity that is nearly impossible to produce, store, and distribute. It is important to note that the specific resistance of water is indicative only of the mineral content and in no way indicates the level of bacterial, pyrogenic, or organic contamination.

Methods of Producing High-grade Water

The four basic methods of producing high-grade or pure water are distillation, demineralization, reverse osmosis, and filtration. Depending on the type of pure water required, one or more of the methods described below will be needed. Under certain conditions, a combination of methods may be required. These processes are explained in detail later in the chapter.

Distillation

Distillation produces biopure water that is free from particulate matter, minerals, organics, bacteria, pyrogens, and most of the dissolved gases and has a minimum specific resistance of 300,000 Ω-cm. The important consideration here is that it is free from bacteria and pyrogen contaminants that are dangerous to a medical patient, particularly where intravenous solutions are concerned. Biopure water is needed in the pharmacy, central supply room, and any other area where there may be patient contact. Biopure water also may be desired in specific laboratories at the owner's request and as a final rinse in a laboratory glassware washer.

The typical water distillation system consists of an evaporator section, internal baffle system, water-cooled condenser, and storage tank. The best material of construction is a pure block-tin coating for both the still and the tank. The heat sources, in order of preference based on economy and maintenance, are steam, electricity, and gas. Gas is a very poor choice. The still may be operated manually or automatically. The distilled water may be distributed from the tank by gravity or by a pump. A drain is required. On stills larger than 50 gallons per hour (gph), a cooling tower should be considered for the condenser water.

Demineralization

Sometimes called deionization, demineralization produces high-purity water that is free from minerals, most particulate matter, and dissolved gases. Depending on the equipment, it can have a specific resistance of 50,000 Ω to nearly 18 MΩ. However, it can be contaminated with bacteria, pyrogens, and organics, as these can be produced inside the demineralizer itself. Demineralized water can be used in most laboratories, in laboratory glassware-washing facilities as a final rinse, and as pretreatment for still feed water.

The typical demineralizer apparatus consists of either a two-bed unit with a resistivity range of 50,000 Ω to 1 MΩ or a mixed-bed unit with a resistivity range of 1 MΩ to nearly 18 MΩ. The columns are of an inert material filled with a synthetic resin that removes the minerals by an ionization process. Since the unit runs on pressure, a storage tank is not required, nor is it recommended as bacteria may grow in it. A demineralizer must be chemically regenerated periodically, during which time no pure water is being produced. If a continuous supply of water is needed, a backup unit should be considered, as the process takes several hours. The regeneration can be done manually or automatically. An atmospheric, chemical-resistant drain is needed. Note that higher-pressure water is required for backwash during regeneration.

If deionized water is required in a small amount and the facility does not want to handle the regenerant chemicals and/or the regenerant wastewater, it may contract with a deionized water service provider to supply the facility with the quality and quantity of deionized water required. The service deionized water (SDI) provider furnishes the facility with service deionized water exchange tanks to supply the quality, flow rate, and quantity of water required. When the tanks are exhausted, the SDI provider furnishes a new set of tanks. The SDI provider takes the exhausted tanks back to its facility for regeneration.

Reverse Osmosis (RO)

Reverse osmosis produces a high-purity water that does not have the high resistivity of demineralized water and is not biopure. Under certain conditions, it can offer economic advantages over demineralized water. In areas that have high mineral content, it can be used as a pretreatment for a demineralizer or still when large quantities of water are needed. Reverse osmosis is used primarily in industrial applications and in some hospitals and laboratories for specific tasks. It also is used by some municipalities and end users for removal of dissolved components or salts.

Several types of reverse osmosis units are available. Basically, they consist of a semipermeable membrane in either a roll form or a tube containing numerous hollow fibers. Water is forced through the semipermeable membrane under high pressure. A drain and storage tank are required with this system.

Filtration

Various types of filters are available to remove the particulate matter from water as a pretreatment. Filters can range from a back-washable filter to filter cartridge housing. Depending on the type of filter, a drain may be required.

Nanofiltration is a membrane system similar to reverse osmosis but with a looser membrane that rejects most polyvalent ions while allowing the monovalent ions of sodium and chloride to pass through. It also is called a softening membrane.

Ultrafiltration is a membrane system that is even looser and generally is used to separate oil and water.

WATER CONDITIONS AND RECOMMENDED TREATMENTS

Turbidity

Turbidity is caused by suspended insoluble matter, including coarse particles that settle rapidly in standing water. Amounts range from almost zero in most groundwater and some surface supplies to 60,000 nephelometric turbidity units (NTU) in muddy, turbulent river water. Turbidity is objectionable for practically all water uses. The standard maximum for drinking water is 1 NTU (accepted by industry), which indicates quite good quality. Turbidity exceeding 1 NTU can cause health concerns.

Generally, if turbidity can be seen easily, it will clog pipes, damage valve seats, and cloud the drinking water. For non-process water, if turbidity cannot be seen, it should present few or no problems.

Turbidity that is caused by suspended solids in the water may be removed from such water by coagulation, sedimentation, and/or filtration. In extreme cases, where a filter requires frequent cleaning due to excessive turbidity, it is recommended that engineers use coagulation and sedimentation upstream of the filter. Such a device can take the form of a basin through which the water can flow at low velocities to let the turbidity-causing particles settle naturally.

For applications where water demand is high and space is limited, a mechanical device such as a clarifier utilizing a chemical coagulant may be more practical. This device mixes the water with a coagulant (such as ferric sulfate) and slowly stirs the mixture in a large circular container. The coarse particles drop to the bottom of the container and are collected in a sludge pit, while the finer particles coagulate and also drop to the bottom of the container. The clarified water then leaves the device ready for use or further treatment, which may include various levels filtration and disinfection.

Hardness

The hardness of water is due mainly to the presence of calcium and magnesium cations. These salts, in order of their relative average abundance in water, are bicarbonates, sulfates, chlorides, and nitrates. They all produce scale.

Calcium salts are about twice as soluble as magnesium salts in natural water supplies. The presence of bicarbonates of calcium and magnesium produces a condition in the water called temporary hardness because these salts can be easily transformed into a calcium or magnesium precipitate plus carbon dioxide gas. The noncarbonic salts (sulfates, chlorides, and nitrates) constitute permanent hardness conditions.

Hardness is most commonly treated by the sodium-cycle ion exchange process, which exchanges the calcium and magnesium salts responsible for the hardness of the water for the very soluble sodium salts. Only calcium and magnesium (hardness ions) in the water are affected by the softening process. This process produces water that is non-scale forming. If the oxygen or carbon dioxide contents of the water are relatively high, the water may be considered aggressive.

The carbonic acid may be removed by aeration or degasification, and the remaining acids may be removed by neutralization. Neutralization by blending hydrogen and sodium cation exchanger water is one of the methods for obtaining water with the desired alkalinity level.

Another method of neutralizing the acid in water is by adding alkali. The advantage of the alkali neutralization method is that the cost of the sodium cation exchange softener is eliminated. However, the engineer may want to weigh the cost of chemicals against the cost of the sodium ion exchange unit.

Aeration and Deaeration

As hardness in water is objectionable because it forms scale, high oxygen and carbon dioxide contents are also objectionable because they corrode iron, zinc, brass, and several other metals.

Free carbon dioxide (CO_2) can be found in most natural water supplies. Surface waters have the lowest concentration, although some rivers may contain as much as 50 ppm. In groundwater, the CO_2 content varies from almost zero to concentrations so high that the carbon dioxide bubbles out when the pressure is released.

Carbon dioxide also forms when bicarbonates are destroyed by acids, coagulants, or high temperatures. The presence of CO_2 accelerates oxygen corrosion.

Carbon dioxide can be removed from water by an aeration process. Aeration is simply a mechanical process for mixing the air and the water intimately. It can be done with spray nozzles, cascade aerators, pressure aerators, or forced draft units. When this aeration process is complete, the water is relatively free of CO_2 gas.

Water with a high oxygen content can be extremely corrosive at elevated temperatures. Oxygen (O_2) can be removed from the water by a deaeration process. Oxygen becomes less and less soluble as the water temperature increases; thus, it is removed easily from the water by bringing the water to its boiling point.

Pressure and vacuum deaerators are available. When it is necessary to heat the water, as in boilers, steam deaerators are used. Where the water is used for cooling or other purposes where heating is not desired, vacuum units may be employed.

With aerators and deaerators in tandem, water free of CO_2 and O_2 is produced.

Minerals

Pure water is never found in nature. Natural water contains a series of dissolved inorganic solids, which are largely mineral salts. These mineral salts are introduced into the natural water by a solvent action as the water passes through (or across) the various layers of the earth. The types of mineral salt absorbed by the natural water depends on the chemical content of the soil through which the natural water passes before it reaches the consumer. This may vary from area to area. Well water differs from river water, and river water differs from lake water. Two consumers separated by a few miles may have water supplies of very dissimilar characteristics. Even the concentration and types of minerals may vary with the changing seasons in the same water supply.

Many industries can benefit greatly by being supplied with high-grade pure water. These industries are finding that they must treat their natural water supplies in various ways to achieve this condition. The recommended type of water treatment depends on the chemical content of the water supply and the requirements of the particular industry. High-grade pure water typically results in greater economy of production and better products.

Before the advent of the demineralization process, the only method used to remove mineral salts from natural water was a distillation process. Demineralization has a practical advantage over distillation. The distillation process involves removing the natural water from the mineral salts (or the larger mass from the smaller mass). Demineralization processes are the reverse of the distillation process as they remove the mineral salts from the natural water. This renders demineralization the more economical method of purifying natural water in most cases. Many industries today are turning to demineralization as the answer to their water problems.

The stringent quality standards for makeup water for modern boilers are making demineralizers and reverse osmosis a must for these users. Modern plating practices also require the high-quality water that demineralization produces.

ION EXCHANGE—THEORY AND PRACTICE

According to chemical theory, compounds such as mineral salts, acid, and bases break up into ions when they are dissolved in water. Ions are simply atoms, singly or in groups, that carry an electric charge. They are of two types: cation, which is positively charged, and anion, which is negatively charged. For example, when dissolved in water, sodium chloride (NaCl) splits into the cation Na^+ and the anion Cl^-. Similarly, calcium sulfate ($CaSO_4$) in solution is present as the cation Ca^{2+} and the anion SO_4^{2-}. All the mineral salts in water are in their ionic form.

Synthetic thermal-setting plastic materials, known as ion exchange resins, have been developed to remove these objectionable ions from the solution and to produce water of very high purity. These resins are small beads (or granules) usually of phenolic, or polystyrene, plastics. They are insoluble in water, and their basic nature is not changed by the process of ion exchange. These beads (or granules) are very porous, and they have readily available ion exchange groups on all their internal and external surfaces. The electrochemical action of these ion exchange groups draws one type of ion out of the solution and puts a different one in its place. These resins are of three types: cation exchanger, which exchanges one positive ion for another, anion exchanger, which exchanges one negative ion for another, and acid absorber, which absorbs complete acid groups on its surface.

A demineralizer consists of the required number of cation tanks and anion tanks (or, in the case of monobeds, combined tanks) with all the necessary valves, pipes, and fittings required to perform the steps of the demineralization process for the cation resin, as well as an acid dilution tank material for the cation resin and an acid dilution tank, as the sulfuric acid is too concentrated to be used directly. If hydrochloric acid is to be used as a cation regenerant, this mix tank is unnecessary since the acid is drawn in directly from the storage vessel. A mixing tank for soda ash or caustic soda, used in anion regeneration, is always provided.

Since calcium and magnesium in the raw regenerant water precipitate the hydroxide (or carbonate) salts in the anion bed, the anion resin must be regenerated with hardness-free water. This condition may be accomplished either with a water softener (which may be provided for this purpose) or by use of the effluent water from the cation unit to regenerate the anion resin. The use of a softener decreases the regeneration time considerably, as both units may be regenerated simultaneously rather than separately.

Provided with each unit is a straight reading volume meter, which indicates gallons per run as well as the total volume put through the unit. Also provided with each unit is a conductivity and resistivity indicator used to check the purity of the effluent water at all times. This instrument is essentially a meter for measuring the electrical resistance of the treated water leaving the unit. It consists of two principal parts: the conductivity cell, which is situated in the effluent line, and the instrument box to which the conductivity cell is connected.

The conductivity cell contains two electrodes across which an electric potential is applied. When these poles are immersed in the treated water, the resistance to the flow of the electricity between the two poles (which depends on the dissolved solids content of the water) is measured by a circuit in the instrument. The purity of the water may be checked by reading the meter. When the purity of the water is within the specific limits, the green light glows. When the water becomes too impure to use, the red light glows. In addition, a bell may be added that rings when the red light glows to provide an audible as well as a visible report that the unit needs regeneration. This contact also can close an effluent valve, shift operation to another unit if desired, or put the unit into regeneration.

Controls

Several types of control are currently available to carry out the various steps of regeneration and return to service. Common arrangements are as follows:

- Type A: Completely automatic, conductivity meter initiation of regeneration, individual air- or hydraulic-operated diaphragm valves controlled by a sequence timer. Any degree of automation can be provided, if desired. This arrangement provides maximum flexibility in varying amounts and concentrations of regenerants, length of rinsing, and all other steps of the operating procedure. The diaphragm valves used are tight seating, offering maximum protection against leakage and thus contamination with a minimum of maintenance.
- Type B: Manually operated individual valves. This system combines maximum flexibility and minimum maintenance with an economical first cost. It is used on larger installations.

Internal Arrangements

The internal arrangements of the vessels are similar for all types of controls. The internal arrangement used on medium to large units is shown in Figure 10-1. Smaller units have simpler arrangements since the distribution problems are less complex. The positive and thorough distribution of regenerants, rinse, and wash waters to achieve maximum efficiency provides economy and reliability.

Ion Exchange Water Softeners

A typical hydrogen-sodium ion exchange plant is shown in Figure 10-2. This process combines sodium-cycle ion exchange softening with hydrogen-cycle cation exchange.

The sodium ion exchange process is exactly the same as a standard ion exchange water softener. The hardness (calcium and magnesium) is replaced with sodium (nonscaling). The alkalinity (bicarbonates) and other anions remain as high as in the raw water.

The cation exchanger is exactly the same as the one used with demineralizers; therefore, its effluent contains carbonic acid, sulfuric acid, and hydrochloric acid. Sodium ion exchange units are operated in parallel, and their effluents are combined. Mineral acids in the hydrogen ion exchange effluent neutralize the bicarbonates in the sodium ion exchange effluent. The proportions of the two processes are varied to produce a blended effluent having the desired alkalinity. The carbon dioxide is removed by a degasifier. The effluent of this plant is soft and reduced in solids and has an alkalinity as low as is desired.

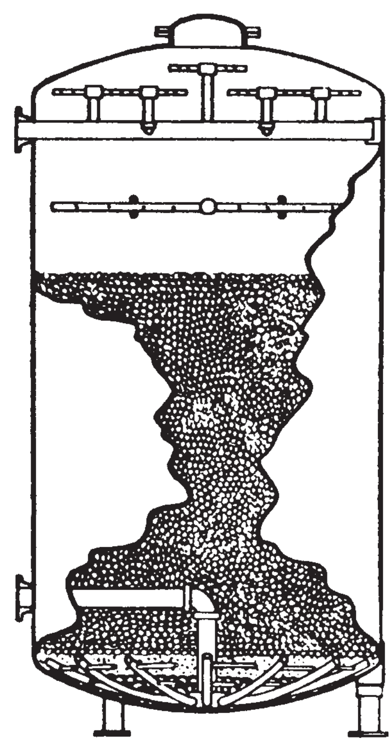


Figure 10-1 Ion Exchange Vessel—Internal Arrangements

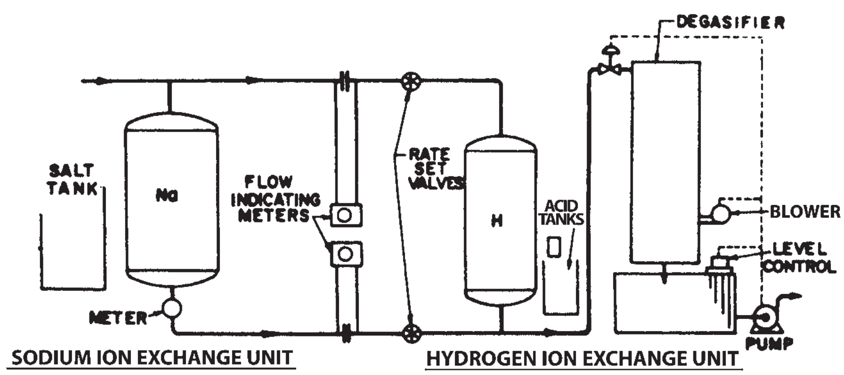


Figure 10-2 Hydrogen-Sodium Ion Exchange Plant

In a sodium ion exchange softener plus acid addition process (see Figure 10-3), the acid directly neutralizes the bicarbonate alkalinity to produce a soft, low-alkalinity water. The carbon dioxide produced is removed by a degasifier. The chief disadvantages of this process are that the total dissolved solids are not reduced and control of the process is somewhat more difficult.

In a sodium ion exchange softener plus chloride dealkalizer process, water passes first through the sodium ion exchange softener, which removes the hardness, and then through a chloride dealkalizer. The chloride dealkalizer is an ion exchanger that operates in the chloride cycle. The bicarbonates and sulfates are replaced by chlorides. The resin is regenerated with sodium chloride (common salt). The equipment is the same as that for sodium ion softeners. This process produces soft, low-alkalinity water. Total dissolved solids are not reduced, but the chloride level is increased. The chief advantages of this process are the elimination of acid and the extreme simplicity of the operation. No blending or proportioning is required.

In some cases, the anion resin can be regenerated with salt and caustic soda to improve capacity and reduce leakage of alkalinity and carbon dioxide.

BASIC WATER TREATMENT

The water provided by municipalities is usually low enough in turbidity and organic constituents to preclude the use of filters, clarifiers, or chlorinators. As always, however, there are exceptions to the rule. When dealing with health and safety or with the operating efficiency of machinery, engineers always must consider the occasional exception.

Chlorination

Chlorination of water is most commonly used to destroy organic (living) impurities. Organic impurities fall into two categories: pathogenic, which cause disease such as typhoid and cholera, and nonpathogenic, which cause algae and slime that clog pipes and valves, discolor water, and produce undesirable odors.

These pathogenic and nonpathogenic organisms can be controlled safely by chlorine with scientifically engineered equipment to ensure constant and reliable applications. An intelligent choice of the treatment necessary cannot be made until a laboratory analysis of the water has determined its quality and the quantities of water to be used are known. If microorganisms are present in objectionable amounts, a chlorination system is required.

When chlorine is added to the water, hypochlorous and hydrochloric acids are formed. Hydrochloric acid is neutralized by carbonates, which are naturally present in the water. It is the hypochlorous acid that provides the disinfecting properties of chlorine solutions. Part of the hypochlorous acid is used quickly to kill (by the oxidation process) the bacteria in the water. The remaining acid keeps the water bacteria free until it reaches the point of ultimate use.

This residual hypochlorous acid can take two forms. It may combine with the ammonia present in almost all waters. This combined residual, or chloramine, takes a relatively long time to kill the bacteria, but it is very stable. Thus, when a water system is large, it is sometimes desirable to keep a combined residual

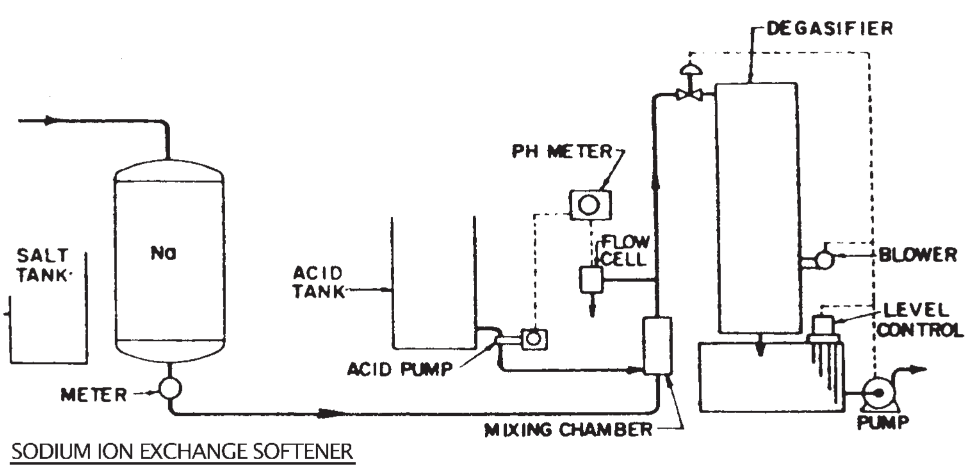


Figure 10-3 Sodium Cycle Softener Plus Acid Addition

in the system to ensure safety from the treatment point to the farthest supply point.

If enough chlorine is added to the system, more hypochlorous acid than can combine with the ammonia in the water is present. The excess hypochlorous acid is called free residual. It is quite unstable, but it kills organic matter very quickly. Though the time it takes for this water to pass from the treatment plant to the point of ultimate use is short, only free residual can ensure that all bacteria will be killed. Maintaining an adequate free residual in the water is the only way to ensure that the water is safe. Its presence proves that enough chlorine was originally added to disinfect the water. If no residual is present, it is possible that not all the bacteria in the water were killed; therefore, more chlorine must be added.

Chlorine gas or hypochlorite solutions can be readily and accurately added to the water at a constant rate or by proportional feeding devices offered by a number of suppliers. Large municipal or industrial plants use chlorine gas because it is less expensive than hypochlorite solutions and convenient. Chlorinators, such as the one shown in Figure 10-4, inject chlorine gas into the water system in quantities proportional to the water flow.

For the treatment of small water supplies, hypochlorite solutions sometimes are found to be more advantageous. In feeding hypochlorite solutions, small proportioning chemical pumps, such as the one illustrated in Figure 10-5, may be used for injecting the hypochlorite solution directly into the pipelines or the reservoir tanks.

Clarification

Turbid water has insoluble matter suspended in it. As turbidity in the water increases, the water looks more clouded, is less potable, and is more likely to clog pipes and valves.

Particles that are heavier than the fluid in which they are suspended tend to settle due to gravity according to Stokes' law:

Equation 10-1

$$\nu = \frac{kd^2 (S_1 - S_2)}{z}$$

where

ν = Settling velocity of the particle
k = Constant, usually 18.5
d = Diameter of the particle
S_1 = Density of the particle
S_2 = Density of the fluid
z = Viscosity of the fluid

From Equation 10-1, it can be seen that the settling velocity of the particle decreases as the density (S_2) and the viscosity (z) of the fluid increase. Because the density and viscosity of the water are functions of its temperature, it is readily understood why, for example, the rate of the particle settling in the water at a temperature of 32°F is only 43 percent of its settling rate at 86°F. Therefore, the removal of water turbidity by subsidence is most efficient in the summer.

Where the water turbidity is high, filtration alone may be impractical due to the excessive requirements for backwash and media replacement. Subsidence is

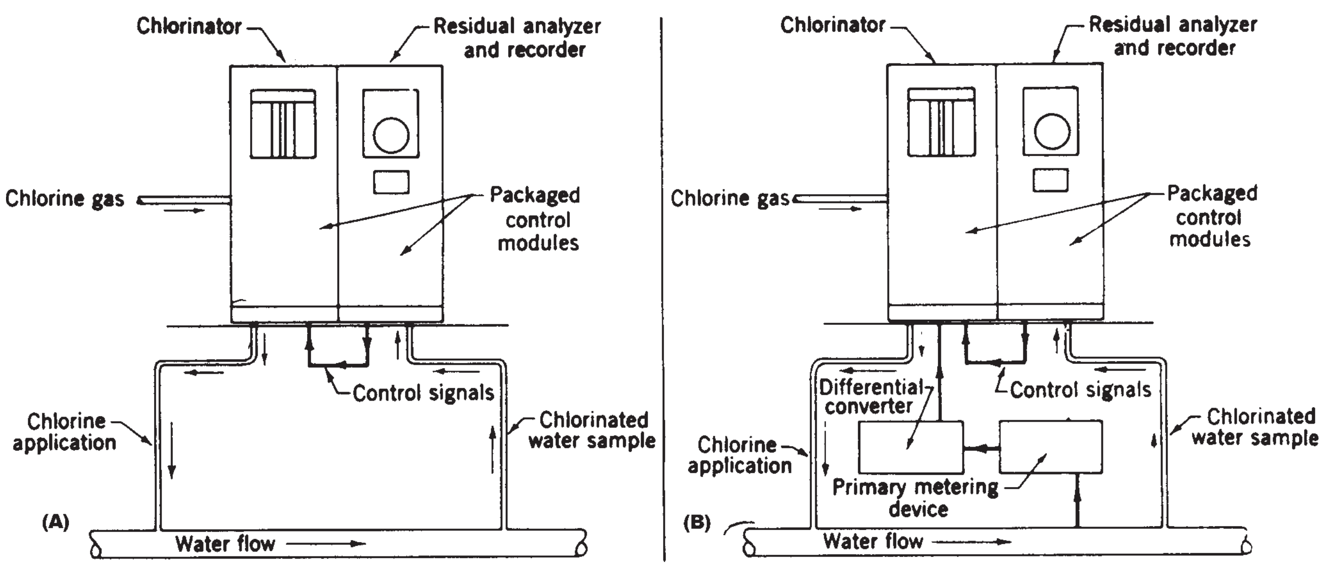


Figure 10-4 Automatic Chlorinators

Notes: The system illustrated in (A) maintains a given residual where the flow is constant or where it changes only gradually. The direct residual control is most effective on recirculated systems, such as condenser cooling water circuits and swimming pools. The desired residual is manually set at the analyzer. The flow is chlorinated until the residual reaches a set upper limit. The analyzer starts the chlorinator and keeps it operating until the residual again reaches the established upper limit. In (B) the compound loop controls the chlorinator output in accordance with two variables, the flow and the chlorine requirements. Two signals (one from the residual analyzer and another from the flow meter), when simultaneously applied to the chlorinator, will maintain a desired residual regardless of the changes in the flow rates or the chlorine requirements.

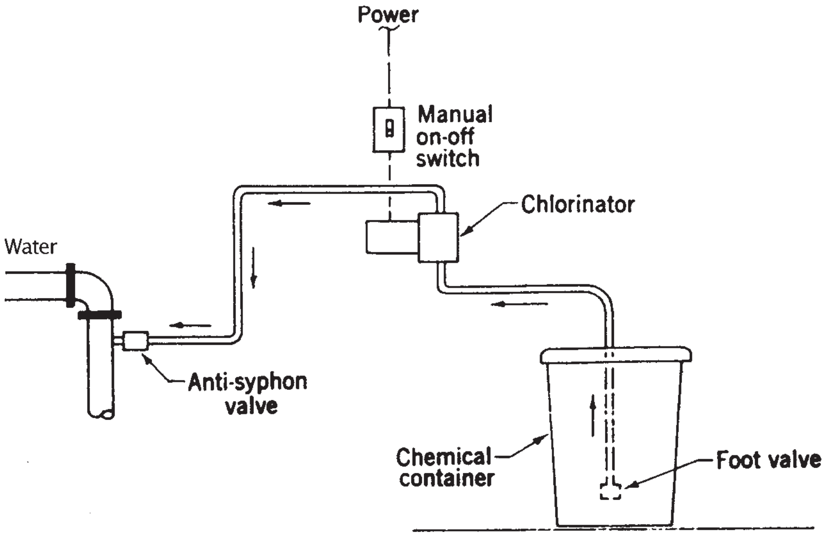


Figure 10-5 Manual Control Chlorinator

an acceptable method for the clarification of water that permits the settling of suspended matter.

Although water flow in a horizontal plane does not seriously affect the particle's settling velocity, an upward flow in a vertical plane prevents particle settling. The design of settling basins should, therefore, keep such interferences to a minimum. For practical purposes, the limit for removal of solids by subsidence is particles of 0.01 millimeter (mm) or larger diameter. Small particles have such a low rate of settling that the time required is greater than can be allowed. Figure 10-6 shows a typical design of a settling basin. Obviously, when large volumes of water are to be handled, the settling basins occupy large amounts of space. Also, they can present safety and vandalism problems if not properly protected.

Where space is limited, a more practical approach might be the use of a mechanical clarifier that employs chemical coagulants (see Figure 10-7). Such devices can be purchased as packaged units with simple in-and-out connections. Many chemical coagulants currently are available from which the designer can choose, including aluminum sulfate, sodium aluminate, ammonium alum, ferric sulfate, and ferric chloride. Each coagulant works better than the others in certain types of waters.

There are no simple rules to guide the engineer in the choice of the proper coagulant, coagulant dosages, or coagulant aids. Water analysis, temperature of the water, type of clarification equipment, load conditions, and end use of the treated water are some of the factors that influence selection of the proper coagulant. A few tests conducted under actual operating conditions can assist the designer in achieving the best results.

Water leaves the settling basin on the mechanical clarifier at atmospheric pressure. Thus, the designer should bear in mind that the outputs must be pumped into the water distribution system.

Filtration

Filtration is the process of passing a fluid through a porous medium to physically remove suspended solids. Where a clarifier of the type described above precedes the filters, the heavier, coagulated particles are removed from the water, and only the smaller, lighter particles reach the filter bed.

As the suspended particles lodge between the grains of the filter medium, flow is restricted. The coagulated particles build up on the surface of the filter bed. Penetration of the filter medium by the coagulated particles is achieved at the surface in the first device or 2 inches of the bed. This coagulated mat then acts as a fine filter for smaller particles.

The filter medium should be selected to provide a top layer coarse enough to allow some penetration of the top few inches of the bed by the coagulated material. Where a clarifier employing a chemical coagulant

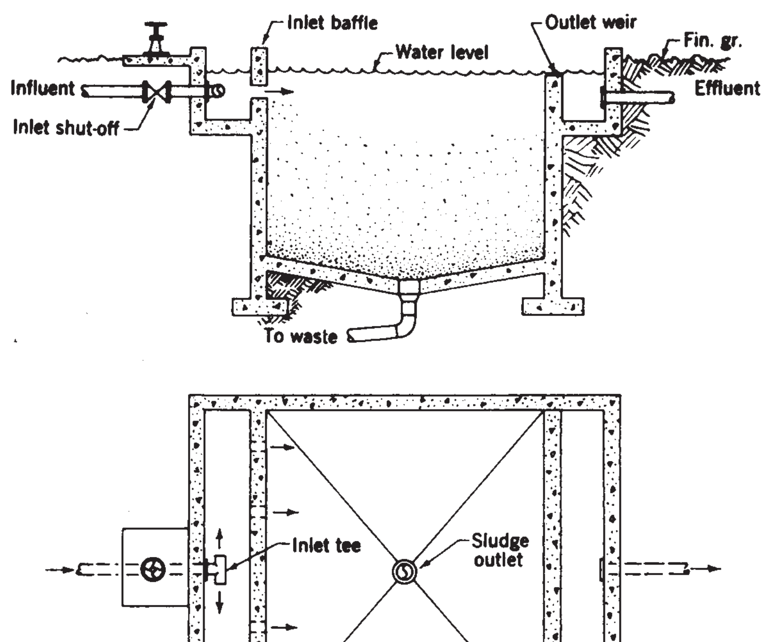
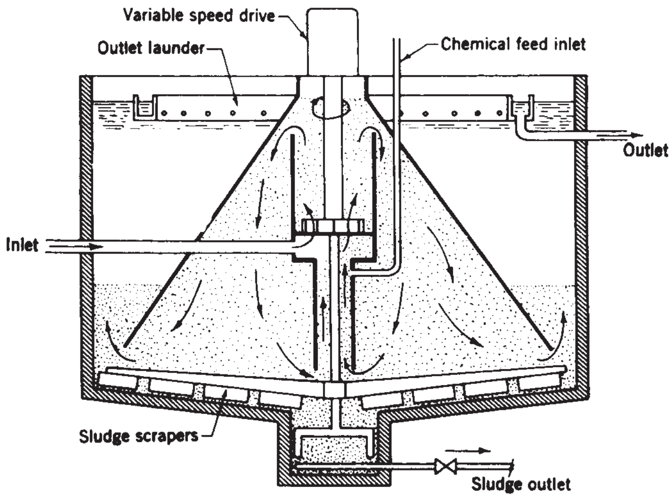


Figure 10-6 Settling Basin



Notes: The turbid water enters the central uptake mixed with the coagulant and is forced toward the bottom of the unit. Some water and the suspended precipitates enter the lower end of the uptake for recirculation and contact with the incoming chemicals and the water. New coagulation is encouraged by contact with these previously formed precipitates. The water then enters the outer settling section. The clarified water rises to the outlet flume above. The heavier particles settle and are moved along the bottom to the sludge pit.

Figure 10-7 Mechanical Clarifier

is placed ahead of the filters, a separate coagulant feed should be used to form a mat on the filter bed surface. Alum commonly is used for this purpose at a rate of about 1/10 pound for each square foot of filter bed surface. This coagulant mat should be replaced after each backwash.

Filters are either gravity or pressure type.

Gravity Filters

As their name implies, the flow of water through gravity filters is achieved by gravity only.

The filter vessel may be rectangular or circular in configuration and made of steel or concrete. The filter most commonly used is the rectangular concrete unit illustrated in Figure 10-8. This unit has a very basic design. In its more sophisticated form, the gravity filter has storage wells for the clarified water, wash troughs for even collection of the backwash, and compressed air systems for agitation of the sand during backwash.

The advantages of the gravity filter over the pressure filter are that the filter sand can be easily inspected and the application of a coagulant is usually more easily controlled. The disadvantages are the initial pressure loss, requiring repumping of the water to pressurize the distribution system; the additional space required for installation; and the possibility of outside bacterial contamination.

Pressure Filters

Pressure filters are more widely favored in industrial and commercial water-conditioning applications. These units have an advantage in that they may be placed in the line under pressure, eliminating the need to repump the water.

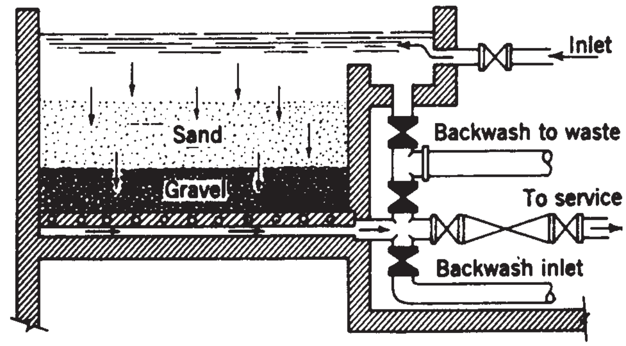


Figure 10-8 Gravity Sand Filter (Rectangular shaped, material)

The design of the pressure filter is similar to that of a gravity filter with respect to the filter medium, gravel bed, underdrain system, and control devices. The filter vessel is usually a cylindrical steel tank.

Vertical pressure sand filters, such as the one shown in Figure 10-9, range in diameter from 1 foot to 10 feet with capacities from 210 gallons per minute (gpm) to 235 gpm at an average filter rate of 3 gpm per square foot.

Multimedia depth filters are replacing single-media pressure filters. The depth filter has four layers of filtration media, each of a different size and density. The media become finer and denser in the lower layers. Particles are trapped throughout the bed, not in just the top few inches, which allows a depth filter to run longer and use less backwash water.

Horizontal pressure sand filters, usually about 8 feet in diameter and 18 feet to 30 feet in length, have a water flow rate range of 218 gpm to 570 gpm. The industry trend in recent years has been back to the horizontal pressure sand filters, which provide the advantages of a vertical filter with frequently a lower installed cost. When the filter tank is used in its horizontal position, a larger bed area can be obtained, thus increasing the flow rate available from a given tank size.

As with any mechanical device, proper operation and maintenance are key to continued high operating efficiency.

Chemical pretreatment often is used to enhance filter performance, particularly when the turbidity includes fine colloidal particles.

Normal water flow rates for most gravity and pressure filters are 3 gpm per square foot of filter area. Recent design improvements in coagulation have enabled flow rates as high as 5 gpm to 6 gpm for gravity filters.

High-rate pressure filters, with filtration rates of 20 gpm per square foot, have proven to be very efficient in many industrial applications. The design overcomes the basic problem of most sand and other single-medium filters, which provide a maximum fil-

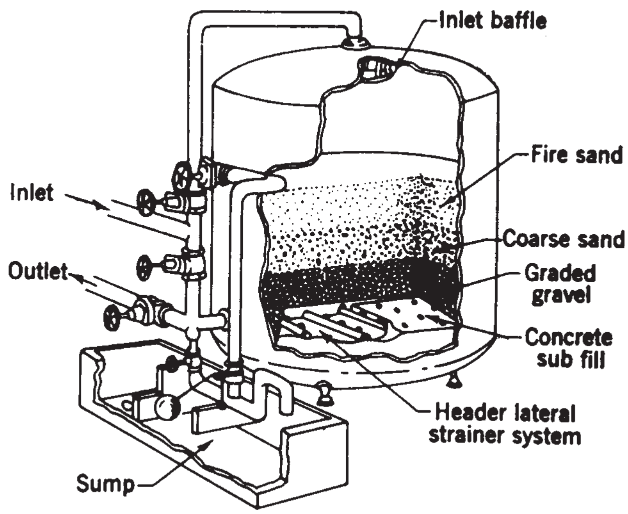


Figure 10-9 Vertical Pressure Sand Filter

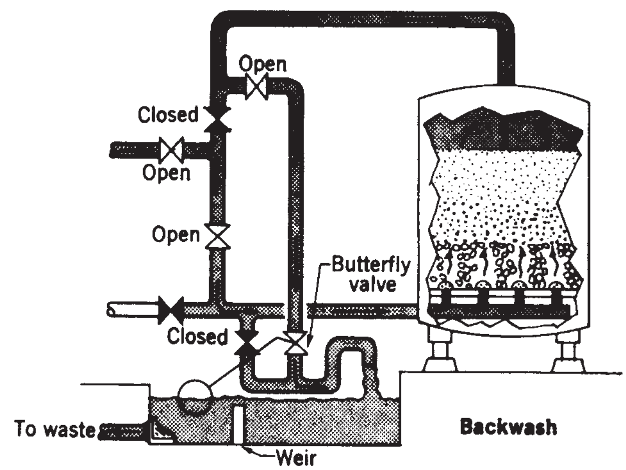


Figure 10-10 Backwashing

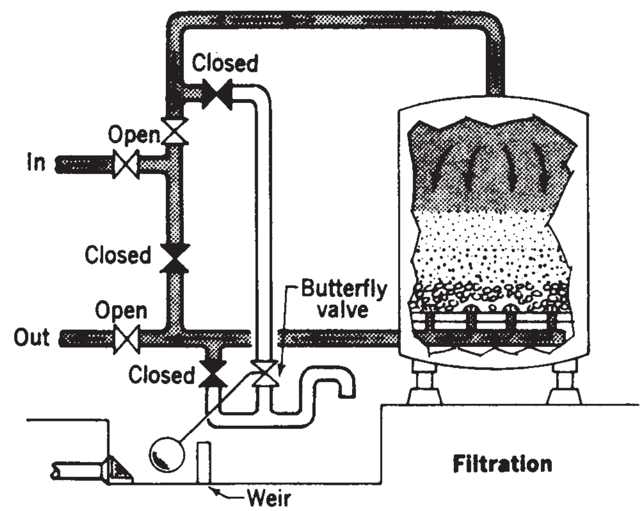


Figure 10-11 Filtration and Backsplash Cycles

tering efficiency only in the top few inches of the filter bed. The high-rate depth filters work at a maximum efficiency throughout the entire filter bed.

Backwashing

As the filter material accumulates the suspended particles removed from the water, it should be cleaned to avoid any excessive pressure drops at the outlet and the carryover of turbidity. The need for cleaning, particularly in pressure filters, is easily determined through the use of pressure gauges, which indicate the inlet and outlet pressures. Generally, when the pressure drop exceeds 5 pounds per square inch (psi), backwashing is in order. (See Figure 10-10.)

Cleaning is most commonly achieved through the process known as backwashing. In this process, the filtered water is passed upward through the filter at a relatively high flow rate of 10–20 gpm per square foot. The bed should expand at least 50 percent, as illustrated in Figure 10-11. This process keeps the grains of the filter medium close enough to rub each other clean, but it does not lift them so high that they are lost down the drain. Backwashing can be automated by employing pressure differential switches (electronically, hydraulically, or pneumatically) to activate the diaphragm or control valves that initiate the backwash cycle at a given pressure drop.

Some problems connected with filter beds are illustrated in Figures 10-12 through 10-14. Extremely turbid water or insufficient backwashing causes accumulations called mudballs (see Figure 10-12). If not removed, mudballs result in uneven filtration and short filter runs and encourage fissures. When the filter bed surface becomes clogged with these deposits and simple backwashing does not remove them, the filter may need to be taken out of service and drained and the deposits removed by hand skimming, or the filter must be rebedded.

When fissures occur in the sand bed, the cause usually can be traced to one or a combination of three items: inlet water is not being distributed evenly or is entering at too high a velocity; backwash water is not being distributed evenly or is entering at too high a velocity; or mudballs have stopped the passage of water through certain areas and raised velocities in others. The filter must be drained and opened and the filter medium cleaned and reoriented. (See Figure 10-13.)

Gravel upheaval usually is caused by violent backwash cycles where water is distributed unevenly or velocities are too high. (See Figure 10-14.) If not corrected, fissures are encouraged, or worse, filter media is allowed to pass into the distribution system where they may cause serious damage to valves and equipment as well as appear in potable water.

Diatomaceous Earth Filters

The use of diatomaceous earth as a water-filtering medium achieved prominence during the 1940s as a result of the need for a compact, lightweight, and portable filtering apparatus.

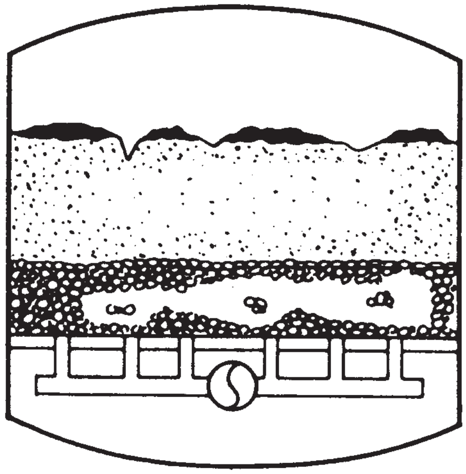


Figure 10-12 Mudballs

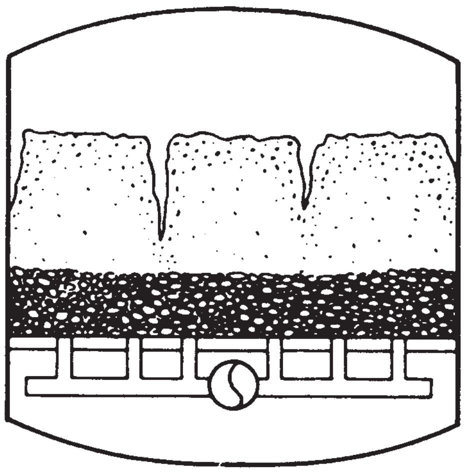


Figure 10-13 Fissures

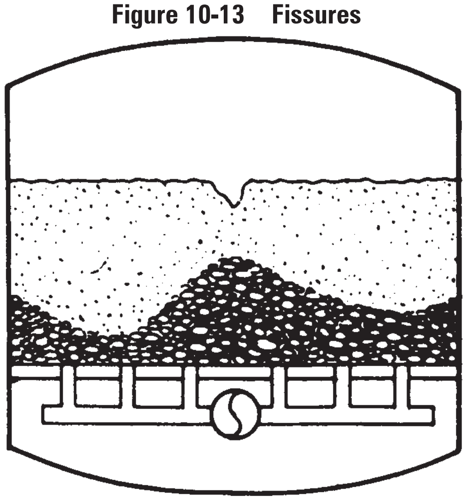


Figure 10-14 Gravel Upheaval

The water enters the filter vessel and is drawn through a porous supporting base that has been coated with diatomaceous earth. Filter cloths, porous stone tubes, wire screens, wire wound tubes, and porous paper filter pads are some of the support base materials most commonly used today. Figure 10-15 illustrates a typical leaf design filter.

Diatomaceous earth, or silica (SiO_4), is produced from mineral deposits formed by diatoms, a fossilized plant that is similar to algae. Deposits of diatoms have been found as much as 1,400 feet in thickness. Commercial filter aids are produced from the crude material by a milling process that separates the diatoms from one another. The finished product is in the form of a fine powder.

When diatomaceous earth forms a cake on the support base, a filter of approximately 10 percent solids and 90 percent voids is achieved. The openings in this filter are so small that even most bacteria are strained out of the water.

The openings in the support base are not small enough initially to prevent the passage of individual diatomite particles. Some of these diatomite particles pass through the support base during the precoating operation. However, once the formation of the coating is complete, the interlocked mass of diatomite particles prevents any further passage of the particles.

Commercial diatomaceous earth is manufactured in a wide range of grades with differing filtration rates and differences in the clarity of the filtered water. The advantages of diatomaceous earth filters, as compared to pressure sand filters, are a considerable savings in the weight and required space, a higher degree of filtered water clarity and purity in the outgoing water, and no required coagulant use. One disadvantage is that only waters of relatively low turbidity can be used efficiently. It is not advisable to use these filters where incoming water turbidities exceed 100 ppm, since low-efficiency, short filter runs will result. Other disadvantages are that the initial and operating costs usually far exceed those of conventional sand filters and that the incidence of high-pressure drop across the unit (as much as 25 psi to 50 psi) and intermit-

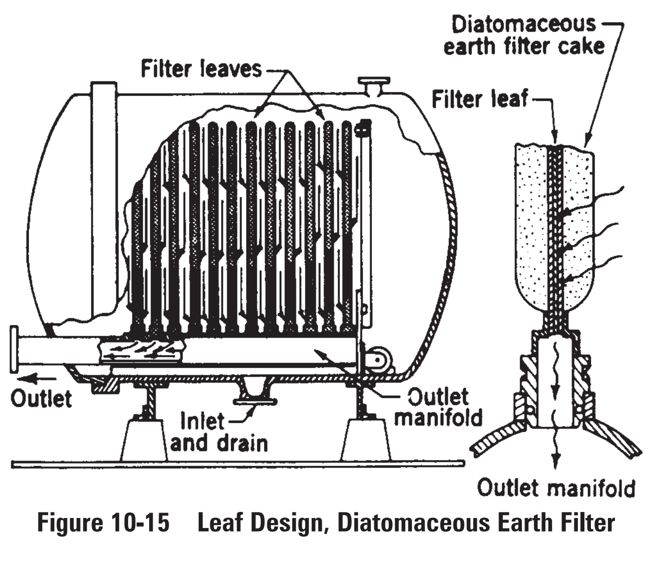


Figure 10-15 Leaf Design, Diatomaceous Earth Filter

tent flows cause the filter cake to detach from the support base.

WATER SOFTENING

The engineer should not overlook the fact that water softening is required for practically all commercial and industrial building water usage. Generally, the engineer is cognizant of the water softening needs only when designing power plants, industrial laundries, and other similar applications. The result is usually that the owner has a water softener installed after occupancy, at greater cost than if it had been done in the original construction.

Generally speaking, almost any building supplied with water having a hardness of 3.5 grains per gallon (gpg) or more should have a water softener. This is true even if the only usage of the water other than for domestic purposes is for heating. Most water heater manufacturers recognize this fact and have stated that the principal threat to water heater life and performance is hard water. Approximately 85 percent of the water supplies in the United States have hardness values above the 3.5 gpg level. Thus, geographically speaking, the engineer should recognize that the need for water softening is almost universal.

Many engineers specify a water softener to supply the heating equipment only and completely disregard the softening needs for the balance of the cold water usage in the building. A typical example of this condition is in a college dormitory. Many fixtures and appliances in a dormitory in addition to the hot water heater require soft water, including the piping itself, flush valve toilets, shower stalls, basins, and laundry rooms. Many fixtures and appliances that use a blend of hot and cold water experience scale buildup and staining, even with the hot water softened.

One of the most common reasons for installing water softening equipment is to prevent hardness scale buildup in piping systems, valves, and other plumbing fixtures. Scale builds up continually and at a faster rate as the temperature increases. The graph in Figure 10-16 illustrates the degree of scale deposit and the rate increase as the temperature of the water is elevated on water having a hardness of 10 gpg. For water of 20-gpg hardness, scale deposit values can be multiplied by two. Although the rate of scale deposit is higher as the temperature increases, significant scale buildup occurs with cold water. Thus, the cold water scale, while taking a longer period of time to build up, is nevertheless significant.

Water Softener Selection

The factors the designer should consider in sizing water softeners include the following: flow rate, softener capacity, frequency of regeneration, single versus multiple systems, space requirements, cost, and operating efficiency.

Flow Rate

After determining the total flow rate requirements for the building, including all equipment, the engineer can consider the size of the water softener. The water softener selected should not restrict the rate of water flow beyond the pressure loss that the building can withstand, based on the pressures available at the

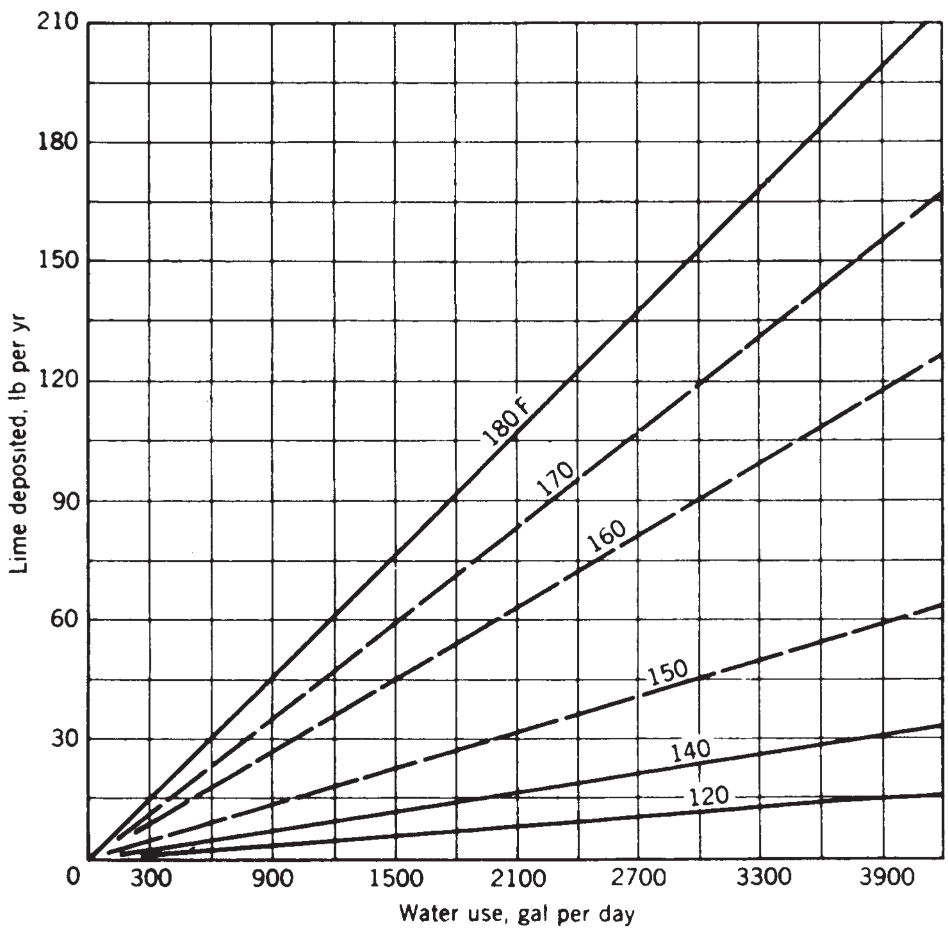


Figure 10-16 Lime Deposited from Water of 10 Grains Hardness as a Function of Water Use and Temperature

source and the minimum pressure needed throughout the entire system.

With the rate of flow and the pressure drop known, a water softener that meets both requirements can be selected. Standard softener units are designed for a pressure differential of approximately 15 psi, the most common differential acceptable for building design. Thus, for general usage, a water softener may be selected from a manufacturer's catalog.

The softener system should be capable of providing the design flow rates within the desired pressure drop. This means not only that the pipe and valve sizes must be adequate, but also that the water softener tank and its mineral must be capable of handling the flows while providing the soft water. The water softener design should be based on hydraulic and chemical criteria.

Good design practices for general use dictate that service flow rates through the water softener be approximately 1–5 gpm per cubic foot with mineral bed depths of 30 inches or more. Based on these accepted practices, the water softener is generally able to handle peak flows for short periods.

The engineer should give more detailed consideration to the selection of water softeners where especially low-pressure losses are needed. Many equipment manufacturers offer complete pressure drop curves for their equipment, allowing the selection of components to fit any flow pressure drop conditions desired.

Softener Capacity

Once the size of the water softener is selected based on flow rate, the designer should consider the length of the service run.

For each standard-size water softener, a nominal quantity of softening mineral is used. This amount is based on the recommended depths of mineral (normally 30–36 inches) and the proper free-board space above the mineral (the space required for the proper expansion of the mineral during backwashing). Thus, from the unit initially selected, a standard capacity is known.

The capacity of a water softener is its total hardness exchange ability, generally expressed in terms of grains exchange. The normal capacity of available softening mineral (resins) is 20,000–30,000 grains for each cubic foot of mineral. Thus, the total capacity for the water softener is obtained by multiplying this value by the number of cubic feet of mineral in the water softener. The hardness of the raw water must be ascertained. By dividing the water hardness (grains per gallon) (expressed as $CaCO_3$ equivalent) into the total softener capacity (grains), the designer can determine the number of gallons of soft water that the unit will produce before requiring regeneration.

Knowing (or estimating) the total gallons of water used per day indicates the frequency of regeneration. Most often, it is best to have a slight reserve capacity to accommodate any small increases in water usage.

Softening is not really a form of water purification since the function of a softener is to remove only the hardness (calcium and magnesium) from the water and substitute, by ion exchange, the softer element of sodium. Softeners frequently are used in hard water areas as pretreatment to distillation to simplify maintenance. They are often necessary as a pretreatment to deionizers and reverse osmosis, depending on the analysis of the feed water and the type of deionizer.

The following steps should be taken prior to selecting a water softener.

1. Perform a water analysis.
   - A. Analyze water with portable test kit.
   - B. Check with local authorities for water analysis.
   - C. Send a water sample to a qualified water testing lab.
2. Determine water consumption.
   - A. Use sizing charts.
   - B. Use consumption figures from water bills. (If bills are in cubic feet, multiply by 7.5 to convert to gallons.)
   - C. Take water meter readings.
3. Determine continuous and peak flow rates.
   - A. Use the fixture count flow rate estimating guide to determine the required flow rate.
   - B. Obtain flow rate figures for equipment to be serviced. (If flow rate data are given in pounds per hour, divide by 500 to convert to gallons per minute.)
   - C. Take water meter readings during peak periods of water consumption.
4. Determine the water pressure.
   - A. If there is a well supply, check the pump's start and stop settings.
   - B. Install a pressure gauge.
5. Determine the capacity: gallons per day × grains per gallon = grains per day.
6. Select the smallest unit that can handle the maximum capacity required between regenerations with a low salt dosage. Avoid sizing equipment with the high dosage unless there is reason to do so, such as a high-pressure boiler.

Example 10-1

For example, the capacity required is 300,000 grains. What size unit should be selected?

- A 300,000-grain unit will produce this capacity when regenerated with 150 pounds of salt.
- A 450,000-grain unit will produce this capacity when regenerated with 60 pounds of salt.

The 450,000-grain unit is the better selection to remove 300,000 grains. Salt consumption is 75 pounds per regeneration as opposed to 150 pounds on the smaller unit, a 50 percent salt consumption savings. It should be noted that while a salt saving is realized in using the lower salting rate on the larger unit, hardness leakage will increase. If minimum hardness leakage is required, such as for boiler feed water, the maximum salting rate (15 pounds per cubic foot) should be used.

7. Determine if the unit selected will deliver the required flow rate.
   A. When sizing to a continuous flow rate, subtract the pressure drop from the line pressure. At least 30 psi should be left for the working pressure.
   B. When sizing to a peak flow rate, subtract the pressure drop from the line pressure. At least 20 psi should be left for the working pressure.
   C. If A or B has less than the minimum allowable working pressure, select a larger model that has a higher flow rate.
   D. The water softener requires a dynamic pressure of 35 psi to draw brine.
8. Compare the dimensions of the unit selected with the space available for installation.
9. Make sure both the softener and brine tank will fit through all doors and hallways to the installation area. If not, a twin unit or smaller brine tank may be used.
10. Make sure a drain is available that will handle the backwash flow rate of the unit selected. Refer to the specification sheet for backwash flow rates.

Fixture Count Flow Rate Estimating Guide for Water Conditioners

This guide is for estimating average and maximum flow rate requirements (in gallons per minute) for both private and public buildings and is based on fixture flow rates and probability of use. It is to be used when actual continuous and peak flow rates are not known.

The average rates may be used when line pressure less the conditioner pressure drop is at least 30 psi at the highest point of use in the building. The maximum rates are equal to the fixture count figures commonly used to size water lines and are applicable especially in low water pressure areas where pressure drop is critical.

Following is a step-by-step procedure for estimating fixture count flow rates.

1. Count and list each type of fixture used intermittently. Multiply the total of each type by its private or public unit weight. Private or public unit weights must be determined by the use of the fixture. For example, lavatories in an apartment house are private. Lavatories in a restaurant are public. Add the products of each type of fixture to determine the total fixture count weight.
2. From the intermittent flow rate chart, select the total fixture count, or the next highest fixture count, determined in step 1.
3. Add to the flow rate determined in step 2 any continuously used flow rates in gallons per minute. These additional requirements may include commercial dishwashers, garbage disposals that run continually, boiler makeup water, or swimming pool makeup water. In some cases, these additional requirements are seasonal and used separately. For example, if boilers are shut down during the summer, use the additional requirement of the boiler or the air-conditioning system, whichever is greater.

Example 10-2 10-unit apartment house

For example, the flow rate for a 10-unit apartment can be estimated as follows:

Type and Number of Fixtures	Private Unit Weight		Total Weight	
10 kitchen sinks	×	2	=	20
10 bathtub/showers	×	2	=	20
10 lavatories	×	1	=	10
10 tank-type toilets	×	3	=	30
3 washing machines	×	2	=	6
1 air-conditioner with 5-gpm makeup			=	86 total

$$\frac{\text{Fixture count weight}}{86} = \frac{\text{Average gpm}}{31}$$

For a total of 86 fixture units, the corresponding flow rate is 31 gpm.

Add 31 gpm to 5 gpm for the air conditioner: $31 + 5 = 36$ gpm.

Select the smallest unit that has a continuous flow rate of 36 gpm.

4. Select the smallest water conditioner with a continuous flow rate that is equal to or greater than the total flow rate requirement in step 3.

The line pressure less the pressure drop of the selected unit must be at least 30 psi to handle the peak flow rate periods. If it is less than 30 psi:

A. Repeat step 2 using the maximum column on the intermittent flow rate chart.

B. Add to A the additional requirements of step 3.

C. Select a water conditioner with a continuous flow rate that is equal to or greater than the new total flow rate requirement.

When the maximum figures are used, the line pressure less the conditioner pressure drop must be 20 psi minimum.

Note: When water conditioners are installed in series, such as an iron filter in a water softener, the 30-psi and 20-psi minimum pressures must be maintained after both units. Select combinations of conditioners with a total pressure drop, when subtracted from the line pressure, of 30 psi minimum when using the average figures or 20 psi when using the maximum figures.

Where measurements of water consumption are not possible—for instance, where water meter records are not available—the information in Table 10-3 can be used to estimate the amount of water consumed in several establishments. (Note: For more accurate figures, take meter readings during average or peak periods—a week or a month. Water bills may be used to determine daily water consumption.)

If manually operated equipment is desired, longer periods between regenerations may be desired to reduce the attention that an operator must give to the water softener. Thus, larger capacity units must be selected.

Single or Multiple Systems

A single-unit softener will bypass the hard water during periods of regeneration (normally 1.5 hours). This is the danger in a single-unit softener. If soft water requirements are critical and adequate soft water storage is not available, a twin or duplex water softener is needed.

Space Needs

Many times a softener system is selected without much concern for space needs. Generally, sufficient floor space is available, although this factor should not be overlooked for storage. More commonly overlooked is the actual height of the softener tank and the additional height required (24 inches) for access through the top manhole opening for loading the unit. If height in the room is critical, the upper manhole can be located on the upper side shell of the softener tank (if so specified).

Severe room height restrictions normally require specifying a large-diameter, squat softener tank with the same specified quantity of softening mineral. Further consideration must be given to the floor space around the equipment, particularly around the salt tanks, for loading purposes and accessibility for servicing the units.

Where water softeners are being installed in existing buildings, the door openings should be checked

Table 10-3 Water Consumption Guide

Apartments	
One-bedroom units	1.75 people/apartment
Two-bedroom units	Three people/apartment
Three-bedroom units	Five people/apartment
Full line	60 gpd/person
Hot only	25 gpd/person
One bath	1.5 gpm/apartment
Two baths	2.5 gpm/apartment
Barber shops	75 gpm/chair
Beauty shops	300 gpd/person
Bowling alleys	75 gpd/lane
Factories (not including process waters)	
With showers	35 gpd/person/shift
Without showers	25 gpd/person/shift
Farm animals	
Dairy cow	35 gpd
Beef cow	12 gpd
Hog	4 gpd
Horse	12 gpd
Sheep	2 gpd
Chickens	10 gpd/100 birds
Turkeys	18 gpd/100 birds
Hospitals	225 gpd/bed (Estimate air-conditioning and laundry separately.)
Motels (Estimate the restaurant, bar, air-conditioning, swimming pool, and laundry facilities separately, and add these to the room gallonage for total consumption.)	
Full line	100 gpd/room
Hot only	40 gpd/room
Mobile home courts	Estimate 3.75 people/home, and estimate 60 gpd/person. (Outside water for sprinkling, washing cars, etc., should be bypassed.)
Restaurants	
Total (full line)	8 gal/meal
Food preparation (hot and cold)	3 gal/meal
Food preparation (hot only)	1.5 gal/meal
Cocktail bar	2 gal/person
Rest homes	175 gpd/bed (Estimate laundry separately.)
Schools	
Full line	20 gpd/student
Hot only	8 gpd/student
Trailer parks	100 gpd/space

for passage of the softener equipment to the final loading.

Cost

Technical advances in the water-softening industry and increasing labor costs are, for the most part, responsible for the fact that almost all the equipment produced is operated automatically.

For budget estimating purposes, automatic water-softening costs range from $15.00 to $40.00 per 1,000 grains of exchange capacity, depending on the degree of sophistication. This estimate is based on the total capacity of all units.

Operating Efficiency

Most water softeners are alike in terms of their operation. Their basic operating cost is the salt consumption. Practically all use a high-capacity, resinous mineral. The mineral can exchange 30,000 grains of hardness per cubic foot of mineral when regenerated with 15 pounds of salt, which is the nominal standard rating currently used in the industry.

As salt is the basic commodity that effects the operating cost, it is the only area where reduced costs may be considered. Fortunately, the softening mineral can be regenerated at different salt levels, yielding actual cost savings on the salt consumption. As indicated, with a 15-pound salt level, 30,000 gains per cubic foot can be obtained. With a salt dosage of 10 pounds or 6 pounds, a resulting capacity yield of 25,000 gains per cubic foot or 20,000 gains per cubic foot respectively is obtained.

Thus, approximately a 40 percent salt rating can be effected at the lower salt level. The lower salt levels can be used effectively on general applications, resulting in lower operating costs. However, where very high-quality soft water is required in an area where very high-hardness water exists, this approach is not recommended.

Sizing

Figure 10-17 will assist the engineer in developing the data required to size the basic softening equipment. The final selection of a system for specification should be made using this information. In many cases, the importance of the water-softening equipment justifies calling on manufacturers' representatives for their recommendations. Their specialized knowledge can help in the design of a reliable, economical water softener system. Figure 10-18 provides a step-by-step procedure for selecting the water softener equipment.

Salt Recycling Systems

If the engineer is interested in increasing the efficiency of the water softener in terms of salt consumption and water usage during the regeneration cycle, one option to consider is the use of a salt recycling system. It is essentially a hardware modification available for both new and existing water softeners that immediately reduces the amount of salt needed to regenerate a softener by 25 percent, without any loss of resin capacity or treated water quality. It works best with water softener equipment that utilize a nested diaphragm valve configuration as seen in Figure 10-19. It is not recommended for water softeners that utilize a top-mounted, multi-port motorized control valve.

The salt recycling process adds a brine reclaim step to the regeneration process after the brine draw has occurred. During brine reclaim, used dilute brine flow is diverted from the drain and routed back to the brinemaker tank where it is stored and resaturated

date ____________________

Project name

Location ____________________

Type of facility ____________________

What is water being used for? ____________________

Water analysis: (express in gr./ gal. or ppm as $CaCo_3$)

Total hardness ____________________

Sodium ____________________

Total dissolved solids ____________________

Sodium to hardness ratio ____________________

Iron ____________________

Flow rate (gpm) peak __________ Normal __________ Average __________

Allowable pressure loss __________ System inlet pressure __________

Operating hours/day __________ Gallons/day __________

Influent header pipe size ____________________

Electrical characteristics ____________________

Type of operation ____________________

Special requirement or options (ASME, lining, accessories) ____________________

Space limitation L __________ W __________ H __________

Figure 10-17 Water Softener Survey Data

Date ____________

Project name ____________

Location ____________

Step I. Operating conditions

A. Operating hours per day ____________

B. Can regeneration take place once each day? Yes ______ No ______

C. If "B" is No, state days between regenerations ____________

D. Is a twin unit required? Yes ______ No ______

E. Type of operation:

Time clock ______ Alarm meter ______ Auto reset meter ______

F. Allowable pressure loss ____________ psi.

Step 2. Flow rate (gpm) ____________ (peak, average, continuous)

Step 3. Water usage per day:

______ × 60 min./hr. × ______GPM = ______

Operating hr/day · Average flow rate · gal/day

Step 4. Required exchange capacity:

______ × ______ = ______

Gal/day water usage · Water hardness (gr/gal) · Required exchange capacity (gr/day)

Step 5. Select resin capacity & salt dosage per cu ft.:

(______) 32,000 gr @ 15# (______) 29,000 gr @ 10# (______) 21,000 gr @ 6#

Step 6. One day of operation per regeneration (step no. 1-B)

______ ÷ ______ = ______

Required exch. cap (gr/day) · Resin cap (gr/ft^3) · Required resin (ft^3/day)

Note: If more than one day between regenerations is required, use step no. 7 instead of step no. 6.

Step 7. More than one day of operation per regeneration (step no. 1-B)

Cubic feet of resin required:

______ × ______ ÷ ______ = ______

Required exch. cap. (gr/day) · Number of days/regn. · Resin cap. (gr/ft^3) · Resin required (ft^3)

Step 8. Salt consumption per regeneration:

______ × ______ = ______

Required resin (ft^3 /regn.) · Salt dosage (lb/ft^3) · Salt regeneration (lb)

Step 9. System selection:

(If auto-reset operation is desired, refer to step no. 10.)

A. Select from the manufacturer's specification table, a single unit that meets the flow rate (step no. 2).
B. Check that selected unit meets the allowable pressure loss at the flow rate (step no. 1-F).
C. If a single unit will not meet both steps no. 9-A and 9-B, then a multiple unit is required (refer to step no. 10).
D. Check that selected unit contains the required cubic feet of resin (step no. 6 or 7).
E. If single unit will not meet step no. 9-D, then a multiple unit is required. (refer to step no. 10).
F. Select a standard system that meets, or exceeds by no more than 10%, step nos. 9-A, 9-B, and 9-D. If a good balance is not available, refer to step no. 10.
G. Check that brine-tank salt storage is sufficient to provide a minimum of two regenerations before requiring refill (step no. 8).

Step 10. Multiple systems:

The following procedure should be followed for a twin unit.

A. Select either auto-reset meter initiation or time clock to start regeneration. Refer to the appropriate subtitle.

Auto-reset meter-initiated regeneration.

B. Select, from the specification table, a tank size that meets the *flow rate* (step no. 2) and the *allowable pressure loss* (step no. 1-F). Each tank in the system must meet these conditions.
C. Divide the required cu. ft. of resin (step no. 6 or 7) by two to determine the required cubic feet of resin contained in the tanks selected in step no. 10-B. Select a tank large enough to match the required cu. ft. resin/tank.
D. Check that the brine tank salt storage is sufficient to provide a minimum of four regenerations per tank.

Time clock regeneration

E. Divide the *flow rate* (step no. 2) by 2 to determine the *flow rate per tank.* Select a tank size that meets this flow rate. (Both tanks will be on line during the operating period.)
F. Check that the tank selected meets the *allowable pressure loss* (step no. 1-F) at the *flow rate per tank.*
G. Follow step no. 10-C to determine the required cubic feet of resin per tank.
H. Follow step no. 10-D to determine the brine tank to be used.

Step 11. Using this data, select a standard system from the softener specifications that most closely matches all the data. If none is available, a detailed specification should be developed which will allow the manufacturer to match the system requirements.

Step 12. Select options such as ASME code tanks, lining, and materials of construction, as required.

Figure 10-18 Water Softener Sizing Procedure

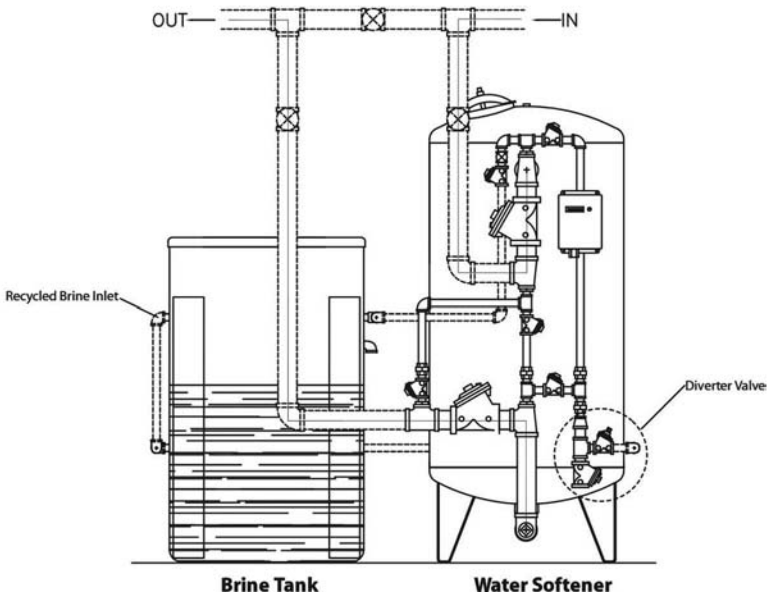


Figure 10-19 Water Softener with Salt Recycling System

for later use, thereby saving both salt and water. The salt savings occur because the make-up water to the brinemaker contains approximately 25 percent of the salt needed for the next regeneration. Therefore, only 75 percent of "new" salt is dissolved for the next regeneration. Water savings occur because the recycled brine is not discharged to drain but is used to make up the brine solution for the next regeneration. The effective salt dosage for the water softener is unchanged; therefore, the 25 percent salt savings can be realized in softener systems that use both maximum and minimum salt dosages.

The hardware package consists of a diverter valve (see Figure 10-19) in the drain line that routes the recycled brine to the brinemaker tank and a modified control system that incorporates the extra brine reclaim step.

Salt Storage Options

There are a few options for salt storage. Salt blocks and bags of salt, or beads, may not be suitable for large systems. Dozens or even hundreds of pounds maybe needed on a daily basis. These systems may require bulk salt storage and delivery systems, which may consist of an aboveground storage tank that is loaded directly from salt trucks. The salt then is conveyed through piping to the brine tank. This system may be wet or dry.

Underground storage tanks almost always require the salt to be premixed with water in the storage tank. It then can be piped to the brine tank as a brine solution and mixed down to the desired concentration levels.

DISTILLATION

The principles of distillation are quite simple. The water passes through two phase changes, from liquid to gas and back to liquid (see Figure 10-20). All the substances that are not volatile remain behind in the boiler and are removed either continuously or intermittently. Water droplets are prevented from coming up with the water vapor by proper design of the still, which takes into account the linear velocity, and by use of an appropriate system of baffles.

It should be understood that, although the nonvolatile substances can be taken care of, the volatile substances in the feed water cause more problems. These, mainly CO_2, which are already present in the feed water or are formed by the decomposition of bicarbonates, can be removed by keeping the distillate at a relatively high temperature. The solubility of CO_2 at higher temperatures is much lower than at normal temperatures.

Ammonia (NH_3) is much more soluble in water than CO_2, and its tendency to redissolve is much higher as well. Moreover, the ionization constant of ammonium hydroxide (NH_4OH) is much greater than that of carbonic acid (H_2CO_3), which means that equal

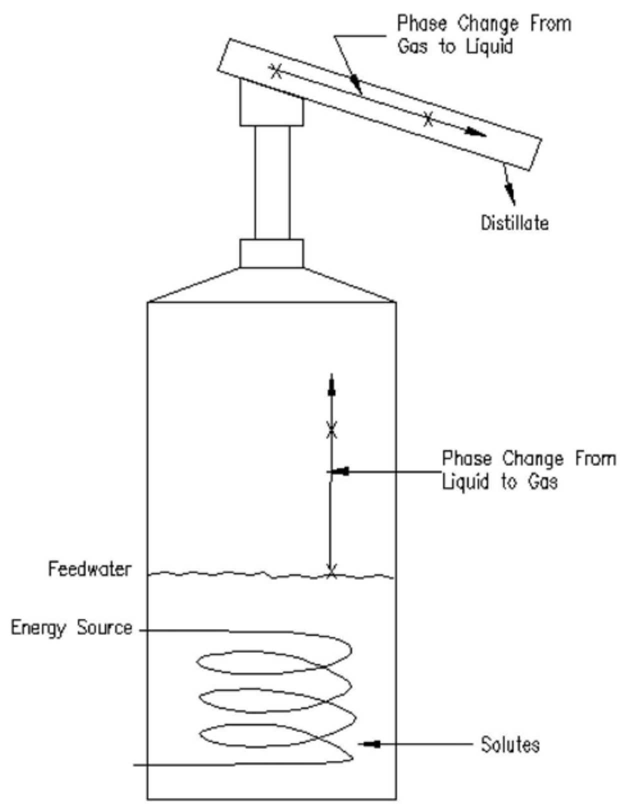


Figure 10-20 Distillation

amounts of NH_3 and CO_2 show different conductivities (that for NH_3 is much higher than that for CO_2).

The purity of the distillate is usually measured with a conductivity meter, and a resistivity of 1 MΩ —or a conductivity of 1 microsiemen (μS)—is equivalent to approximately 0.5 ppm of NaCl. Most of the conductivity is accounted for by the presence of CO_2 (and NH_3) and not by dissolved solids. The question arises: Which is preferred, 1 MΩ resistivity or a maximum concentration of dissolved solids? It is quite possible that a distillate with a resistivity of 500,000 Ω (a conductivity of 2 μS) contains fewer dissolved solids than a distillate with a resistivity of 1,000,000 Ω (1 μS).

A problem in distillation can be scale formation. Scale forms either by the decomposition of soluble products of insoluble substances or because the solubility limit of a substance is reached during the concentration. There are several solutions to this problem:

- A careful system of maintenance, with descaling at regular intervals.
- Softening of the feed water, that is, removing all Ca^{2+} and Mg^{2+} ions. However, this does not remove the silica, which then may form a hard, dense scale that is very difficult to remove.
- Removal of the alkalinity (HCO_3^-). When originally present, sulfate and silica still form a harder scale than a carbonate scale.
- Removal of all or most of the dissolved substances. This can be done by demineralization with ion exchangers or by reverse osmosis.

It may sound foolish to remove the impurities from the water before distilling the water. However, keep in mind that distillation is the only process that produces water guaranteed to be free of bacteria, viruses, and pyrogens. It may pay to have a pretreatment before a still to cut down on maintenance (descaling), downtime, and energy consumption and to have better efficiency, capacity, and quality. It may require a higher initial investment, but the supplier who has the experience and technology in all water treatment systems can give unbiased advice—that is, to offer a systems approach instead of pushing only one method.

Distilled water is often called hungry water. This refers to the fact that distilled or deionized water absorbs in solution much of the matter, in any phase, with which it comes in contact. It becomes important, therefore, to select a practical material for the production, storage, and distribution of distilled water.

Years of experience and research have shown that pure tin is the most practical material for the production, storage, and distribution of distilled water due to its inert characteristic. It is the least soluble. (Other materials, such as gold, silver, and platinum, have equal or superior qualities but are not considered for obvious reasons.) A secondary but almost equal advantage of tin is its relatively low porosity, which virtually eliminates the possibility of particle entrapment and growth in pores. In a good water still, therefore, all the surfaces that come in contact with the pure vapors and distillate should be heavily coated with pure tin. Likewise, the storage tank should be heavily coated or lined with pure tin on all interior surfaces. Tinned stills and storage tanks are not significantly more expensive than glass ones in all but the smallest sizes.

Titanium is being strongly considered as a promising material for distillation equipment. Although some stills have been made of titanium, it is more expensive than tin and has not yet been proven superior.

Distillation Equipment Applications and Selection

The use of distilled water was limited to hospitals and some pharmaceutical applications until recent advances in the industry. Now, in virtually every hospital, schools with science departments, laboratories, and industries other than pharmaceuticals, distilled water is vital to many operational functions.

In the construction of buildings requiring distilled water, the selection of the appropriate equipment to furnish it is usually the responsibility of the plumbing engineer. Before the proper equipment can be selected, the following factors should be considered:

- The quantity of distilled water that will be required per day (or per week) by each department
- The purity requirements of each department and how critical these requirements are
- The space available for the equipment
- The availability of power

Regarding the first two items, the engineer should obtain the anticipated quantity and purity requirements from all department heads who require distilled water.

In this section, it is assumed that less than 1,000 gallons per day (gpd) of distilled water is required for applications. The single-effect still operated at atmospheric pressure is generally the most practical and widely used still. For the consumption of larger quantities of distilled water, consideration may be given by the engineer to other types of stills (such as the multiple-effect and vapor-compression stills). These stills have advantages and disadvantages that should be studied when conditions warrant.

Centralized versus Decentralized Stills

The designer's choice between central distillation equipment and individual stills in each department is a matter of economics. In the case of central distillation, the factors to consider are the distances involved in piping the water to the various departments, hence, the cost of the appropriate piping and, possibly, the pumping requirements. For individual stills in each department, the original and maintenance costs of multiple stills can be high. In the majority of installations, the use of one or two large, centrally located stills with piped distribution systems has proven more practical and economical than a number of small, individual stills.

Example 10-3

Assume that a total of 400 gpd of distilled water is required by all departments. A fully automatic still and storage tank combination should be used in this application. Fully automatic controls stop the still when the storage tank is full and start the still when the level in the storage tank reaches a predetermined low level. In addition, the evaporator is flushed out each time it stops. A 30-gph still (with a 300-gallon storage tank) produces more than the desired 400 gpd. Because the still operates on a 24-hour basis, as the storage tank calls for distilled water (even if no distilled water is used during the night), 300 gallons are on hand to start each day. As water is withdrawn from the storage tank, the still starts and replenishes the storage tank at a rate of 30 gph.

In the foregoing example, the storage tank volume, in gallons, is 10 times the rated gallons-per-hour capacity of the still. This is a good rule of thumb for a fully automatic still and storage tank combination. A closer study of the pattern of the anticipated demands may reveal unusual patterns, which may justify a larger ratio.

Still Construction

Due to the amount of heat required in the operation to change the water into steam, it is impractical to make large-capacity, electrically heated and gas-heated stills. All stills larger than 10 gph, therefore, should be heated by steam. For each gallon per hour of a still's rated capacity, steam-heated stills require approximately ⅓ boiler horsepower, electrically heated stills need 2,600 watts, and gas-fired stills need 14,000 British thermal units per hour.

The still must be well designed and baffled to effect an efficient vapor separation without the possibility of carryover of the contaminants and to ensure optimum removal of the volatile impurities. It is equally important that the materials used in construction of the still, storage reservoir, and all components coming in contact with the distilled water do not react with the distilled water.

Distribution Systems

Cost can be a significant factor in the distribution system, particularly if it is extensive. The distribution system can consist of 316 stainless steel, CPVC Schedule 80, and polyvinylidene fluoride (PVDF). The fittings should be of the same material.

The purity requirements should be considered and a careful investigation made of the properties and characteristics of the materials being considered. Many plastics have a relatively porous surface, which can harbor organic and inorganic contaminants. With some metals, at least trace quantities may be imparted to the distilled water.

Types of Stills

While a well-designed still can produce pure distilled water for most purposes, the distilled water to be used by a hospital for intravenous injections or by a pharmaceutical company manufacturing a product for intravenous injections must be free of pyrogens (large organic molecules that cause individuals to go into shock). For such uses, a still with special baffles to produce pyrogen-free distilled water must be specified.

Other types of stills are designed to meet various purity requirements. The recommendations of the manufacturer should be obtained as to the proper type of still to specify for a specific application.

Storage Reservoir

The storage reservoir used for distilled water should be made of a material that is suited for the application and sealed with a tight cover so that contaminants from the atmosphere cannot enter the system. As the distilled water is withdrawn from the storage tank, air must enter the system to replace it. To prevent airborne contamination, an efficient filter should be installed on the storage tank so that all air entering the tank may be filtered free from dust, mist, bacteria, and submicron particulate matter, as well as carbon dioxide.

Figure 10-21 illustrates a typical air filter. This air filter (both hydrophilic and hydrophobic) removes gases and airborne particles down to 0.2 μ. Purified air leaves at the bottom. The rectangular chamber is a replaceable filter cartridge. A and B are intake breather valves, and C is an exhaust valve.

As a further safeguard against any possible contamination of the distilled water by biological impurities, an ultraviolet light can be attached to the inside of the cover (not very effective) and/or immersed in the distilled water (also not very effective) or in the flow stream to effectively maintain its sterility. Ultraviolet lighting should be given strong consideration for hospital and pharmaceutical installations, as well as for any other applications where sterility is important.

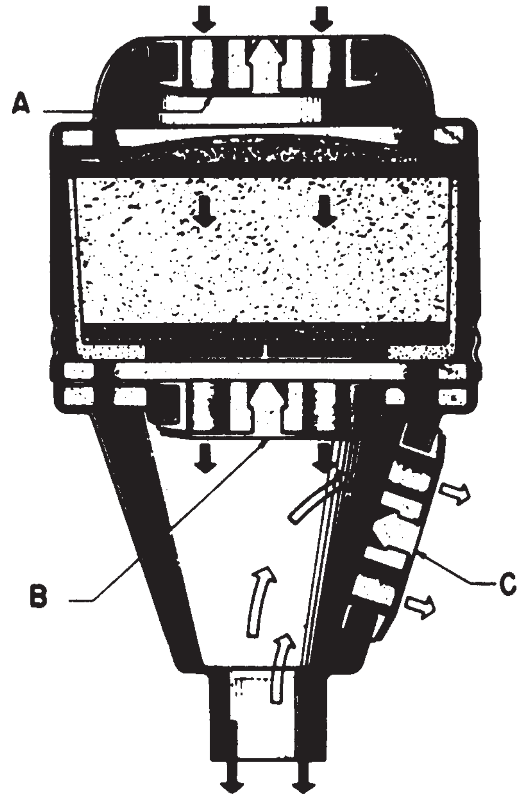


Figure 10-21 Typical Air Filter

Purity Monitor

One frequently used accessory is the automatic purity monitor. This device tests the purity of the distilled water coming from the still with a temperature-compensated conductivity cell. This cell is wired to a resistivity meter that is set at a predetermined standard of distilled water commensurate with the capability of the still. If, for any reason, the purity of the distilled water is below the set standard, the substandard water does not enter the storage tank and is automatically diverted to waste. At the same time, a signal alerts personnel that the still is producing substandard water so that an investigation may be made as to the cause. Simple wiring may be used to make the alarm signal visual or audible at any remote location, such as the plant engineer's office. The advantages of this automatic purity monitor are obvious, particularly ahead of large storage tanks (as one slug of bad water can ruin a whole tank).

Feed Water

Pretreated Feed Water

In the conventional or basic operation of a still, potable water is used to condense the pure vapors from the evaporator and is heated. Part of this preheated water enters the evaporator as feed water, while the greater part goes to the drain. A well-designed still has the intrinsic features to retard the formation of scale in the evaporator. These features include frequent, automatic flushing and a bleeder valve that continuously deconcentrates the buildup of the impurities in the evaporator.

As a further aid in reducing the maintenance of a still in areas having exceptionally hard water, it is often desirable (but not essential) to demineralize (with a deionizer or reverse osmosis), soften, or otherwise pretreat the feed water. Demineralizing the feed water practically eliminates the need for cleaning the evaporator. For this purpose, the demineralizing process is relatively expensive; however, it does contribute to a higher purity of the distilled water.

Because water softening is less expensive than the demineralizing process, it is used more often as a method of pretreatment. It does not have the advantages of demineralized water—eliminating cleaning and contributing to a higher purity—but it does eliminate hard scale formation in the evaporator.

When any kind of pretreated feed water is used, an adequate preheater (for pretreated water) and a float feeder valve should be specified by the designer. With these devices, the raw water is used only as cooling water for the condenser, and the pretreated feed water is piped separately to the still, eliminating the waste of the pretreated water. When the float feeder valve is used on any still equipped with an automatic drain, an automatic shutoff valve to the float feeder valve also should be specified so that the supply of pretreated water stops at the same time the drain valve opens. Specifications prepared by the designer should describe the type of pretreated water to be used.

Condensate as Feed Water

Another method of reducing maintenance on a steam-heated still is to use the condensed boiler steam as feed water. Here again, the raw water is used only as condenser cooling water. The condensate from the steam trap is cooled and then passed through an ion exchange cartridge and an organic removal filter. These cartridges remove any traces of scale-forming salts, ionized amines, odor, or taste impurities present in the original condensate, as well as organics that may be given off by the ion exchange cartridge.

This type of system commonly is referred to as the feedback purifier. This design contributes to a higher purity of the distillate and virtually eliminates the need to clean the still (since scale-forming hardness has been eliminated from the feed water).

It is important for the engineer to determine the characteristics of the steam condensate when considering the feedback purifier system. If amines are used as the treatment for the boiler feed water in an excessive amount, this method should not be used. However, most condensates are satisfactory for this purpose.

Distribution Pressure

Whenever possible, it is best to locate the still and the storage tank where gravity can be employed to provide an adequate pressure to operate the distribution system. When this condition is not possible, centrifugal pumps of the appropriate size must be used. Along with the circulation pump, an orificed bypass back to the storage tank should be installed so that the pump can be operated continuously, maintaining adequate pressure in the distribution system. Then the distilled water is available in any outlet all the time. The bypass relieves the pressure on the circulating pump when the water is not being drawn at its outlets.

A low-water cutoff also should be installed on the storage tank to shut off the pump if the storage tank runs dry. This pump arrangement is simple in construction, efficient to operate, and less expensive than a pressurized tank.

SPECIALIZED WATER TREATMENT

Chlorination

Chlorination traditionally has been used for the disinfection of drinking water. However, the initial investment required to properly chlorinate a potable water supply has, in many cases, restricted its use to the large water consumer or to cities, which have the adequate financial support and sufficient manpower to properly maintain the chlorination system. This situation has forced small water consumers either to go to the expense of purchasing an automatic chlorination system or possibly to consume contaminated water from a poorly disinfected water supply.

The chlorination process has other drawbacks as a disinfectant beside finances. The transportation and handling of a gas chlorination system are potentially dangerous. When the safety procedures are followed, however, there are few problems than with either liquid or solid products. Chemically, chlorine is the most reactive halogen and is known to combine with nitrogenous and organic compounds to form weak bactericidal compounds. These compounds (chloramines) require an extended period of contact time to effectively kill pathogenic microorganisms. Chlorine also combines with hydrocarbons to form potentially carcinogenic compounds (trihalomethanes).

Ozone Treatment

Ozone is a compound in which three atoms of oxygen are combined to form the ozone molecule O_3. It is a strong, naturally occurring, oxidizing, and disinfecting agent. The unstable ozone (O_3) compound can be generated by the exposure of oxygen molecules to ultraviolet radiation or high-energy electrical discharge in manufactured ozone generators.

Ozone can react with any oxidizable substance, such as certain forms of inorganic material like iron and manganese, many organic materials, and microorganisms. In an oxidation reaction, energy is transferred from the ozone molecule, leaving a stable oxygen (O_2) and a highly reactive oxygen atom (O_1). The molecule being oxidized then bonds with the loose oxygen atom creating an oxidized product or a derivation of the substance. Bacterial cells and viruses are literally split apart (lysed) or inactivated through oxidation of their DNA and RNA chains by ozone in water and wastewater treatment applications. Ozone

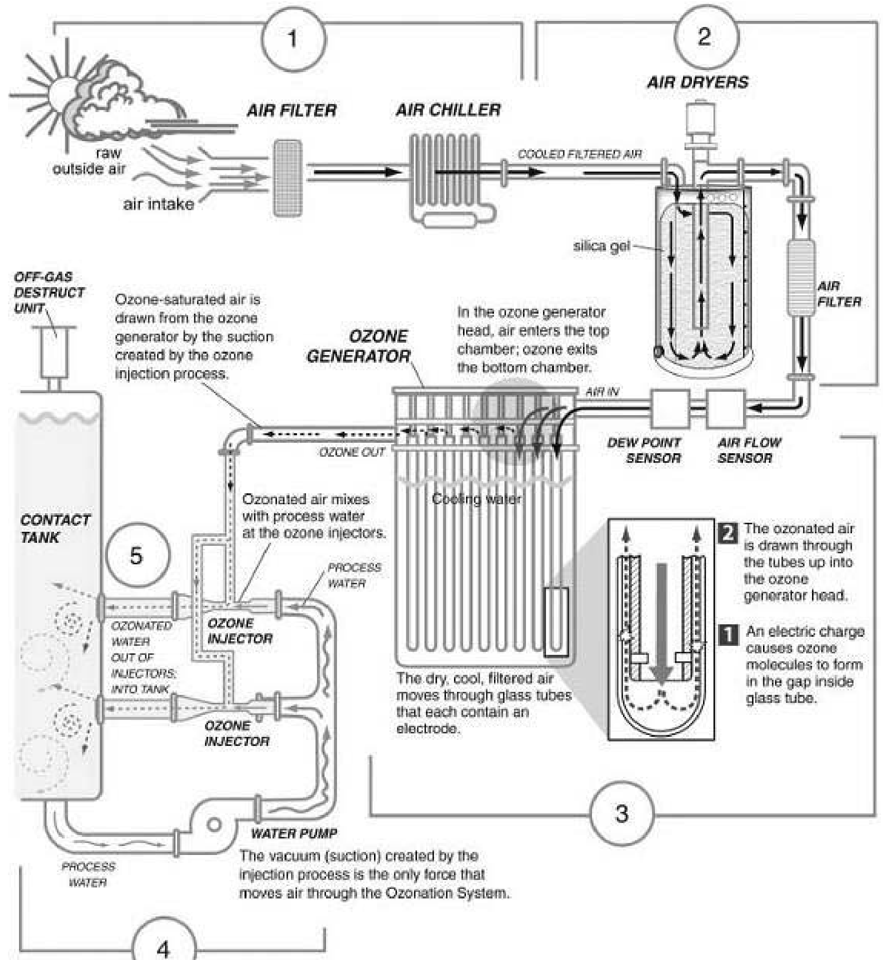


Figure 10-22 Schematic Diagram of a Large-scale System

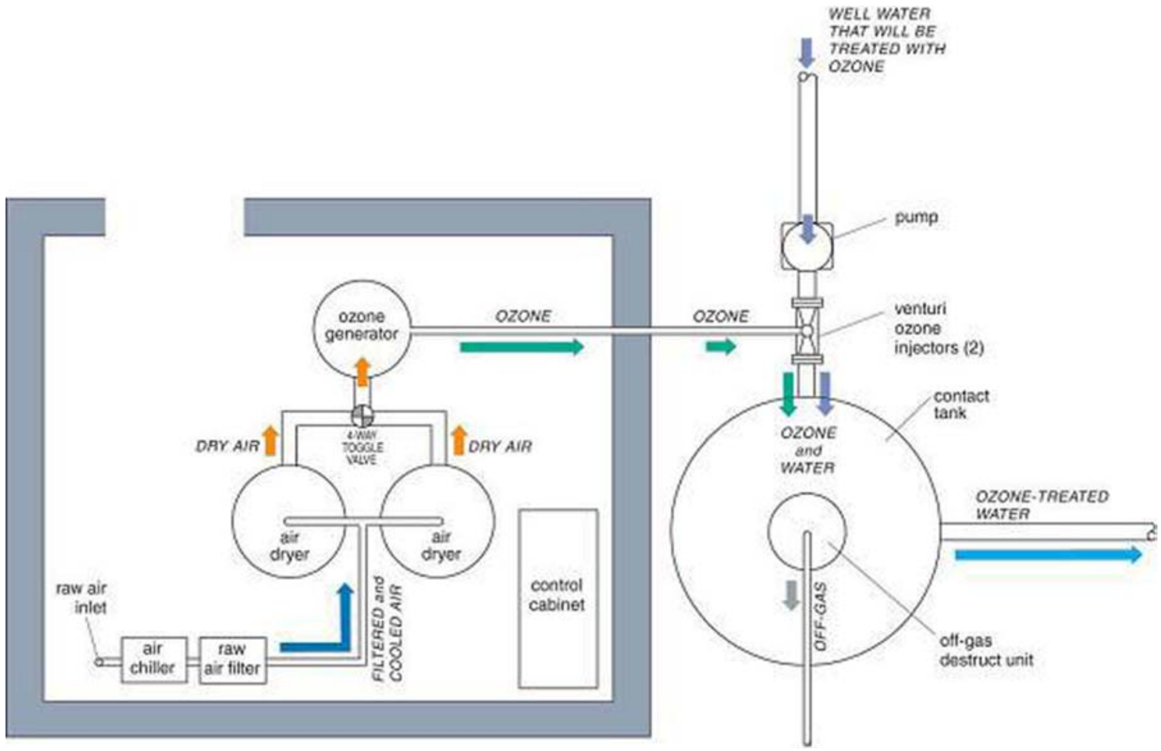


Figure 10-23 Simplified Plan View

is the most powerful oxidizer that can be safely used in water treatment.

Ozone frequently is used to treat wastewater and as a disinfectant and oxidant for bottled water, ultrapure waters, swimming pools, spas, breweries, aquariums, soft drinks, cooling towers, and many other applications. Ozone is not able to produce a stable residual in a distribution system. However, ozone can lower the chlorine demand and thus the amount of chlorine required and the chlorinated by-products.

Ozone systems can be big enough to serve central plants or municipalities. The RO membrane is only one part of a system. Figure 10-22 shows an example of a large-scale system. Figure 10-23 shows a simplified plan view of such a system.

Ultraviolet Light Treatment

Ultraviolet light is electromagnetic radiation, or radiant energy, traveling in the form of waves. When ultraviolet light of a sufficient energy level is absorbed into matter, it causes a chemical or physical change. In the case of microorganisms, ultraviolet light is absorbed to a level that is just enough to physically break the bonds in DNA to prevent life reproduction. Therefore, ultraviolet light is a mechanism capable of the disinfection of water. The most widely used source of this light is low-pressure mercury vapor lamps emitting a 254-nanometer (nm) wavelength. However, 185 nm can be used for both disinfection and total oxidizable carbon reduction. The dosage required to destroy microorganisms is the product of light intensity and exposure time. The exposure requirements for different microorganisms are well documented by the EPA. Ultraviolet bulbs are considered to provide 8,000 hours of continuous use and not to degrade to more than 55 percent of their initial output.

When ultraviolet equipment is sized, the flow rate and quality of incoming water must be taken into consideration. It is generally necessary to filter the water before the ultraviolet equipment. Sometimes it may be necessary to filter downstream of the ultraviolet equipment with 0.2-μ absolute filter cartridges to remove dead bacteria and cell fragments.

Ultraviolet equipment often is used in drinking water, beverage water, pharmaceutical, ultra-pure rinse water, and other disinfection applications.

Reverse Osmosis

Reverse osmosis (RO) is a water purification method that, over the past several years, has become an alternative to the more traditional techniques of distillation and deionization. This process is proving itself to be very practical and economical in a growing number of applications. Technical innovations and good design have handled many of the earlier limitations of the RO technology. Ozone systems can be small enough for an undercounter system in a home kitchen or big enough to serve central plants or municipalities. The RO membrane is only one part of a system. Various filters, including carbon, are still required.

RO is a relatively simple concept. In normal osmosis, the water diffuses through a membrane and dilutes the more concentrated of the two solutions (see Figure 10-24). If a pressure is applied to the concentrated solution, however, the flow can be reversed, hence the term reverse osmosis (see Figure 10-25). When this condition happens, the dissolved salts, organics, and colloidal solids are rejected by the membrane, thus resulting in a higher quality of water.

However, in practice only a certain percentage of the incoming water is allowed to permeate this membrane. The concentrate is diverted to the drain, carrying with it the rejected contaminants. The continuous flushing process of the membrane prevents a phenomenon known as concentration polarization, which is a buildup of the polarized molecules on the membrane surface that further restricts flow in a short period.

Note: When equal volumes of water are separated by a semipermeable membrane, osmosis occurs as pure water permeates the membrane to dilute the more concentrated solution. The amount of physical pressure required to equalize the two volumes after equilibrium has been reached is called the osmotic pressure (see Figure 10-25).

Note: If physical pressure is applied in excess of the osmotic pressure, reverse osmosis occurs as water passes back through the membrane, leaving contaminant concentrated upstream. In practice, the concentrate is diverted to drain, thus rejecting contaminants from the system altogether (see Figure 10-25).

Current Technology and History of RO

The current technology of RO developed rapidly as one specific application of the larger technology of synthetic membranes. Several code requirements had to be met before these membranes could be considered practical or economical for water purification processes.

First, the membrane had to be selective, i.e., it had to be capable of rejecting contaminants and yet still be highly permeable to water. This condition meant that it had to have a consistent polymeric structure with a pore size in the range of the smallest contaminant molecules possible.

Second, the membrane had to be capable of sustained high flux rates to be economical and practical in water application. This condition meant that the membrane had to be thin and yet durable enough for long-term use.

The original cellulose-acetate membranes developed proved to be highly permeable to the water. However, later developments led to a membrane with a thin skin (approximately 0.05 μ) cast on the top of a porous support structure (100 μ thick). This resulted in high flux rates, selectivity, and structural strength. The resulting RO membrane proved to be highly resistant to chemical and microbial degradation. It also could maintain the required water quality and flow rates under a sustained high pressure. Such a membrane could be incorporated into a system with relatively low capital, equipment, and operating costs. These attributes were combined successfully, and the resulting membrane achieved a flow rate of 20 gallons per square foot per day at 800 psi with 95 percent removal of salt.

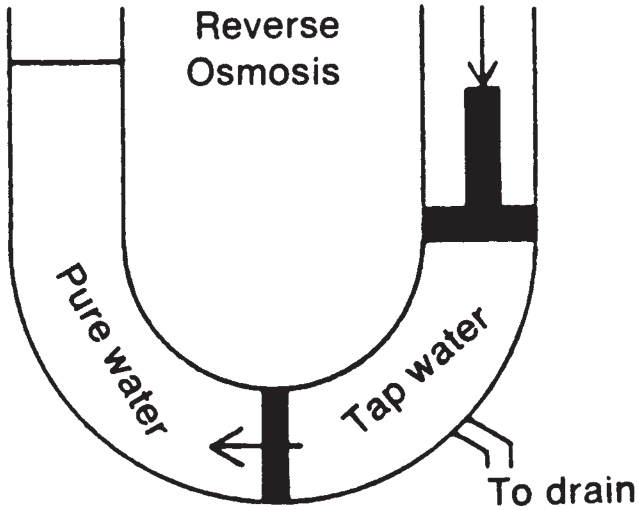


Figure 10-24 Reverse Osmosis Process

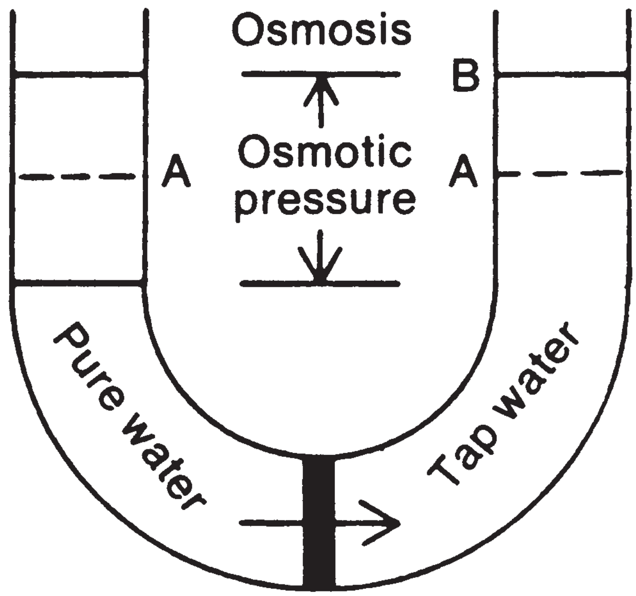


Figure 10-25 Osmotic Pressure

RO Water Quality

The term "high purity" often is applied to a type of water that may be exceptionally free of one class of contaminant and yet may contain large amounts of another. The key, of course, is the application involved. For injectable pharmaceutical preparations, particles and pyrogens are a major concern. In atomic absorption spectrophotometry or high-pressure liquid chromatography, however, even parts-per-billion traces of heavy metals or organics can present serious problems.

One useful distinction is between reagent-grade water and laboratory-grade water. Reagent-grade water means that all classes of contaminants have been removed from the water. There are several nationally recognized standards for reagent-grade water, including those published by the American Society for Testing and Materials (ASTM) and the College of American Pathologists (CAP). The minimum resistivity for reagent-grade water is 10 MΩ-cm at 25°C. The production of reagent-grade water always requires more than one stage of treatment. It should be produced at the point of use to minimize (or eliminate) transportation and storage, which invariably degrade the reagent water purity. A system for producing reagent-grade water might, for example, use the RO process to produce laboratory-grade water, plus a combination of activated carbon, deionization, and 0.20-μ membrane filtration. Only the laboratory-grade water would be accumulated and stored. The reagent water would be produced at high flow rates as needed, thus eliminating the need to store it.

Laboratory-grade water is less rigorously defined, but it still refers to the water from which one or more types of contaminants have been removed. This definition should be distinguished from other processes that exchange one contaminant for another, such as water softening (in which calcium and magnesium salts are removed by exchanging them with sodium salts). The reverse osmosis, deionization, and distillation processes are all capable of producing laboratory-grade water.

The quality of the laboratory-grade water produced by several methods of central-system water production is shown in Table 10-4. The RO and distillation processes remove more than 99 percent of all bacteria, pyrogens, colloidal matter, and organics above molecular weight 200. These methods remove the dissolved inorganic material, such as multivalent ions, calcium, magnesium, carbonates, and heavy metals to the level of 98 percent, while monovalent ions, such as sodium, potassium, and chloride, are removed to the level of 90 percent to 94 percent by RO and 97 percent by distillation processes.

Large-scale deionization processes achieve similar levels of inorganic ion removal, but they do not remove bacteria, pyrogens, particles, and organics. Bacteria, in fact, can multiply on the resins, resulting in an increase of biological contaminants over normal tap water.

It should be stressed that the degrees of water purity shown in Table 10-4 are obtainable only from well-cleaned equipment that is performing to its original specifications. Maintaining this condition for the deionization process means that the resins must be replaced (or regenerated) regularly and that the internal components of the still must be thoroughly cleaned. If a still is not properly and regularly cleaned, the residual contaminants can cause the pH value of the end product water to fall as low as pH 4. Reverse osmosis is the only one of the methods that uses a reject stream to continuously remove the residual contaminants. Regularly scheduled prefilter changes and system maintenance are, of course, necessary to maintain the desired water quality.

For dependable long-term performance, the construction of the RO equipment for large-volume applications should be of all stainless steel fittings and bowls. Such a system should use solid-state controls (with simple indicator lights and gauges) plus a conductivity meter that reads the tap and permeates water quality. High-pressure relief devices and

Table 10-4 Comparison of Laboratory-grade Water Quality Produced by Centralized Systems

Contaminant	Tap, Typical	Reverse Osmosis		Distilled		Deionized	
		Actual	Percent Removal	Actual	Percent Removal	Actual	Percent Removal
Microorganism/ mL	100	1	>99	1	>99	1000 [a]	none
Particles 5 μm/mL	10,000	1	>99	200	>97	10,000	none
Pyrogens	Variable	—	>99	—	>99	Variable	none
Dissolved organics ppm	12	1	>95	1	>95	12 [b]	none
Dissolved inorganics ppm $CaCO^3$	170	1–17	>90–98	1–8	>95–99	1–8	>95–99
Monovalent ions [c]	—	—	>90	—	>97	—	>97
Multivalent ions [d]	—	—	>97	—	>97	—	>97
Conductivity, μS, 25°C	333	2–40	—	2–10	—	2–10	—
Specific resistance MΩ/cm, 25°C	0.003	0.025–0.5	—	0.1–0.5	—	0.1–0.5	—
Silicates ppm	1	0.1	>90	0.1	>90	0.1	>90
Heavy metals ppm	1	0.1	>97	0.1	>97	0.1	>90
pH	7.5	6. 8	—	4–7. 5	—	7.0	—

[a] Bacteria often multiply in large deionizing (D.I.) resin beds used directly on tap water.
[b] Large D.I. resin beds also contribute organics from the resin beds.
[c] Monovalent ions: Singly charged ions such as Na^+, K^+, Cl^-
[d] Multivalent ions: Multiply charged ions such as Ca^{2+}, Mg^{2+}, CO_3^{2-}, SO_4^{2-}

Table 10-5 Applications of RO Water

Water Use	Method of Purification		
	RO	Distilled	Deionized
1. General process use	Yes	Yes	Yes
2. General lab use (buffers, chemical mfg.)	Yes	Yes	Yes (except for pyrogens, bacteria, and organics)
3. Dishwasher final rinse	Yes	Yes	Yes
4. Critical lab use (reagents, tissue culture, etc.)	Post-treatment necessary		
5. USP XXIII water for injection	Yes (Must meet purified water standard)	Yes	No
6. Hemodialysis	Yes	No	Yes (except for pyrogens, bacteria, and organics)

low-pressure switches protect the membrane and the pump from any prefilter blockage and accidental feed water shutoff. A water-saver device that completely shuts off water flow when the storage tank is full but allows an hourly washing of the membrane is essential.

Three types of semipermeable membranes are manufactured from organic substances: tubular membrane, cellulose-acetate sheet membrane, and polyamide-hollow fiber membrane. They may be used for similar applications, assuming that the proper pretreatment for each is furnished.

With the type of RO equipment described above and the feed water within production specifications, RO membranes may last two or three years.

Applications for RO

The quality and cost of RO water make RO a strong competitor for distillation and deionization in many applications. Table 10-5 compares the three methods of water purification for several research and industrial applications.

Frequently, the user needs both laboratory-grade and reagent-grade waters to meet a wide range of needs. Figure 10-26 shows two ways of approaching this situation. Alternative A consists of a central RO system from which the water is piped to a point-of-use polishing system to be upgraded to reagent-grade water. This approach utilizes the economics of a large central RO system while ensuring the highest reagent-grade purity at those use points that require it. Alternative B employs smaller point-of-use RO systems, with point-of-use polishing, which eliminates the lengthy distribution piping, a potential source of recontamination. Both alternatives include a final polishing by activated carbon, mixed-bed deionization, and 0.2-μ membrane filtration. In each case, laboratory-grade water is readily available directly from the RO system. Moreover, the transportation and storage of the reagent-grade water are avoided.

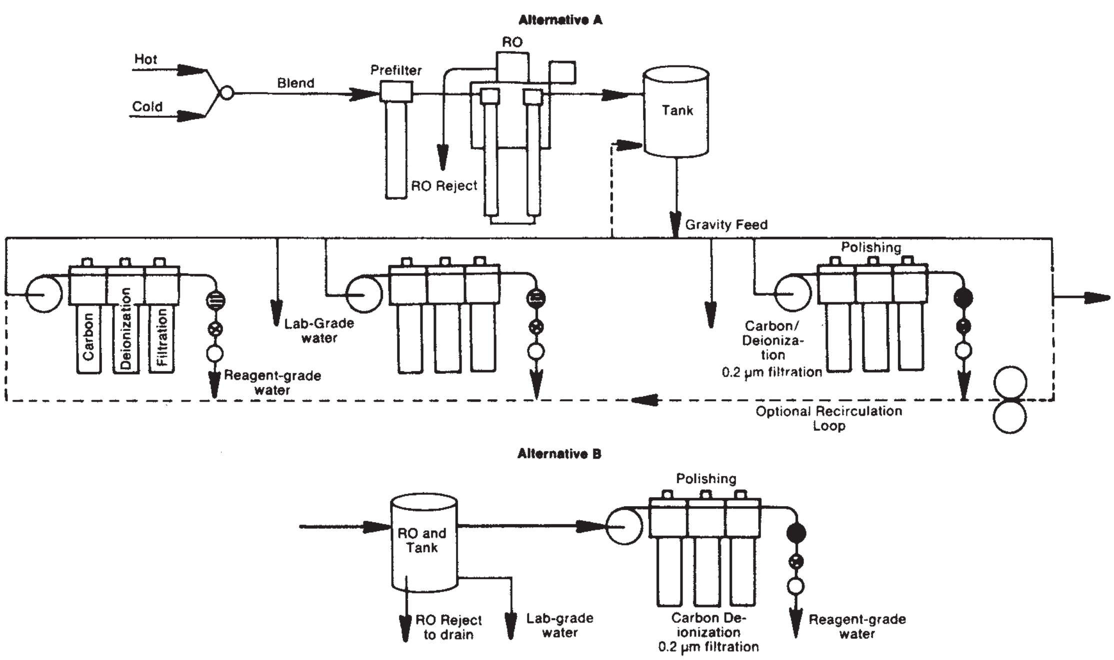


Figure 10-26 Approaches to Providing Laboratory-grade and Reagent-grade Water: (A) RO Water Purified Centrally and Transported by Pipe to Points of Use Then Polished, (B) RO System Coupled with Deionization System Totally at the Point of Use, Eliminating Piping

Figure 10-27 Silver Ionization Unit and Control Panel

Nanofiltration

Nanofiltration (NF) is a membrane filtration system that removes particles in approximately the 300–1,000 molecular weight range, rejecting selected ionic salts and most organics. Nanofiltration rejects the dissociated inorganic salts that are polyvalent, such as calcium, magnesium, and sulfate, while passing monovalent salts, such as sodium and chloride. Therefore, nanofiltration often is called a softening membrane system. Nanofiltration operates at low feed pressures. The equipment is similar to that for reverse osmosis.

Ultrafiltration

Ultrafiltration (UF) is a membrane filtration system of separating liquids and solids. It provides filtration in the range of 0.0015 μ to 0.1 μ, or approximately 1,000–100,000 molecular weight. Ultrafiltration often is used to separate oil and water as in cutting solutions, mop water, and coolants.

Copper-Silver Ionization

Copper-silver ionization is a not a filtration system, but a method of injecting positive ions into the water stream. The positive cations attach to the negative anions of organic pathogens, destroying their cell structures. It is used to eliminate Legionella and other waterborne organisms. These systems are used in tens of thousands of installations around the world. They are used extensively in hospitals and health-care centers. Figure 10-27 shows the basic system components.

GLOSSARY

The following is a list of common terms used in connection with water conditioners. A thorough knowledge of these terms and their applications will enable the designer to offer more complete service. The following should not be used as the official definitions of such terms. The designer is referred to the Plumbing Terminology section of *Plumbing Engineering Design Handbook, Volume 1,* Chapter 1, "Formulae, Symbols, and Terminology" or other acceptable definition sources.

Absorption The process of taking up a substance into the physical structure of a liquid or solid by a physical or chemical action but without a chemical reaction.

Adsorption The process by which molecules, colloids, and/or particles adhere to surfaces by physical action but without a chemical reaction.

Algae A microscopic plant growth that may be found in some well waters in certain areas of the country. This plant growth may collect on the resin in the water conditioner and result in poor operation because of a restricted water flow. Chlorination and dechlorination control this problem and protect plumbing lines and fixtures.

Alkalinity The capacity to neutralize acid, usually because of the presence of bicarbonate or carbonate ions.

Anion Negatively charged ion in a solution.

Automatic softener A fully automatic water softener that regenerates at regular intervals, without attention, to provide a continuous supply of soft, conditioned water.

Backwashing After the ion exchange capacity of the water softener resin is exhausted, it is necessary to regenerate the resin so that its original capacity may be restored. A very important step in this process is called backwashing, which is accomplished by reversing the flow of the water through the resin. This upward flow of water carries out to the drains any dirt and oxidized iron collected on top of the resin bed. Backwashing also prevents the resin from becoming packed or channeled.

Bacteria Tiny organisms occurring naturally in waters. Pathogenic (disease-causing) bacteria cause illnesses, such as typhoid, dysentery, and cholera.

Bacteriological examination New wells and private water supplies should be tested at periodic intervals to determine if the water is safe to drink. This bacteria test should be conducted by an official representative for the state board of health or drinking water regulatory agency in accordance with accepted practice and local standards. A water softener, iron remover, clarifier, or neutralizer does not purify the water.

Bed depth In every water conditioner, there is a material for a specific purpose. In the water softener, it is called high-capacity resin or ion exchange mineral. Depending on the size of the tank, this material is measured in inches of depth in the tank. This measurement is called the bed depth.

Biochemical oxygen demand A measurement of the amount of oxygen required for the biochemical degradation of organic material in water.

Bleed through When all of the iron is not removed during the service cycle of a water softener (or iron remover), the iron remaining in the effluent of treated water usually is referred to as the bleed through.

Brine A solution of sodium chloride (common salt) used for regenerating water softeners.

Brine tank A separate tank in the system employed to store the water and salt (sodium chloride) to form a brine solution.

Bypass A connection or a valve system that allows hard water to supply the system while the water softener is being regenerated or serviced.

Calcium As one of the principal elements that constitutes the earth's crust, calcium compounds, when dissolved in water, make the water hard. The presence of calcium in the water is one of the major factors contributing to the formation of scale and insoluble soap curds, which are two ways of easily identifying hard water. Often it is expressed as calcium carbonate ($CaC0_3$).

CAP College of American Pathologists, which has set water purification standards for laboratory use.

Capacity The ability of certain size water conditioners to remove a specific quantity of hardness minerals, iron, or manganese from the water going through the water conditioner.

Carbon dioxide (CO_2) A gas that is produced from the air when water falls as rain or by the decaying action of organic matter in the earth.

Cartridge filter A filter device, usually disposable, with a wide range of micron sizes.

Cation Positively charged ion.

Chemical oxygen demand A measurement of the amount of oxygen required to oxidize chemicals in water.

Chloride (Cl) An element commonly found in most natural groundwater and generally combined with other minerals, such as sodium chloride (NaCl).

Clarifier A device that removes turbidity, which is defined as sand, clay, silt, or other undissolved foreign matter.

Coagulant A chemical added to water and wastewater applications to form flocs that adsorb, entrap, and bring together suspended matter so that it can be removed.

Coalescing The separation of immiscible fluids (such as oil and water) with different specific gravities.

Concurrent regeneration During regeneration of a water conditioner, the flow is in the same direction of the service flow in all steps in the regeneration cycle except the backwash.

Concentrate In cross-flow filtration, reverse osmosis, nanofiltration, and ultrafiltration, concentrate is that amount of feed stream that does not permeate (go through) the membrane and thus concentrates the ions, suspended solids, and organics in the waste stream.

Conductivity The ability of water to conduct electricity. Conductivity is the inverse of resistivity. It is measured with a conductivity meter and described as microsiemens per centimeter, which is the same as micromhos per centimeter, which was used in the past.

Control valve A device on a water conditioner that may be manually or automatically operated and used to direct (or control) the flow of the water in a certain direction.

Conversion formula—parts per million to grains per gallon Hardness minerals, calcium and magnesium, are measured in parts per million (ppm) or grains per gallon (gpg). The accepted conversion factor is 17.1 ppm = 1 gpg, i.e., 10 gpg of hardness = 171 ppm.

Corrosion The attack by water on any part of a water system causing the wasting away of metal parts.

Countercurrent regeneration During the regeneration of a water conditioner, in all steps of the regeneration cycle, the flow is in the opposite direction of the service flow.

Cross-flow membrane filtration The separation of components of a fluid by a semipermeable membrane such as reverse osmosis, nanofiltration, ultrafiltration, and microfiltration.

Cubic foot of mineral The high-capacity resin or ion exchange mineral used in a water softener is measured and rated in cubic foot lots. For example, 1 cubic foot of high-capacity resin will remove approximately 30,000 grains per gallon of hardness minerals (calcium and magnesium) before a regeneration of the material is required.

Cycle The cycle of a water softener is generally defined as the length of time it will operate without a backwashing and/or regeneration.

Cycle operation Usually the sequence of valve operations on automatic water softeners. A two-cycle valve is a device in which upflow brining is combined with the backwash cycle, sacrificing the performance on both the backwashing and the brining. The five-cycle valve, such as the one fully automatic softeners feature, performs each essential regeneration step separately. Therefore, under optimum conditions, this type of valve provides a longer life, more efficient service, and better performance.

Diatom An organism commonly found in waters and considered by health officials to be non-harmful. Diatoms occasionally may impart objectionable odors, and their calcified skeletons make chalk and provide a diatomite powder used for swimming pool features.

Dissolved iron In water treatment, iron usually is described as being dissolved in water. The dissolved, or ferrous, iron is highly soluble in most waters, and the undissolved, or ferric, iron is almost always insoluble in water.

Dissolved solids The residual material remaining after a filtered solution evaporates.

Distributor Sometimes this device is called a strainer. It is used within a softener tank to distribute the flow of the water throughout the tank and to prevent the resin from escaping into the lines.

Down flow Usually designates the down direction in which the water flows. For example, during the brine cycle of manual and semiautomatic water softeners, the direction of the water flow is in the down direction.

Drain valve (drain line) A valve or line employed to direct or carry the backwash water, used regenerant, and rinse water to the nearest drain of the waste system.

Effluent The water moving away from, or out of, a water conditioner.

Endotoxin A heat-resistant pyrogen found in the cell walls of viable and nonviable bacteria. Expressed as EDU units.

Exhaustion In water softening or ion exchange, the point where the resin no longer can exchange additional ions of the type for which the process was designed.

Ferric iron The insoluble form of iron. Ferrous iron in the water is readily converted to ferric iron by exposure to oxygen in the air.

Ferrous iron The soluble form of iron.

Filter-ag A mineral used in the clarifier to physically separate the suspended matter in some water supplies. This ceramic-like granular material is insoluble, and it backwashes freely with less water than sand and other similar filter materials.

Filtration The process of passing a fluid through a filter material for the purpose of removing turbidity, taste, color, or odor.

Floc The suspended particles in the water that have coagulated into larger pieces and may form a mat on the top of the mineral or resin bed in a water conditioner and reduce or impair the efficient operation of the equipment.

Flow rate In water treatment, this term refers to the quantity of water flowing, in a unit of time, often given in gallons per minute (gpm) or gallons per hour (gph).

Flow regulator A mechanical or automatic device used in water treatment equipment to regulate the flow of the water to a specified maximum flow rate.

Flux In cross-flow filtration, the unit membrane throughput, expressed as volume per unit of time per area, such as gallons per day per square foot.

Free board The space above a bed of ion exchange resin or mineral in a water softener tank that allows for the unobstructed expansion of the bed during the backwash cycle.

Grains capacity The amount of hardness mineral (calcium or magnesium) that is removed by a water softener mineral or resin within a specified length of time or by a specific quantity of the resin.

Grains per gallon (gpg) A common basis of reporting water analysis. One grain per gallon equals 17.1 parts per million. One grain is 1/7,000 of a pound.

Hardness The compounds of calcium and magnesium that are usually present in hard water.

Hardness leakage The presence of hardness minerals (calcium and magnesium) after the water has passed through the softener. Hardness leakage is encountered primarily because of hardness retained in the resin bed from the previous service run. This is normal, as a point of diminishing return is realized in salt consumed versus percentage of original new capacity. In normal practice, 15 pounds of salt per cubic foot of resin is considered the practical upper limit for a regeneration. The amount of leakage expected in a properly operating system is directly proportional to the salt rate and the total dissolved solids in the incoming water. The greater the total dissolved solids and the lower the skating rate (5 pounds per cubic foot generally is considered the minimum), the greater the hardness leakage. While some leakage is normal, as explained above, excessive leakage usually indicates faulty regeneration.

High-capacity resin This term applies to the manufactured material, in the form of beads or granules, that can be described as having the power to take hardness-forming ions and give up softness-forming ions and the reverse cycle thereof. This material sometimes is called ion exchange resin.

High purity A term describing highly treated water with attention to microbiological reduction or elimination, commonly used in the electronic and pharmaceutical industries.

Hose bib An outside plumbing connection for attaching a hose.

Hydrogen sulfide A highly corrosive gas that often is found in water supplies. Water containing hydrogen sulfide gas has a characteristic boiled or rotten egg odor. A water softener is not designed to correct this condition.

Influent The water moving toward, or into, a water softener.

Inlet or outlet valve A gate valve on the inlet or outlet piping of a water conditioner.

Installation sequence In water treatment applications, it sometimes is necessary to install more than one piece of water treatment equipment to properly condition the untreated water. When this situation is necessary, it is imperative for the water treatment equipment to be installed in the proper sequence to ensure a satisfactory operation.

Ion An electrically charged atom or molecule. For example, one particle of salt is composed of approximately 100 million molecules, and each molecule of sodium chloride (salt) is composed of one sodium atom and one chlorine atom. The chlorine and sodium atoms in a sodium chloride molecule are separated by dissolving the molecule in water in a process known as ionization. However, the ions retain the electrostatic charge present in the original salt molecule.

Ion exchange The replacement of one ion by another. In the softening process, the sodium in the softener resin is exchanged for calcium, magnesium, iron, and manganese (if present).

Iron An element common to most underground water supplies, though not present in the large quantities that calcium and magnesium can be. Even small amounts of iron are objectionable in the water system. The small amounts of the dissolved iron may be removed by an ion exchange process or by precipitation and filtration processes. For the latter method, an iron remover is used.

Limestone A common rock of the earth composed primarily of calcium. It combines with carbon dioxide present in groundwater to form calcium carbonate and causes hardness of water.

Magnesium An element that, along with calcium, is responsible for the hardness of water.

Natural water Water containing dissolved inorganic solids, which are largely mineral salts. These salts are introduced into the water by a solvent action, as the water passes through, or across, various layers of the earth. The type of mineral salts absorbed depends on the chemical contents of the soil through which the water passes. Note: Pure water (no impurities) is never found in nature.

Nitrate Something that sometimes is found in natural water, but in trace amounts. It is becoming more of a concern, as nitrate contamination from sewage or predominantly concentrated nitrogen fertilizers in the groundwater table is surfacing in some areas of the country. High nitrate levels, generally 10 parts per million or more, can cause a condition known as blue baby, a condition that inhibits the transfer of oxygen through the lung tissue to the bloodstream, resulting in oxygen starvation. Pregnant women and young children are cautioned in this regard. Pregnant women are cautioned in regard to their unborn child as opposed to their own physical well-being. Adults do not normally suffer any effect at these levels. In animals, such as cattle and horses, high nitrate levels can cause stillborn offspring and miscarriages, as well as a high mortality rate of the newly born.

Ohm A unit of measurement. One ohm (1Ω) is equals 0.5×10^{-6} parts per million or 10^{-6} microsiemens.

Parts per million (ppm) A common method of reporting water analyses. 17.1 ppm equals 1 grain per gallon. Parts per million commonly is considered equivalent to milligrams per liter.

pH value A number denoting the alkaline or acid nature of the water (or solution). The pH scale ranges from 0 to 14, 7.0 being the accepted neutral point. A pH value below 7.0 indicates acidity in the water (or solution). Values for pH above 7.0 indicate alkalinity of the water (or solution).

Precipitate A solid residue formed in the process of removing certain dissolved chemicals out of a solution.

Pressure drop A decrease in the water pressure, typically measured in pounds per square inch.

Regeneration Complete regeneration of a water softener, consisting of a backwash cycle, addition of sodium chloride (salt), and rinsing the sodium chloride solution through the ion exchange resin to exchange the hardness ions collected in the resin and prepare the solution for a service cycle.

Resin A synthetic polystyrene ion exchange material (often called a high-capacity resin).

Rinse Part of the regeneration cycle of a water softener where freshwater is passed through a water softener to remove the excess salt (sodium chloride) prior to placing the water softener into service.

Salt A high-grade sodium chloride of a pellet or briquette type used for regenerating a water softener.

Service run The operating cycle of a water softener, during which the hard water passes through the ion exchange resin and enters the service lines as soft water.

Sodium (Na^+) An element usually found in water supplies (depending on local soil conditions) that is a basic part of common salt (sodium chloride).

Soft water Water without hardness material, which has been removed either naturally or through ion exchange.

Sulfate ($S0_4^{2-}$) A compound commonly found in waters in the form of calcium sulfate ($CaS0_4$) or magnesium sulfate ($MgS0_4$).

Suspension The foreign particles carried (but not dissolved) in a liquid, like rusty iron in water.

Tannin An organic color or dye, not a growth, sometimes found in waters. (The latter is the result of decomposition of wood buried underground.)

Titration A laboratory method of determining the presence and amount of chemical in a solution, such as the grains hardness (calcium and magnesium) of water.

Total dissolved solids (TDS) All dissolved materials in the water that cannot be removed by mechanical filtration, generally expressed in terms of parts per million.

Turbidity A term used to define the degree of cloudiness of water. Laboratory analysis shows the turbidity in nephelometric turbidity units. All undissolved materials, such as clay, silt, or sand, are taken into consideration. If the turbidity is high and the water is unacceptable for use, a clarifier is recommended.

Up flow The up direction in which the water flows through the water conditioner during any phase of the operating cycle.

Virus A tiny organism that is smaller than bacteria and is resistant to normal chlorination. Viruses cause diseases, such as poliomyelitis and hepatitis (both of which are transmitted primarily through water supplies). Cross-connections or polluted waters are the primary means of transmission.

RESOURCES

American Water Works Association: www.awwa.org

U.S. Environmental Protection Agency: www.epa.gov

EPA Water Quality Standards: www.epa.gov/waterscience/standards

Partnership for Safe Water: www.epa.gov/safewater/psw/psw.html

The Joint Commission: www.jointcommission.org

Ozone Technology Inc.: www.o3ti.com

11 Thermal Expansion

All piping materials undergo dimensional changes due to temperature variations in a given system. The amount of change depends on the material characteristics (the linear coefficient of thermal expansion or contraction) and the amount of temperature change. The coefficient of expansion or contraction is defined as the unit increase or decrease in length of a material per 1°F increase or decrease in temperature. Coefficients of thermal expansion or contraction for a number of commonly used pipe materials are shown in Table 11-1. These coefficients are in accordance with American Society of Testing and Materials (ASTM) D696: *Standard Test Method for Coefficient of Linear Thermal Expansion of Plastics Between -30°C and 30°C With a Vitreous Silica Dilatometer* and are based on completely unrestrained specimens.

Table 11-1 Linear Coefficients of Thermal Expansion or Contraction

Material	Coefficient in./in./°F	Expansion or Contraction in/100 ft/10°F
Steel	6.5×10^{-6}	0.078
Cast iron	5.6×10^{-6}	0.067
Copper	9.8×10^{-6}	0.118
Brass	10.4×10^{-6}	0.125
ABS	5.5×10^{-5}	0.66
PVC type I (PVC 1120 and 1220)	3.0×10^{-5}	0.36
PVC type II (PVC 2110, 2112, 2116, and 2120)	4.5×10^{-5}	0.54
PB	7.5×10^{-5}	0.90
PE	8.0×10^{-5}	0.96
CPVC	3.5×10^{-6}	0.42
SR	6.0×10^{-5}	0.72

Notes: ABS = acrylonitrile butadiene styrene; PVC = polyvinyl chloride; PB = polybutylene; PE = polyethylene; CPVC = chlorinated polyvinyl chloride; SR = Styrene Rubber.

If the coefficients of thermal expansion or contraction are known, the total changes in length may be calculated as follows:

Equation 11-1

$$L_2 - L_1 = \alpha L_1 (T_2 - T_1)$$

where

L_1 = Original pipe length, feet
L_2 = Final pipe length, feet
T_1 = Original temperature, °F
T_2 = Final temperature, °F
α = Coefficient of expansion or contraction, foot/foot°F

A typical range of temperature change in a hot water piping system is from 40°F entering water to 120°F distribution water, for an 80°F temperature differential. Total linear expansion or contraction for a 100-foot length of run when subject to an 80°F change in temperature can be calculated for the usual piping materials in a hot water system. A typical range of temperature in a drain, waste, and vent (DWV) system is from 100°F (the highest temperature expected) to 50°F (the lowest temperature expected), for a 50°F temperature differential.

ABOVEGROUND PIPING

Two examples of aboveground piping are hot water pipe that carries hot water intermittently with a gradual cooling in between, and drain, waste, and vent pipe into which water ranging from 50°F to 100°F is intermittently discharged. These greater temperature changes are offset by the fact that most aboveground piping involves short runs with several changes in direction. Thus, for many installations, such as one- or two-family dwellings, no special precautions need to be taken. Of particular concern are hot water and DWV systems in high-rise buildings.

Pressure Piping

Aboveground pressure piping incorporating short runs and several changes in direction normally accommodate expansion or contraction. Precaution should be taken to ensure that pipe hangers or clamps allow longitudinal movement of the pipe and that the 90-degree bends are not butted against a wall or similar structure that restricts movement.

If runs in excess of 20 feet are required, flexural offsets or loops should be provided. To not exceed the maximum allowable strain in the piping, the developed length that should be provided in the offset or loop can be calculated from the following equation:

Equation 11-2

$$\Delta = \frac{PL^3}{3EI}$$

where

Δ = Maximum deflection at the end of a cantilever beam, inches
P = Force at end, pounds
L = Length of pipe subjected to flexible stress, inches
E = Flexural modulus of elasticity, pounds per square inch (psi)
I = Moment of inertia, $inches^4$

For pipes in which the wall thickness is not large with respect to the outside diameter, the moment of inertia and the sectional modulus can be calculated as follows:

$$I = \pi R^3 t$$

and

$$Z = \pi R^2 t$$

where

R = Outside radius, inches
t = Wall thickness, inches
Z = Section modulus, cubic inches

For thin-walled pipes, the maximum allowable stress and the maximum allowable strain can be calculated as follows:

$$S = \frac{4PL}{\pi D^2 t}$$

$$\varepsilon = \frac{\pi D^2 St}{4L}$$

where

S = Maximum fiber stress in bending = M/Z, psi
M = Bending moment = PL, inch pounds
D = Outside diameter, inches
ε = Strain

Substituting the maximum allowable stress and the maximum allowable strain into Equation 11-2, the development length of piping can be estimated by Equations 11-3 and 11-4 respectively.

Equation 11-3

$$L = \left(\frac{3ED\Delta}{2S}\right)^{1/2}$$

Equation 11-4

$$L = \left(\frac{3D\Delta}{2\varepsilon}\right)^{1/2}$$

Equation 11-3 is used when the maximum allowable stress is fixed, and Equation 11-4 is used when the maximum allowable strain is fixed. When Equation 11-4 is used, the flexural modulus of elasticity must be known. In cases where the modulus of the specific compound is not available, the following approximately average values are usually adequate:

Compound	E at 73°F, psi	Hydrostatic Design Stress for Water at 73°F, S
Copper	15.6×10^{-6}	6,000
Steel	30×10^{-6}	
Cast iron		
Brass		
PVC 1120	400,000	2,000
PVC 2110	340,000	1,000
ABS 1210	240,000	1,000
ABS 1316	340,000	1,600
PE 2306	90,000	630

Equation 11-3 can be factored to yield the following equation:

Equation 11-5

$$L = \left(\frac{3E}{2S}\right)\left(D\Delta\right)^{1/2}$$

where

E and S = Constants for any given material

Using the values for E and S in the above table, Equation 11-3 or Equation 11-5 reduces to the following table:

Compound	Equation 11-3, inches[a]
Steel pipe	$L = 6.16 (D\Delta)^{1/2}$
Brass pipe	$L = 6.83 (D\Delta)^{1/2}$
Copper pipe	$L = 7.40 (D\Delta)^{1/2}$
PVC 1120	$L = 17.3 (D\Delta)^{1/2}$
PVC 2110	$L = 22.8 (D\Delta)^{1/2}$
ABS 1210	$L = 19.0 (D\Delta)^{1/2}$
ABS 1316	$L = 17.9 (D\Delta)^{1/2}$
PE 2306	$L = 14.6 (D\Delta)^{1/2}$
PE 3306	$L = 16.9 (D\Delta)^{1/2}$

[a] L = Developed length of piping used to absorb movement (feet); D = Outside diameter of pipe (inches); Δ = Amount of movement to be absorbed (inches)

Provisions must be made for the expansion and contraction of all hot water and circulation mains, risers, and branches. If the piping is restrained from moving, it will be subjected to compressive stress on a temperature rise and to tensile stress on a temperature drop. The pipe itself usually can withstand these stresses, but failure frequently occurs at pipe joints and fittings when the piping cannot move freely.

Two methods commonly are used to absorb pipe expansion and contraction without damage to the piping:

1. Expansion loops and offsets
2. Expansion joints

The total movement to be absorbed by any expansion loop or offset often is limited to a maximum of 1½ inches for metallic pipes. Thus, by anchoring at the points on the length of run that produce 1½-inch movement and placing the expansion loops or joints midway between the anchors, the maximum movement that must be accommodated is limited to ¾ inch. The piping configuration used to absorb the movement can be in the form of a U bend; a single-elbow offset; a two-elbow offset; or a three-, five-, or six-elbow swing loop. In the great majority of piping systems, the loop or joint can be eliminated by taking advantage of the changes in direction normally required in the layout.

Table 11-2 gives the total developed length required to accommodate a 1½-inch expansion. (The developed length is measured from the first elbow to the last elbow, see Figure 11-1.)

Table 11-2 Developed Length of Pipe to Accommodate 1½-in. Movement

Pipe Size, in.	Steel Pipe, ft	Brass Pipe, in.	Copper Pipe, ft
0.5	7.7	7.7	8.3
0.75	8.7	8.6	9.3
1	9.8	9.6	10.4
1.25	10.4	10.8	11.7
1.5	11.5	11.5	12.5
2	12.8	12.7	13.8
2.5	14.2	14.2	15.4
3	16.0	15.7	17.0
4	16.0	17.7	19.2

Note: mm = in. × 25.4,
m = ft × 0.3048.

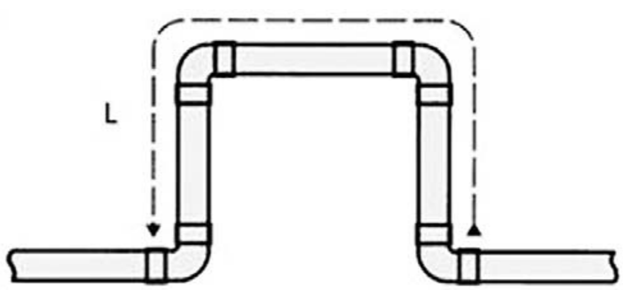


Figure 11-1 Expansion Loop Detail

If a maximum allowable strain of 0.01 inch per inch for plastic pipes is used, Equation 11-4 reduces to

$$L = 12.2\ (D\Delta)^{1/2}$$

Use of the factors given in the table for Equation 11-3 or Equation 11-5 above indicates that a strain of less than 0.01 inch per inch will result.

Computer programs are available that readily solve these equations as well as address the various installation configurations.

Drain, Waste, and Vent Piping

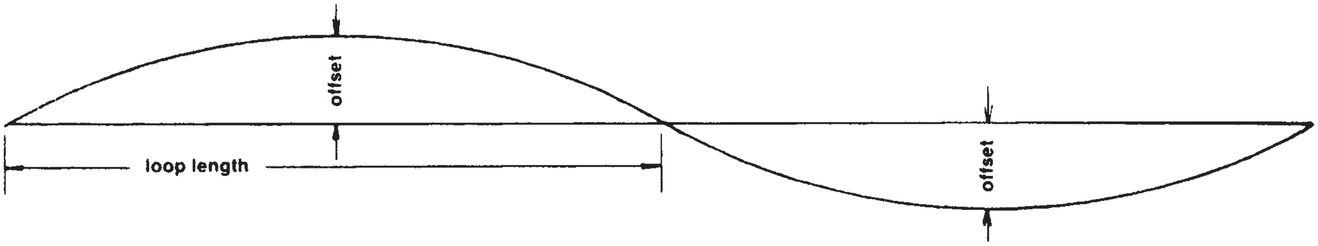
Expansion or contraction usually does not present a problem in DWV installations in one- and two-family dwellings due to the short lengths of piping involved. It does create problems in high-rise buildings where long stacks are installed. Three methods of accommodating expansion or contraction are described below:

1. To accommodate expansion and contraction in building drains and drainage stacks, offsets may be provided. The developed length of the offset that should be provided can be calculated in accordance with the appropriate formula. For example, for a 50°F temperature differential in the straight run, the amount to be accommodated at the branch connection is approximately ⅜ inch. To accommodate this amount of expansion, the branch pipe must have sufficient development length to overcome a bending twist without being subjected to excessive strain.
2. Where allowed by applicable codes, expansion joints may be used. There are two types of expansion joints: slip and bellows. The slip-type joint with an elastomeric seal requires packing and lubrication. The bellows-type expansion joint is satisfactory for the 1½-inch design limitation in movement. Proper pipe guiding is essential when using expansion joints. Guides allow axial movement, but prevent lateral and angular movement. Without guides, the pipe may buckle, causing the expansion joint to fail. Most manufacturers of expansion joints require guides to be installed properly to ensure the manufacturer's warranty. The quantity and location of the guides depend on the pipe size, proximity of the expansion joint to the anchor, and length of pipe run. An expansion joint should be installed every 30 feet according to the manufacturer's recommendations. Normally, the expansion joint is installed in the thermal neutral position so that it can move in either direction to absorb either expansion or contraction. On vertical piping, the pipe should be anchored by side inlets or clamps at or near the joint.
3. Engineering studies have shown that by restraining the pipe every 30 feet to prevent movement, satisfactory installations can be made. Tensile or compressive stresses developed by contraction or expansion are readily absorbed by the piping without any damage. Special stack anchors are available and should be installed according to the manufacturer's recommendations.

UNDERGROUND PIPING

Underground piping temperature changes are less drastic because the piping is not exposed to direct heating from solar radiation, the insulating nature of the soil prevents rapid temperature changes, and

Table 11-3 Approximate Sine Wave Configuration With Displacement



Flexible Pipe
Maximum Temperature Variation (Between Installation and Service), °F

	10	20	30	40	50	60	70	80	90	100
Loop Length, ft	**Offset for Contraction, in.**									
20	3	4	5	6	7	8	9	10	11	12
50	7½	10	12½	15	17½	20	22½	25	27½	30
100	15	20	25	30	35	40	45	50	55	60

Rigid Pipe
Maximum Temperature Variation (Between Installation and Service), °F

	10	20	30	40	50	60	70	80	90	100
Loop Length, ft	**Offset for Contraction, in.**									
20	1½	2	2½	3	3½	4	4½	5	5½	6
50	3¾	5	6¼	7½	8¾	10	11¼	12½	13¾	15
100	7½	10	12½	15	17½	20	22½	25	27½	30

Note: °C = (F – 32) /1.8
mm = in. × 25.4
m = ft × 0.3048

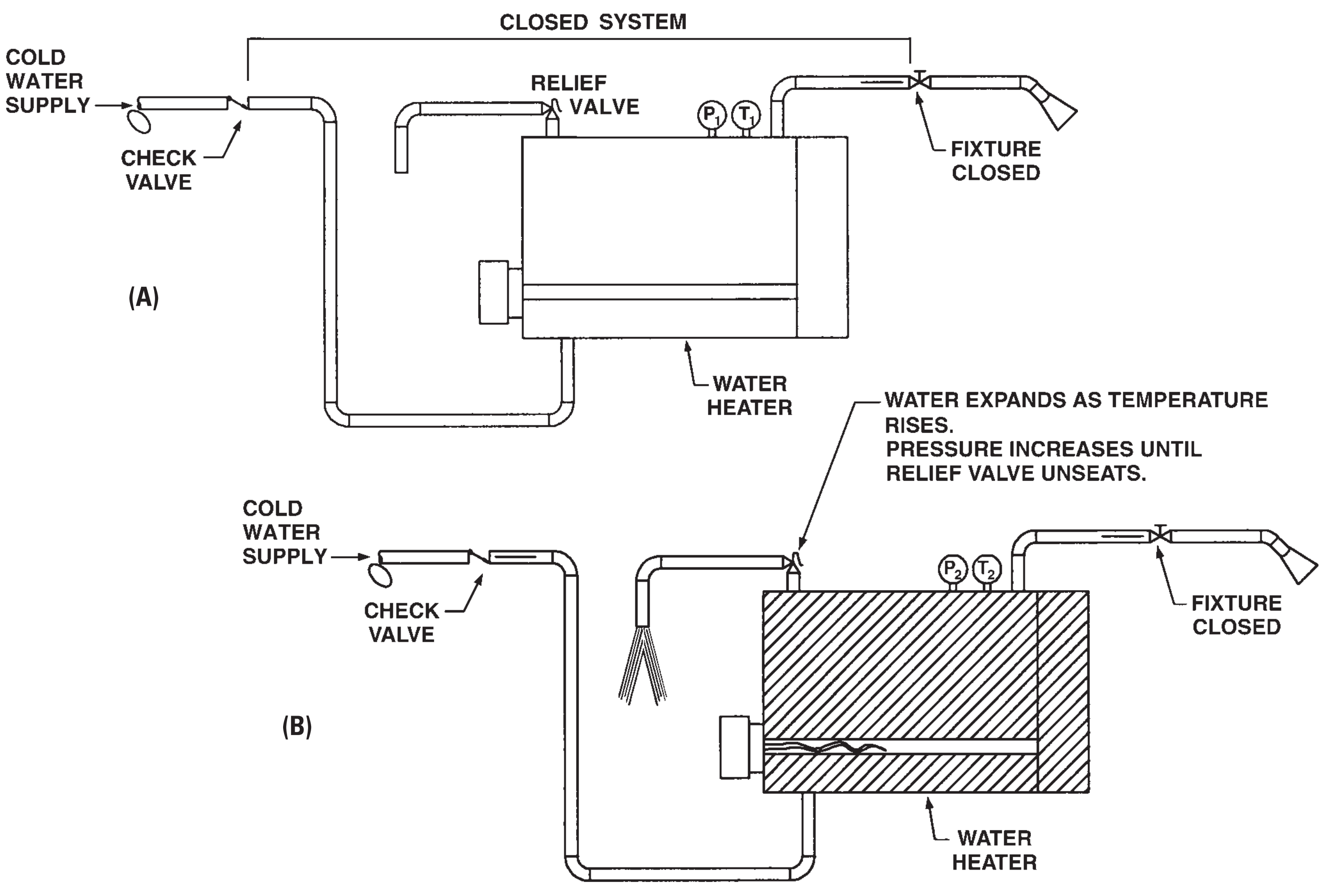


Figure 11-2 Closed Hot Water System Showing the Effects as Water and Pressure Increase from (A) P_1 and T_1 to (B) P_2 and T_2

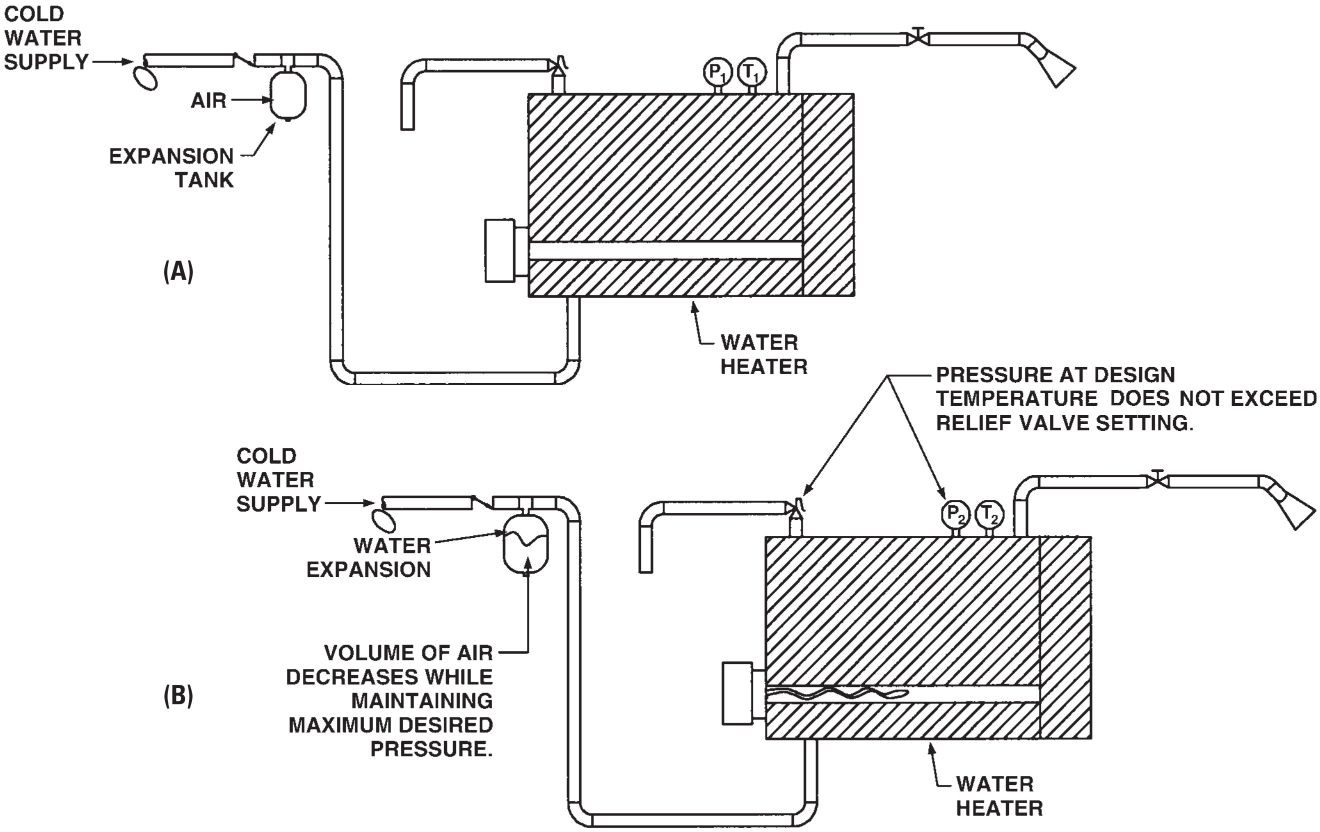


Figure 11-3 Effects of an Expansion Tank in a Closed System as Pressure and Temperature Increase from (A) P_1 and T_1 to (B) P_2 and T_2

the temperature of the transported medium can have a stabilizing effect on the pipe temperature.

Contraction or expansion of flexible pipe can be accommodated by snaking the pipe in the trench. An approximate sine wave configuration with a displacement from the centerline and a maximum offset as shown in Table 11-3 accommodate most situations. The installation should be brought to the service temperature prior to backfilling. After increased length is taken up by snaking, the trench can be backfilled in the normal manner.

Up to 3-inch nominal size, rigid pipe can be handled by snaking in the same manner used for flexible pipe. Offsets and loop lengths under specific temperature variations are shown in Table 11-3. For distances of less than 300 feet, 90-degree changes in direction take up any expansion or contraction that occurs.

For larger sizes of pipe, snaking is not practical or possible in most installations. In such cases, the pipe is brought to within 15°F of the service temperature, and the final connection is made. This can be accomplished by shade backfilling, allowing the pipe to cool at night and then connecting early in the morning, or cooling the pipe with water. The thermal stresses produced by the final 15°F service temperature are absorbed by the piping.

EXPANSION TANKS

When water is heated, it expands. If this expansion occurs in a closed system, dangerous water pressures can be created. A domestic hot water system can be a closed system. When hot water fixtures are closed and the cold water supply piping has backflow preventers or any other device that can isolate the domestic hot water system from the rest of the domestic water supply, a closed system can be created. (See Figure 11-2(A).)

These pressures can quickly rise to a point at which the relief valve on the water heater unseats, thus relieving the pressure, but at the same time compromising the integrity of the relief valve. (See Figure 11-2(B).) A relief valve installed on a water heater is not a control valve, but a safety valve. It is not designed or intended for continuous usage. Repeated excessive pressures can lead to equipment and pipe failure and personal injury.

When properly sized, an expansion tank connected to the closed system provides additional system volume for water expansion while ensuring a maximum desired pressure in a domestic hot water system. It does this by utilizing a pressurized cushion of air. (See Figure 11-3.)

The objectives of this section are to show the designer how to size an expansion tank for a domestic hot water system and to explain the theory behind the design and calculations. The following discussion is based on the use of a diaphragm or bladder-type expansion tank, which is the type most commonly used in the plumbing industry. This type of expansion tank does not allow the water and air to be in contact with each other.

Expansion of Water

A pound of water at 140°F has a larger volume than the same pound of water at 40°F. To put it another way, the specific volume of water increases with an increase in temperature. Specific volume data show the volume of 1 pound of water for a given temperature and are expressed in cubic feet per pound. If the volume of water at each temperature condition is known, the expansion of water can be calculated as follows:

$$Vew = Vs_2 - Vs_1$$

where

Vew = Expansion of water, gallons
Vs_1 = System volume of water at temperature 1, gallons
Vs_2 = System volume of water at temperature 2, gallons

Vs_1 is the initial system volume and can be determined by calculating the volume of the domestic hot water system. This entails adding the volume of the water-heating equipment with the volume of piping and any other part of the hot water system.

Vs_2 is the expanded system volume of water at the design hot water temperature. Vs_2 can be expressed in terms of Vs_1. To do that, look at the weight of water at both conditions.

The weight (W) of water at temperature 1 (T_1) equals the weight of water at T_2, or $W_1 = W_2$. At T_1, $W_1 = Vs_1/vsp_1$, and similarly at T_2, $W_2 = Vs_2/vsp_2$, where vsp equals specific volume of water at the two temperature conditions. (See Table 11-4 for specific volume data.) Since $W_1 = W_2$, then:

$$\frac{Vs_1}{vsp_1} = \frac{Vs_2}{vsp_2}$$

Solving for Vs_2:

$$Vs_2 = Vs_1\left(\frac{vsp_2}{vsp_1}\right)$$

Earlier it was stated that $Vew = Vs_2 - Vs_1$. Substituting Vs_2 from above, it can be calculated that since

$$Vs_2 = Vs_1\left(\frac{vsp_2}{vsp_1}\right)\text{, then}$$

$$Vew = Vs_1\left(\frac{vsp_2}{vsp_1}\right) - Vs_1\text{, or}$$

Equation 11-6

$$Vew = Vs_1\left(\frac{vsp_2}{vsp_1 - 1}\right)$$

Example 11-1

A domestic hot water system has 1,000 gallons of water. How much will the 1,000 gallons expand from a temperature of 40°F to a temperature of 140°F?

Solution

From Table 11-4,

$vsp_1 = 0.01602$ (at 40°F)
$vsp_2 = 0.01629$ (at 140°F)

Utilizing Equation 11-6,

$$Vew = 1000\left(\frac{0.01629}{0.01602 - 1}\right)$$

Vew = 16.9 gallons

Note that this is the amount of water expansion and should not be confused with the size of the expansion tank needed.

Table 11-4 Thermodynamic Properties of Water at a Saturated Liquid

Temp., °F	Specific Volume, ft^3/lb
40	0.01602
50	0.01602
60	0.01604
70	0.01605
80	0.01607
90	0.01610
100	0.01613
110	0.01617
120	0.01620
130	0.01625
140	0.01629
150	0.01634
160	0.01639

Expansion of Material

Will the expansion tank receive all the water expansion? The answer is no, because not just the water is expanding. The piping and water-heating equipment expand with an increased temperature as well. Any expansion of these materials results in less of the water expansion being received by the expansion tank. Another way of looking at it is as follows:

$$Venet = Vew - Vemat$$

where

Venet = Net expansion of water received by the expansion tank, gallons
Vew = Expansion of water, gallons
Vemat = Expansion of material, gallons

To determine the amount of expansion each material experiences per a certain change in temperature, look at the coefficient of linear expansion for that material. For copper, the coefficient of linear expansion is 9.5×10^{-6} inch/inch°F and for steel it is 6.5×10^{-6} inch/inch°F. From the coefficient of linear expansion, the coefficient of volumetric expansion of material can be determined. The coefficient of volumetric expansion is three times the coefficient of linear expansion:

$$\beta = 3\alpha$$

where

β = Volumetric coefficient of expansion
α = Linear coefficient of expansion

The volumetric coefficient for steel, then, is 19.5×10^{-6} gallon/gallon°F, and for copper it is 28.5×10^{-6} gallon/gallon°F. The material will expand proportionally with an increase in temperature.

Equation 11-7

$$Vemat = Vmat \times \beta\ (T_2 - T_1)$$

Making the above substitution and solving for Venet,

Equation 11-8

$$Venet = Vew - [Vmat_1 \times \beta_1\ (T_2 - T_1) + Vmat_2 \times \beta_2\ (T_2 - T_1)]$$

Example 11-2

A domestic hot water system has a water heater made of steel with a volume of 900 gallons. It has 100 feet of 4-inch piping, 100 feet of 2-inch piping, 100 feet of 1½-inch piping, and 300 feet of ½-inch piping. All of the piping is copper. Assuming that the initial temperature of water is 40°F and the final temperature of water is 140°F, (1) how much will each material expand, and (2) what is the net expansion of water that an expansion tank will see?

Solution

1. Utilizing Equation 11-7 for the steel (material no. 1),

   $Vmat_1 = 900$ gallons

   $Vemat_1 = 900\ (19.5 \times 10^{-6})(140 - 40) = 1.8$ gallons

For the copper (material no. 2), first look at Table 11-5 to determine the volume of each size of pipe.

4 inches	100 × 0.67 = 67 gallons
2 inches	100 × 0.17 = 17 gallons
1½ inches	100 × 0.10 = 10 gallons
½ inch	300 × 0.02 = 6 gallons
Total volume of copper piping: 100 gallons	

Utilizing Equation 11-7 for copper,

$Vmat_2 = 100$ gallons

$Vemat_2 = 100\ (28.5 \times 10^{-6})(140 - 40) = 0.3$ gallon

Table 11-5 Nominal Volume of Piping

Pipe Size, in.	Volume of Pipe, gal/linear ft of pipe
½	0.02
¾	0.03
1	0.04
1¼	0.07
1½	0.10
2	0.17
2½	0.25
3	0.38
4	0.67
6	1.50
8	2.70

2. The initial system volume of water (Vs_1) equals $Vmat_1 + Vmat_2$, or 900 gallons + 100 gallons. From Example 11-1, 1,000 gallons of water going from 40°F to 140°F expands 16.9 gallons. So, utilizing Equation 11-8, Venet = 16.9 – (1.8 + 0.03) = 15 gallons. This is the net amount of water expansion that the expansion tank will see. Once again, note that this is not the size of the expansion tank needed.

Boyle's Law

After determining how much water expansion the expansion tank will see, it is time to look at how the cushion of air in an expansion tank allows the designer to limit the system pressure.

Boyle's law states that at a constant temperature, the volume occupied by a given weight of perfect gas (including for practical purposes atmospheric air) varies inversely as the absolute pressure (gauge pressure + atmospheric pressure). It is expressed by

Equation 11-9

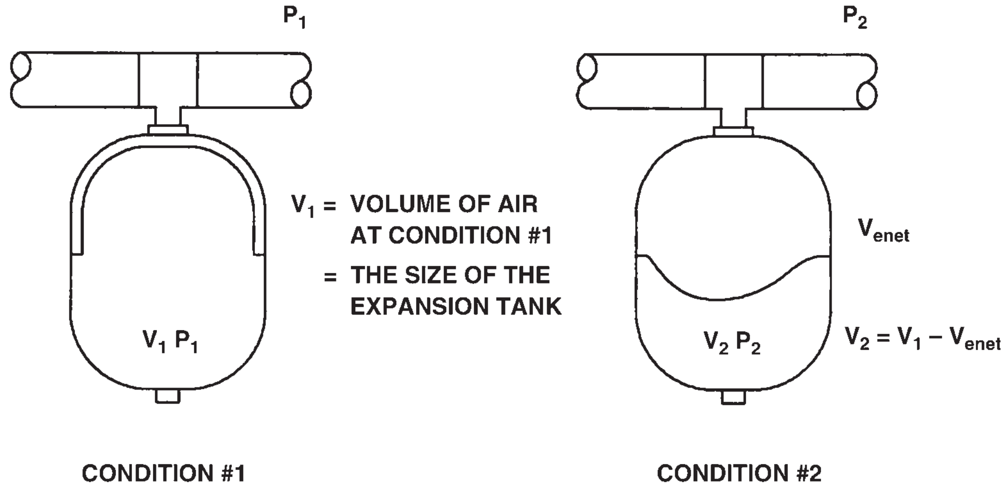
$$P_1V_1 = P_2V_2$$

where

P_1 = Initial air pressure, pounds per square inch absolute (psia)
V_1 = Initial volume of air, gallons
P_2 = Final air pressure, psia
V_2 = Final volume of air, gallons

How does this law relate to sizing expansion tanks in domestic hot water systems? The air cushion in the expansion tank provides a space into which the expanded water can go. The volume of air in the tank decreases as the water expands and enters the tank. As the air volume decreases, the air pressure increases.

Utilizing Boyle's law, the initial volume of air (i.e., the size of the expansion tank) must be based on (1) initial water pressure, (2) desired maximum water pressure, and (3) change in the initial volume of the air. To utilize the above equation, realize that the pressure of the air equals the pressure of the water



NOTE: PRESSURE OF WATER = PRESSURE OF AIR

Figure 11-4 Sizing the Expansion Tank

at each condition, and make the assumption that the temperature of the air remains constant at condition 1 and condition 2. This assumption is reasonably accurate if the expansion tank is installed on the cold water side of the water heater. Remember, in sizing an expansion tank, the designer is sizing a tank of air, not a tank of water.

Referring to Figure 11-4, at condition 1, the tank's initial air pressure charge, P_1, equals the incoming water pressure on the other side of the diaphragm. The initial volume of air in the tank, V_1, is also the size of the expansion tank. The final volume of air in the tank, V_2, also can be expressed as V_1 less the net expansion of water (Venet). The pressure of the air at condition 2, P_2, is the same pressure as the maximum desired pressure of the domestic hot water system at the final temperature, T_2. P_2 always should be less than the relief valve setting on the water heater.

Utilizing Boyle's law,

$$P_1V_1 = P_2V_2$$

Since $V_2 = V_1 - \text{Venet}$, then

$$P_1V_1 = P_2(V_1 - \text{Venet})$$

$$P_1V_1 = P_2V_1 - P_2\text{Venet}$$

$$(P_2 - P_1)V_1 = P_2\text{Venet}$$

$$V_1 = \frac{P_2\text{Venet}}{P_2 - P_1}$$

Multiplying both sides of the equation by $(1/P_2)/(1/P_2)$, or by 1, the equation becomes:

Equation 11-10

$$V_1 = \frac{\text{Venet}}{1 - (P_1/P_2)}$$

where

V_1 = Size of expansion tank required to maintain the desired system pressure, P_2, gallons

Venet = Net expansion of water, gallons

P_1 = Incoming water pressure, psia (Note: Absolute pressure is gauge pressure plus atmospheric pressure, or 50 psig = 64.7 psia.)

P_2 = Maximum desired pressure of water, psia

Example 11-3

Looking again at the domestic hot water system described in Example 11-2, if the cold water supply pressure is 50 psig and the maximum desired water pressure is 110 psig, what size expansion tank is required?

Example 11-2 determined that Venet equals 15 gallons. Converting the given pressures to absolute and utilizing Equation 11-10, the size of the expansion tank needed can be determined as:

$$V_1 = \frac{15}{1 - (64.7/124.7)} = 31 \text{ gallons}$$

Note: When selecting the expansion tank, make sure the tank's diaphragm or bladder can accept 15 gallons of water (Venet).

SUMMARY

Earlier in this section, the following were established:

Equation 11-6

$$\text{Vew} = \text{Vs}_1\left(\frac{\text{vsp}_2}{\text{vsp}_1 - 1}\right)$$

Equation 11-8

$$\text{Venet} = \text{Vew} - [\text{Vmat}_1 \times \beta_1 (T_2 - T_1) + \text{Vmat}_2 \times \beta_2 (T_2 - T_1)]$$

In Equation 11-6, Vs_1 was defined as the system volume at condition 1. Vs_1 also can be expressed in terms of Vmat:

$$Vs_1 = Vmat_1 + Vmat_2$$

Making this substitution and combining the equations provides the following two equations:

Equation 11-11

$$Venet = (Vmat_1 + Vmat_2)\left(\frac{vsp_2}{vsp_1 - 1}\right) - [Vmat_1 \times ß_1(T_2 - T_1) + Vmat_2 \times ß_2(T_2 - T_1)]$$

Equation 11-10

$$V_1 = \frac{Venet}{1 - (P_1/P_2)}$$

where

Venet = Net expansion of water seen by the expansion tank, gallons
Vmat = Volume of each material, gallons
vsp = Specific volume of water at each condition, cubic feet per pound
β = Volumetric coefficient of expansion of each material, gallon/gallon°F
T = Temperature of water at each condition, °F
P = Pressure of water at each condition, psia
V_1 = Size of expansion tank required, gallons

These two equations are required to properly size an expansion tank for a domestic hot water system.

RESOURCES

Copper Tube Handbook. Copper Development Association.

Steele, Alfred. *Engineered Plumbing Design II*. American Society of Plumbing Engineers.

PPI-TR 21: *Thermal Expansion and Contraction in Plastics Piping Systems*. Plastics Pipe Institute.

12 Potable Water Coolers and Central Water Systems

First invented in 1906, the water cooler has experienced an ever-changing transformation. This invention is credited to Halsey Willard Taylor and Luther Haws. Haws patented the first drinking faucet in 1911 (see Figure 12-1). The original units consisted of large blocks of ice used to chill the water. They evolved into cumbersome floor-standing units with belt-driven ammonia compressors used to chill the water.

Figure 12-1 Early Drinking Faucet
Source: Haws Corp.

Today, a plethora of types and aesthetically pleasing models satisfies even the most demanding applications. The industry is focused on providing the highest quality of water while using the least amount of floor space, allowing water coolers to be installed in heavy-traffic areas while satisfying code and end-user requirements.

WATER IN THE HUMAN BODY

The importance of nutrients is judged by how long the human body can function without them. Water is essential because humans can subsist for only about a week without it. Water constitutes approximately 75 percent of the human body, and on average it takes eight cups of water to replenish the water a body loses each day.

Water has two primary tasks in the metabolic process: It carries nutrients and oxygen to different parts of the body through the bloodstream and lymphatic system, and it allows the body to remove toxins and waste through urine and sweat. Furthermore, it regulates body temperature, cushions joints and soft tissues, and lubricates articulations, hence balancing the functions of the body.

UNITARY COOLERS

A mechanically refrigerated drinking-water cooler consists of a factory-made assembly in one structure. This cooler uses a complete, mechanical refrigeration system and has the primary functions of cooling potable water and providing such water for dispensing by integral and/or remote means.

Water coolers differ from water chillers. Water coolers are used to dispense potable water, whereas water chillers are used in air-conditioning systems for residential, commercial, and industrial applications and in cooling water for industrial processes.

The capacity of a water cooler is the quantity of water cooled in one hour from a specified inlet temperature to a specified dispensing temperature, expressed in gallons per hour (gph) (liters per hour [L/h]). (See the section on ratings, which follows, and Table 12-1.) Standard capacities of water coolers range from 1 gph to 30 gph (3.8 L/h to 114 L/h).

Types

The three basic types of water coolers are as follows:

1. A bottled water cooler (see Figure 12-2) uses a bottle, or reservoir, for storing the supply of water to be cooled and a faucet or similar means for filling glasses, cups, or other containers. It also includes a wastewater receptacle. The

designer should check local codes, because even though bottle water coolers are permitted, they may not satisfy minimal plumbing fixture requirements.

2. A pressure-type water cooler (see Figures 12-3 and 12-4) is supplied with potable water under pressure and includes a wastewater receptacle or means of disposing water to a plumbing drainage system. Such coolers can use a faucet or similar means for filling glasses or cups, as well as a valve to control the flow of water as a projected stream from a bubbler so that water may be consumed without the use of glasses or cups.

Table 12-1 Standard Rating Conditions

Type of Cooler	Temperature, °F (°C)				
	Ambient	Inlet Water	Cooled Water	Heated Potable Water[a]	Spill(%)
Bottle type	90 (32.2)	90 (32.2)	50 (10)	165 (73.9)	None
Pressure type					
Utilizing precooler (bubbler service)	90 (32.2)	80 (26.7)	50 (10)	165 (73.9)	60
Not utilizing precooler	90 (32.2)	80 (26.7)	50 (10)	165 (73.9)	None
Compartment type cooler	During the standard capacity test, there shall be no melting of ice in the refrigerated compartment, nor shall the average temperature exceed 46°F (7.8°C).				

Source: ARI Standard 1010, reprinted by permission.

Note: For water-cooled condenser water coolers the established flow of water through the condenser shall not exceed 2.5 times the base rate capacity, and the outlet condenser water temperature shall not exceed 130°F (54.4°C). The base rate capacity of a pressure water cooler having a precooler is the quantity of water cooled in 1 h, expressed in gallons per hour, at the standard rating conditions, with 100% diversion of spill from the precooler.

[a] This temperature shall be referred to as the "standard rating temperature" (heating).

3. A remote-type cooler is a factory-assembled single structure that uses a complete, mechanical refrigeration system and has the primary function of cooling potable water for delivery to a separately installed dispenser.

Figure 12-2 Bottled Water Cooler

Figure 12-3 Wheelchair-accessible Pressure-type Water Cooler

Source: Halsey Taylor

Figure 12-4 Pressure-type Pedestal Water Cooler

Source: Halsey Taylor

Figure 12-5 Wheelchair-accessible Unit
Source: Halsey Taylor

Figure 12-6 Dual-height Design
Source: Halsey Taylor

In addition to these basic descriptions, coolers are described by specialized conditions of use, additional functions they perform, or the type of installation.

Special-purpose Water Coolers

Explosion-proof water coolers are constructed for safe operation in hazardous locations (volatile atmospheres), as classified in Article 500 of the National Electrical Code.

Vandal-resistant water cooler are made for heavy-use applications such as in schools or prisons.

Extreme climate water coolers include frost resistance for occasional cold temperatures and freeze protection for those used during sustained cold temperatures.

A cafeteria-type cooler is one that is supplied with water under pressure from a piped system and is intended primarily for use in cafeterias and restaurants for dispensing water rapidly and conveniently into glasses or pitchers. It includes a means for disposing wastewater to a plumbing drainage system.

Figure 12-7 Dual-height Design with Chilling Unit Mounted Above Dispenser
Source: Haws Corp.

A drainless water cooler is a pressure-type cooler supplied by ¼-inch tubing from an available source and does not have a waste connection. As with the bottled water cooler, a drip cup sits on a pressure switch to activate a solenoid valve on the inlet supply to shut off the supply by the weight of the water in the cup.

Water coolers for wheelchair use are available in several styles. The original design mounted the chilling unit behind the backsplash, with a surface-mounted bubbler projecting 14 inches from the wall, enabling a person in a wheelchair to roll under the fixture. Today's wheelchair-accessible units contain a chilling unit below the level of the basin (see Figures 12-3, 12-5, and 12-9), with the bubbler projecting from the wall at such a height that a person in a wheelchair can roll under it. Dual-height designs (see Figure 12-6 and Figure 12-7), also known as barrier-free, are the most popular designs today. These units recognize the needs of able-bodied individuals, those with bending difficulties, and those in wheelchairs at a consolidated location. Fully recessed accessible designs, or barrier-free inverted, mount the chilling unit above the dispenser (see Figure 12-7) to allow a recess under the fountain for wheelchair access. When using this style, the designer should ensure that the grill

Figure 12-8 Floor-mount Water Cooler
Source: Halsey Taylor

Figure 12-9 Wall-hung water cooler
Source: Haws Corp.

Figure 12-10 Fully Recessed Water Cooler
Source: Halsey Taylor

vanes go upward and that the recess is of sufficient depth and width for a person in a wheelchair. (For additional information on ADA-compliant fixtures, refer to *Plumbing Engineering Design Handbook, Volume 1,* Chapter 6, "Plumbing for People With Disabilities" and American National Standards Institute (ANSI) A117.1: *Accessible and Useable Buildings and Facilities.* Child requirements are based on the final ruling of the U.S. Access Board.)

Types of installations include the following:

- Freestanding or floor mount (see Figures 12-4 and 12-8)
- Wall hung (see Figure 12-9)
- Fully recessed (see Figure 12-10), allowing an unobstructed path
- Fully recessed with accessories (see Figure 12-11)
- Fully recessed (inverted) barrier-free (see Figure 12-12), for wheelchair access
- Semi-recessed or simulated recessed (see Figure 12-13)

Options and Accessories

The designer should consider all accessories and options to satisfy project requirements. Water coolers are available with several different options:

- Activation devices, such as hands-free, sensor-operated, foot pedals, or push bottoms and push bars
- Glass or pitcher fillers, such as push lever or push down
- Ice and/or cup dispensers, cane apron, hot water dispensers, water filters, and refrigerated compartments
- Bubblers, including standard, vandal resistant, and the flexible bubbler, which is constructed of pliable polyester elastomer that flexes on impact before returning to its original position to help protect against accidental injuries. Flexible bubblers usually contain an antimicrobial agent blended into the plastic to prevent bacteria from multiplying on the surface of the bubbler.

Water Cooler Features

Water coolers may have any of the following accessories (see Figure 12-14):

Figure 12-11 Fully Recessed Water Cooler with Accessories

Source: Halsey Taylor

Figure 12-12 Fully Recessed, Barrier-free Water Cooler for Wheelchair Access

Source: Oasis

Figure 12-13 Semi-recessed or Simulated Recessed Water Cooler

Source: Halsey Taylor

1. Antimicrobial safety
2. Stainless steel basin
3. Activation, such as push button, push bar, or infrared
4. Stream height regulator, which automatically maintains a constant stream height
5. Water system, manufactured of copper components or other lead-free materials
6. Compressor and motor
7. Non-pressurized cooling tank
8. Fan motor and blade
9. Condenser coil, fin or tube type
10. Drier, which prevents internal moisture from contaminating the refrigeration system
11. Drain outlet with $1\frac{1}{4}$-inch slip-joint fitting
12. Preset cooler control
13. Water inlet connection (not shown), which accepts $\frac{3}{8}$-inch outside diameter tubing for hookup to incoming water line
14. Inline strainer (not shown)
15. Water filtration

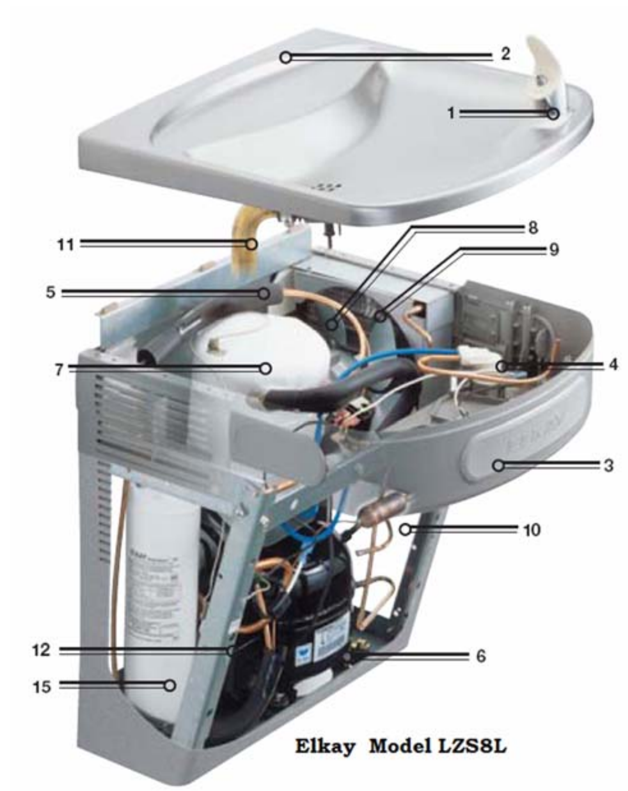


Figure 12-14 Water Cooler Accessories

REFRIGERATION SYSTEMS

As stipulated in the Montreal Protocol of 1987 and substantially amended in 1990 and 1992. HFC-134a refrigerant replaced the use of chlorofluorocarbons (CFC), which have been implicated in the accelerated depletion of the ozone layer. HFC-134a is a commercially available, environmentally acceptable hydrofluorocarbon (HFC) commonly used as a refrigerant on HVAC systems.

Hermetically sealed motor compressors commonly are used for alternating-current (AC) applications, both 50 hertz (HZ) and 60 Hz. Belt-driven compressors generally are used only for direct-current (DC) and 25-Hz supply. The compressors are similar to those used in household refrigerators and range from 0.08 horsepower (hp) to 0.5 hp (0.06 kilowatt [kW] to 0.37 kW).

Forced-air-cooled condensers are most commonly used. In coolers rated less than 10 gallons per hour (gph) (38 liters per hour [L/h]), natural convection, air-cooled (static) condensers sometimes are included. Water-cooled condensers of tube-on-tube construction are used on models intended for high ambient temperatures or where lint and dust in the air make air-cooled types impractical.

Capillary tubes are used almost exclusively for refrigerant flow control in hermetically sealed systems.

Pressure-type coolers often are equipped with precoolers to transfer heat from the supply water to the wastewater. When drinking from a bubbler stream, the user wastes about 60 percent of the cold water down the drain. In a precooler, the incoming water is put in a heat exchange relationship with the wastewater. Sometimes the cold wastewater also is used to subcool the liquid refrigerant. A precooler with this arrangement is called an "economizer." Coolers intended only to dispense water into cups are not equipped with precoolers since there is no appreciable quantity of wastewater.

Most water coolers manufactured today consist of an evaporator formed by refrigerant tubing bonded to the outside of a water circuit. The water circuit is usually a tank or a coil of large tubing. Materials used in the water circuit are usually nonferrous or stainless steel. Since the coolers dispense water for human consumption, sanitary requirements are essential. (See Underwriters Laboratories [UL] 399: *Drinking Water Coolers.)*

Water coolers that also provide a refrigerated storage space, commonly referred to as "compartment cooler," have the same control compromises common to all refrigeration devices that attempt two-temperature refrigeration using a single compressor.

Most bottle-type compartment coolers are provided with the simplest series system, one in which the refrigerant feeds first to a water-cooling coil and then through a restrictor device to the compartment. When the compressor operates, both water cooling and compartment cooling take place. The thermostat usually is located to be more affected by the compartment temperature, so the amount of compressor operation and water cooling available depends considerably on the usage of the compartment.

Some compartment coolers, generally pressure types, are equipped with more elaborate systems, ones in which separate thermostats and solenoid valves are used to switch the refrigerant flow from a common high side to either the water-cooling evaporator or the compartment evaporator. A more recently developed method of obtaining the two-temperature function uses two separate and distinct systems, each having its own compressor, high side, refrigerant flow-metering device, and controls.

STREAM REGULATORS

Since the principal function of a pressure-type water cooler is to provide a drinkable stream of cold water from a bubbler, it usually is provided with a valve to maintain a constant stream height, independent of supply pressure. A flow rate of 0.5 gallon per minute (gpm) (0.03 liter per second [L/s]) from the bubbler generally is accepted as providing an optimum stream for drinking.

WATER CONDITIONING

Most water coolers are classified by UL in accordance with National Sanitation Foundation (NSF)/ANSI 61: *Drinking Water System Components—Health Effects* and with the Safe Drinking Water Act, which protects public health by regulating the nation's public drinking water and its sources. Also, this legislation makes professional engineers, contractors, architects, building owners, and maintenance staff responsible for the quality of water dispensed from the equipment and fixtures they provide.

The effects of lead are devastating to the human body, as it accumulates on vital organs and alters the neurological system. Children are particular sensitive to lead because of their development stage—their bodies are still developing their vital organs. Even in low concentrations, lead can hinder growth and create learning disabilities. High lead levels can promote seizures, unconsciousness, and in extreme cases, death from encephalopathy.

In cases where the quality of a building's water supply is a concern, manufacturer units can be equipped with lead-reduction systems designed to remove cysts, lead particles, and chlorine. Methods to avoid and remove lead before it enters the water for the cooler include:

- Bottled water, which should be purchased from a reliable source
- Lead-absorbent filters, for installation on the incoming water to the cooler
- Reverse osmosis (RO) systems, which can be built into the water cooler

RATINGS

Water coolers are rated on the basis of their continuous flow capacity under specified water temperature and ambient conditions. Air-conditioning and Refrigeration Institute (ARI) 1010: *Self-contained, Mechanically Refrigerated Drinking Water Coolers* provides the generally accepted rating conditions and references test methods as prescribed in American Society of Heating, Refrigerating, and Air-conditioning Engineers (ASHRAE) 18: *Methods of Testing for Rating Drinking Water Coolers with Self-contained Mechanical Refrigeration*.

CENTRAL SYSTEMS

A central, chilled drinking water system typically is designed to provide water at 50°F (10°C) to the drinking fountains. Water is cooled to 45°F (7.2°C) at the central plant, thus allowing for a 5°F (2.8°C) increase in the distribution system. System working pressures generally are limited to 125 pounds per square inch gauge (psig) (861 kilopascals [kPa]). (The designer should check the local code for the maximum pressure allowed.) A central, chilled drinking water system should be considered in any building, such as a multistory office building, where eight or more drinking fountains are stacked one above the other.

A central, chilled drinking water system consists of the chilling unit, distribution piping, drinking fountains, and controls.

Chillers

The chiller may be a built-up or factory-assembled unit, but most installations use factory-assembled units. In either case, the chiller consists of the following:

- A semi-hermetic, direct-driven compressor using HFC-134a
- A condenser of the shell-and-tube or shell-and-coil type. It may be water or air cooled.
- A direct-expansion water cooler of the shell-and-tube type, with a separate field-connected storage tank or an immersion-type coil installed in the storage tank. If a separate tank is used, a circulating pump normally is needed to circulate the water between the evaporator and the tank. Evaporator temperatures of 30°F to 34°F (-1.1°C to 1.1°C) are used.
- An adequately sized storage tank to accommodate the fluctuating demands of a multiple-outlet system. Without a tank or with a tank that is too small, the fluctuations will cause overloading or short-cycling, causing excessive wear on the equipment. The tank must be of nonferrous construction. The evaporator mounted in the tank should be of the same construction as the tank to reduce galvanic action.
- Circulating pumps, normally of the bronze-fitted, close-coupled, single-stage type with mechanical seals. For systems designed for 24-hour operation, duplex pumps are installed, with each pump being used 12 hours per day.
- Controls consisting of high- and low-pressure cutouts, freeze protection, and thermostatic control to limit the temperature of the water leaving the chiller. A flow switch or differential pressure control also should be provided to stop the compressor when there is no flow through

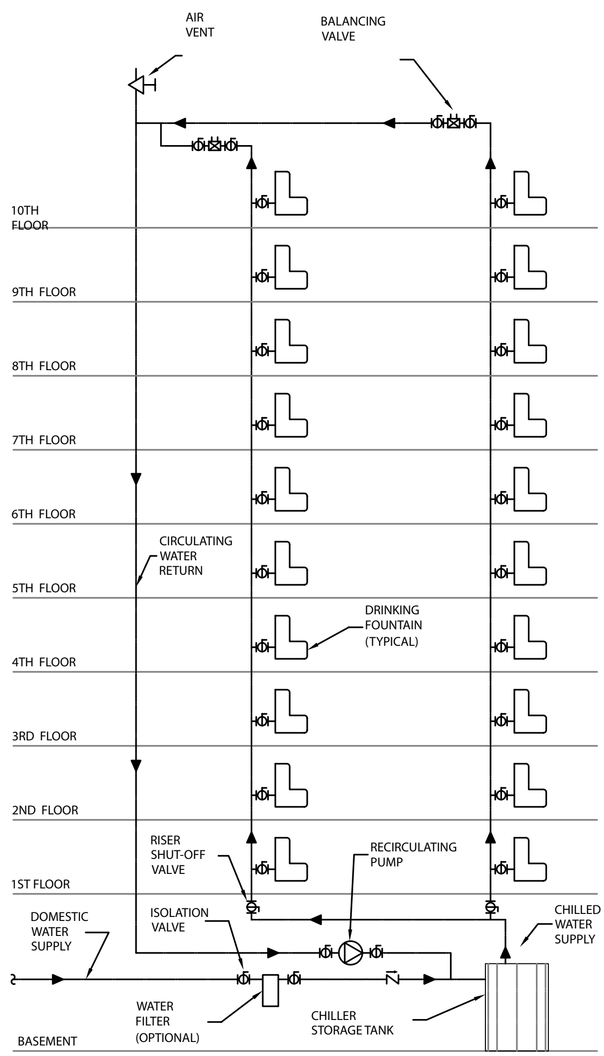


Figure 12-15 Upfeed Central System

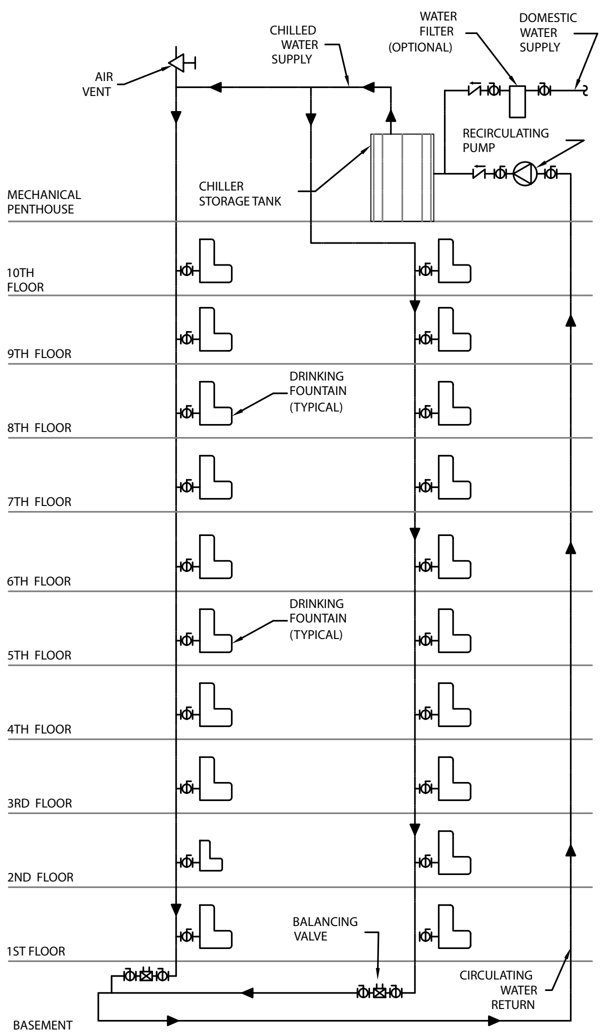


Figure 12-16 Downfeed Central System

Figure 12-17 Drinking Fountain
Source: Halsey Taylor

Figure 12-18 Drinking Fountain
Source: Haws Corp.

the cooler. Another desirable item is a time switch that can be used to operate the plant during periods of building occupancy.

Distribution Piping System

The distribution piping delivers chilled water to the drinking fountains. Systems can be upfeed as shown in Figure 12-15 or downfeed as shown in Figure 12-16. The piping can be galvanized steel, copper, or brass designed for a working pressure of 125 psig (861 kPa).

Drinking Water Coolers and Central Systems

The makeup cold water lines are made of the same material as the distribution piping. When the water supply has objectionable characteristics, such as high iron or calcium content, or contains odoriferous gases in solution, a filter should be installed in the makeup water line.

Insulation is necessary on all the distribution piping and the storage tanks. The insulation should be glass fiber insulation—such as that normally used on chilled-water piping, with a conductivity (*k*) of 0.22 (32) at a 50°F (10°C) mean temperature and a vapor barrier jacket—or equal. All valves and piping, including the branch to the fixture, should be insulated. The waste piping from the drinking fountain, including the trap, should be insulated. This insulation is the same as is recommended for use on cold water lines.

Drinking Fountains

Any standard drinking fountain can be used on a central drinking water system. Drinking fountains typically are made of vitreous china or stainless steel. However, the automatic volume or stream regulator provided with the fountain must be capable of providing a constant stream height from the bubbler with inlet pressures up to 125 psig (861 kPa). (See Figures 12-17 and 12-18.)

SYSTEM DESIGN

Refrigeration

For an office building, a usage load of 5 gph (19 L/h) per fountain for an average corridor and office is normal. The water consumption for other occupancies is given in Table 12-2. Table 12-3 is used to convert the usage load in gph (L/h) to the refrigeration load in British thermal units per hour (Btuh) (watts [W]). The heat gain from the distribution piping system is based on a circulating water temperature of 45°F (7.2°C). Table 12-4 lists the heat gains for various ambient temperatures. The length of all lines must be included when calculating the heat gain in the distribution piping. Table 12-5 tabulates the heat input from variously sized circulating pump motors.

The total cooling load consists of the heat removed from the makeup water, heat gains from the piping, heat gains from the storage tank, and heat input from the pumps. A safety factor of 10 percent to 20 percent is added before selecting a condensing unit. The size of the safety factor is governed by usage. For example, in a building with weekend shutdowns, the higher safety factor allows pickup when reopening the building on Monday morning when the total volume of water in the system would need to be cooled to the operating temperature. Since the water to the chiller is a mixture of makeup and return water, the chiller selection should be based on the resultant mixed water temperature.

Circulating Pump

The circulating pump is sized to circulate a minimum of 3 gpm (0.2 L/s) per branch or the gpm (L/s) necessary to limit the temperature rise of the circulatory water to 5°F (2.8°C), whichever is greater. Table 12-6 lists the circulating pump capacity needed to limit the temperature rise of the circulated water to 5°F (2.8°C). If a separate pump is used to circulate water between the evaporator and the storage tank, the energy input to this pump must be included in the heat gain.

Storage Tank

The storage tank's capacity should be at least 50 percent of the hourly usage. The hourly usage may be selected from Table 12-2.

Table 12-2 Drinking-water Requirements

Location	Bubbler Service: Persons Served Per Gallon (Liter) of Standard Rating Capacity	Cup Service: Persons Served Per Gallon (Liter) of Base Rate Capacity
Offices	12 (3)	30 (8)
Hospitals	12 (3)	—
Schools	12 (3)	—
Light manufacturing	7 (2)	—
Heavy manufacturing	5 (2)	—
Hot heavy manufacturing	4 (1)	—
Restaurants		10 (3)
Cafeterias		12 (3)
Hotels (corridors)		—

		Required Rated Capacity per Bubbler, gph (L/h)	
		One Bubbler	Two or More Bubblers
Retail stores, hotel lobbies, office building lobbies	12 (3)	5 (20)	5 (20)
Public assembly halls, amusement parks, fairs, etc.	100 (26)	20–25 (80–100)	15 (60)
Theaters	19 (5)	10 (40)	7.5 (30)

Source: Reprinted from ARI Standard 1010, by permission.
Note: Based on standard rating conditions, with delivered water at 50°F (10°C).

Table 12-3 Refrigeration Load

	Btu/Gal (W/L) Cooled to 45°F (7.2°C)					
Water inlet temp., °F (° C)	65(18.3)	70(21.1)	75(23.9)	80(26.7)	85(29.4)	90(32.2)
Btu/gal	167(13)	208(17)	250(20)	291(23)	333(27)	374(30)

Multiply load for 1 gal (L) by total gph (L/h).

Table 12-4 Circulating System Line Loss

Pipe Size, in. (mm)	Btu/h per Ft Per °F (W/°C/m)	Btu/h per 100 Ft (W per 100 m) [45°F (7.2°C) Circulating Water] Room Temperature, °F (°C)		
		70 (21.1)	80 (26.7)	90 (32.2)
½ (13)	0.110(0.190)	280(269)	390(374)	500(480)
¾ (19)	0.119(0.206)	300(288)	420(403)	540(518)
1 (25)	0.139(0.240)	350(336)	490(470)	630(605)
1¼ (32)	0.155(0.268)	390(374)	550(528)	700(672)
1½ (38)	0.174(0.301)	440(422)	610(586)	790(758)
2 (51)	0.200(0.346)	500(480)	700(672)	900(864)
2½ (64)	0.228(0.394)	570(547)	800(768)	1030(989)
3 (76)	0.269(0.465)	680(653)	940(902)	1210(1162)

Table 12-5 Circulating Pump Heat Input

Motor, Hp (kW)	¼(0.19)	⅓(0.25)	½(0.37)	¾(0.56)	1(0.75)
Btu/h (W)	636(186)	850(249)	1272(373)	1908(559)	2545(746)

Table 12-6 Circulating Pump Capacity

Pipe Size, in. (mm)	Room Temperature, °F (°C)		
	70 (21.1)	80 (26.7)	90 (32.2)
½ (13)	8.0(99)	11.1(138)	14.3(177)
¾ (19)	8.4(104)	11.8(146)	15.2(188)
1 (25)	9.1(113)	12.8(159)	16.5(205)
1¼ (32)	10.4(129)	14.6(181)	18.7(232)
1½ (38)	11.2(139)	15.7(195)	20.2(250)

Notes
1. Capacities are in gph per 100 ft (L/h per 100 m) of pipe including all branch lines necessary to circulate to limit temperature rise to 5°F (2.8°C) [water at 45°F (7.2°C)].
2. Add 20% for a safety factor. For pump head, figure longest branch only. Install pump on the return line to discharge into the cooling unit. Makeup connection should be between the pump and the cooling unit.

Distribution Piping

Sizing

General criteria for sizing distribution piping for a central, chilled drinking water system are as follows:

1. Limit the maximum velocity of the water in the circulating piping to 3 feet per second (fps) (0.9 meters per second [m/s]) to prevent the water from having a milky appearance.
2. Avoid excessive friction head losses. The energy necessary to circulate the water enters the water as heat and requires additional capacity in the water chiller. Accepted practice limits the maximum friction loss to 10 feet (3 meters) of head per 100 feet (30 m) of pipe.
3. Dead-end piping, such as that from the main riser to the fountain, should be kept as short as possible, and in no event should it exceed 25 feet (7.6 m) in length. The maximum diameter of such dead-end piping should not exceed ⅜-inch (9.5-mm) iron pipe size (IPS), except on very short runs.
4. Size piping on the total number of gallons circulated. This includes gallons consumed plus gallons necessary for heat leakage.

Design Layout

General criteria for the design layout of piping for a central chilled drinking water system are as follows:

1. Keep pipe runs as straight as possible with a minimum number of offsets.
2. Use long sweep fittings wherever possible to reduce friction loss.
3. In general, limit maximum pressure developed in any portion of the system to 80 psi (552 kPa). If the height of a building should cause pressures in excess of 80 psi (552 kPa), divide the building into two or more systems.
4. If more than one branch line is used, install balancing cocks on each branch.
5. Provide a pressure relief valve and air vents at high points in the chilled water loop.

The following example illustrates the calculations required to design a central chilled drinking water system.

Example 12-1

Design a central drinking water system for the building in Figure 12-15. The net floor area is 14,600 square feet (1,356 square meters) per floor, and occupancy is assumed to be 100 square feet (9.3 m^2) per person. Domestic water is available at the top of the building, with 15-psig (103-kPa) pressure. Applicable codes are the Uniform Plumbing Code and the Uniform Building Code.

Solution

1. Number of drinking fountains required: Occupancy = 14,600/100 = 146 people per floor (1,356/9.3 = 146 people per floor). The Uniform Building Code requires one fountain on each floor for every 75 people. So, 146/74 = 1.94 fountains per floor. Therefore, use two fountains per floor, or a total of 20 fountains.
2. Estimated fountain usage: From Table 12-2, (146 × 0.083)/2 = 6 gph (22.7 L/h) per fountain
3. Total anticipated makeup water: 6 gph × 10 fountains = 60 gph per riser, or 120 gph for two risers (see Figure 12-15) (22.7 L/h × 10 fountains = 227 L/h per riser, or 454 L/h for two risers)
4. Refrigeration load to cool makeup water: From Table 12-3, assuming 70°F (21.1°C) water inlet temperature, 120 gph × 208 Btuh per gallon = 25,000 Btuh (454 L/h × 16 W/L = 7,300 W)
5. Refrigeration load due to piping heat gain: Determination of heat gain in piping requires pipe sizes, but these sizes cannot be accurately known until the heat gains from the makeup water, piping, storage tank, and pumps are known. Therefore, assume 1-inch (25-mm) diameter chilled water risers, circulation line,

Table 12-7 Friction of Water in Pipes

gpm (L/h)	½-in. (13-mm) Pipe Velocity, ft/s (m/s)	½-in. (13-mm) Pipe Head, ft (m)	¾-in. (19-mm) Pipe Velocity, ft/s (m/s)	¾-in. (19-mm) Pipe Head, ft (m)	1-in. (25-mm) Pipe Velocity, ft/s (m/s)	1-in. (25-mm) Pipe Head, ft (m)	1¼-in. (32-mm) Pipe Velocity, ft/s (m/s)	1¼-in. (32-mm) Pipe Head, ft (m)	1½-in. (38-mm) Pipe Velocity, ft/s (m/s)	1½-in. (38-mm) Pipe Head, ft (m)
1 (227)	1.05 (0.32)	2.1 (0.64)	—	—	—	—	—	—	—	—
2 (454)	2.10 (0.64)	7.4 (2.26)	1.20 (0.37)	1.90 (0.58)	—	—	—	—	—	—
3 (681)	3.16 (0.96)	15.8 (4.82)	1.80 (0.55)	4.1 (1.25)	1.12 (0.34)	1.26 (0.38)	—	—	—	—
4 (912)	—	—	2.41 (0.73)	7.0 (2.13)	1.49 (0.65)	2.14 (0.65)	0.86 (0.26)	0.57 (0.17)	—	—
5 (1,135)	—	—	3.01 (0.92)	10.5 (3.20)	1.86 (0.57)	3.25 (0.99)	1.07 (0.33)	0.84 (0.26)	0.79 (0.24)	0.40 (0.12)
10 (2,270)	—	—	—	—	3.72 (1.13)	11.7 (3.57)	2.14 (0.65)	3.05 (0.93)	1.57 (0.48)	1.43 (0.44)
15 (3,405)	—	—	—	—	—	—	3.20 (0.98)	6.50 (1.98)	2.36 (0.72)	3.0 (0.91)
20 (4,540)	—	—	—	—	—	—	—	—	3.15 (0.96)	5.2 (1.58)

Note: Table gives loss of head in feet (meters) due to friction per 100 ft (30 m) of smooth straight pipe.

Table 12-8 Pressure Drop Calculations for Example 12-1

From[a]	Pipe Length, ft (m)		Water Flow, gpm (L/h)	Selected gpm Size, in.	Pressure Drop, ft (m)		Cumulative Pressure Drop, ft (m)
	Actual	Equivalent[b]			100 ft	Actual ft	
A to B	30(9)	45(14)	6(23)	1	5.0(1.5)	2.25 (0.7)	2.25(0.7)
B to D	180(55)	270(82)	3(11.5)	1	1.3(0.4)	3.5 (1.1)	5.75(1.8)
D to A	270(82)	406(124)	6(23)	1	5.0(I.5)	20.02 (6.1)	25.77(7.9)

[a] Refer to Figure 12-15.
[b] Increase 50% to allow for fittings. If an unusually large number of fittings is used, each should be considered for its actual contribution to pressure drop.

and distribution piping to the risers. Then, the heat gains in the piping system are (from Table 12-4):

Risers: (120 feet) (490 Btu/100 feet) (2 risers) =	1,189 Btuh (349 W)
Distribution mains: (90 feet) (490 Btu/100 feet) =	440 Btuh (129 W)
Return riser: (330 feet) (490 Btu/100 feet) =	1,620 Btuh (475 W)
Total piping heat gain =	3,249 Btuh (953 W)

The water that must be cooled and circulated is at a minimum of 3 gpm (11.4 L/h) per riser, or a total of 6 gpm (22.7 L/h).

6. Refrigeration load due to circulating pump input: The pump head can be determined from data given in Table 12-7 and Figure 12-15. The results of the calculations are given in Table 12-8, with the indicated pumping requirements being 6 gpm (22.7 L/h) at a 25.77-foot (7.85-m) head. Data from one manufacturer indicates that a ¾-hp (0.56-kW) motor is needed. From Table 12-5, the heat input of the pump motor is 1,908 Btuh (559 W).
7. Refrigeration load due to storage tank heat gain: The tank is normally sized for 50 percent of the total hourly demand. Thus, for 100 gph (379 L/h), a 50-gallon (190-L) tank would be used. This is approximately the capacity of a standard 16-inch (406-mm) diameter, 60-inch (1,524-mm) long tank. Assume 1½-inch (38-mm) insulation, 45°F (7.2°C) water, with the tank in a 90°F (32.2°C) room. Assume an insulation conductivity of 0.13 Btuh per square foot (0.4 W/m^2). The surface area of the tank is about 24 square feet (2.2 m^2). Thus, the heat gain is (24)(0.13)(90 – 45) = 140 Btuh (41 W).

   Thus, the load summary is as follows:

Item	Heat Gain, Btuh (W)
Makeup water	25,000 (7,325)
Piping	3,240 (949)
Pump heat input	1,908 (559)
Storage tank	140 (41)
Subtotal	30, 288 (8,874)
20 percent safety factor	6,050 (1,773)
Required chiller capacity	36,338 (10,647)

Installation

A supply stop should be used so that the unit may be serviced or replaced without having to shut down the water system. Also, the designer should consult local, state, and federal codes for proper mounting height.

STANDARDS, CODES, AND REGULATIONS

Whether a self-contained (unitary) cooler or a central chilled water system, most mechanical installations are subject to regulation by local codes. They must comply with one or more plumbing, refrigeration, electrical, and accessibility codes. The majority of such local codes is based on guide codes prepared by associations of nationally recognized experts.

Municipalities choose one of these model codes and modify it to suit local conditions. For this reason, it is important to refer to the code used in the locality and the authority having jurisdiction.

Local refrigeration codes vary considerably. The Uniform Building Code sets up guide regulations pertaining to the installation of refrigeration equipment. It is similar in most requirements to ANSI/ASHRAE 15: *Safety Standard for Refrigeration Systems,* with some notable exceptions. Therefore, it is important to carefully apply the local codes in the design of the refrigeration portion of chilled drinking water systems. Other local codes that merit a careful review are the electrical regulations as they apply to controls, disconnection switches, power wiring, and American Society of Mechanical Engineer (ASME) requirements for tanks and piping.

In addition to ARI 1010 and ASHRAE 18: *Methods of Testing for Rating Drinking Water Coolers with Self-contained Mechanical Refrigeration*, UL 399 covers safety and sanitation requirements. Federal Specification WW-P-541: *Plumbing Fixtures*, among others, usually is prescribed by government purchasers.

ANSI/NSF 61 is intended to cover specific materials or products that come into contact with drinking water, drinking water treatment chemicals, or both. The focus of the standard is the evaluation of contaminants or impurities imparted indirectly to drinking water.

Many local plumbing codes apply directly to water coolers. Primarily, these codes are directed toward eliminating any possibility of cross-connection between the potable water system and the wastewater (or refrigerant) system. Therefore, most coolers are made with double-wall construction to eliminate the possibility of conflict with any code.

13 Bioremediation Pretreatment Systems

Pretreatment of effluent prior to discharge is a requirement established by federal legislation and implemented by federal regulations and state and local legislation. Pretreatment requirements apply to both direct discharges (i.e., to drain fields, streams, lakes, and oceans) and indirect discharges, as in collection systems leading to treatment works. Pretreatment is required of all industrial discharges, which are all discharges other than those from a domestic residence.

Pretreatment can involve the removal of metals, adjustment of pH, and removal of organic compounds. CFR Title 40: Protection of Environment, published by the U.S. Environmental Protection Agency (EPA), defines pretreatment as "the reduction of the amount of pollutants, or the alteration of the nature of pollutant properties in wastewater prior to or in lieu of discharging or otherwise introducing such pollutants into a POTW (publicly owned treatment works). … The reduction or alteration may be obtained by physical, chemical, or biological processes, process changes, or by other means, except as prohibited."

Bioremediation is one method of simultaneously removing the pollutant from the waste stream and disposing of the pollutant by altering its chemical or physical structure such that it no longer causes depreciation of water quality, in the case of direct discharges, or interference or pass-through, in the case of indirect discharges. Generally speaking, bioremediation can be described as the action of living organisms on organic or inorganic compounds resulting in reduction in complexity or destruction of the compound. Typically, bioremediation processes are conducted at the source of the pollutant to avoid transporting large quantities of polluted wastewater or concentrations of pollutants. The most common application of bioremediation to plumbing systems is for the disposal of fats, oils, and grease (FOG).

PRINCIPLE OF OPERATION

Bioremediation systems, as described here, do not include the practice of adding enzymes, bacteria, nutrients, or combinations thereof (additives) to grease waste drainage, grease traps, or grease interceptors. The use of additives in conventional apparatus is a cleaning method resulting in the removal of FOG from the apparatus and its deposition downstream. Recombined FOG is usually a denser form, which is more difficult to remove from sewer mains and lift stations than the substance not altered by the application of additives.

Bioremediation systems are engineered systems containing the essential elements of a bioreactor that can be operated by the kinetic energy imparted from flowing water or mechanically agitated by various pumping and aeration methods. Bioremediation systems can be aerobic (requiring oxygen for the metabolic activity of the organisms), anaerobic (not requiring oxygen), or a combination of both. The type of bioremediation system employed is determined mainly by the target compound and the organisms necessary to metabolize that compound. In the case of FOG, typically the application of bioremediation is aerobic. Figure 13-1 shows a kinetically operated aerobic bioremediation system.

Central to the operation of all on-site bioremediation systems applied to FOG are the following:

- Separation, or the removal of FOG from the dynamic waste flow
- Retention, allowing the cleaned wastewater to escape except for the static water content of the device
- Disposal, or the metabolic disassembly of FOG to its elements of hydrogen, oxygen, and carbon, usually in the form of water and carbon dioxide

Incidental to the application of a bioremediation system to FOG are the following:

- Sizing, or the calculation of the potential maximum flow over a designated interval
- Food solids removal from the liquid waste stream

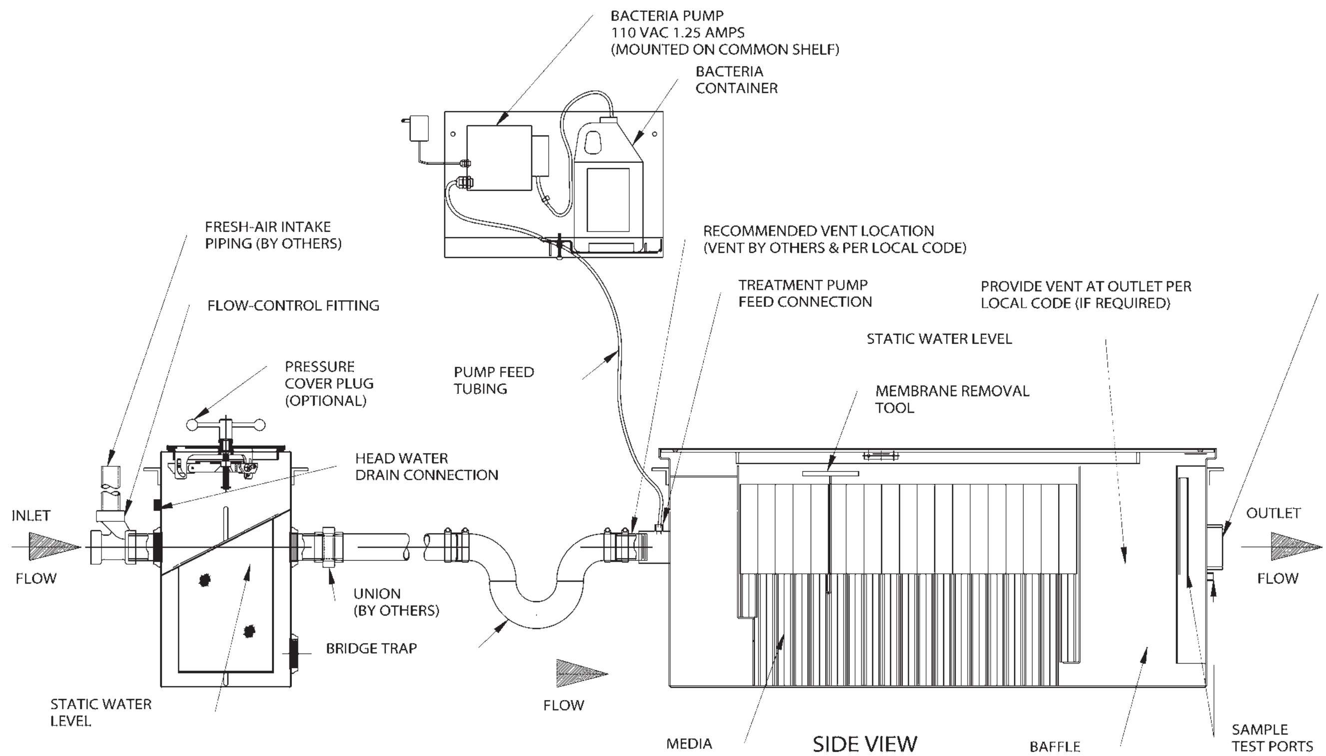


Figure 13-1 Kinetically Operated Aerobic Bioremediation System

- Placement, to minimize the length of untreated grease waste piping

Separation

Separation of FOG with the greatest efficiency, measured as the percentage of FOG present in the waste stream and the time necessary to effect separation, is essential to the accomplishment of retention and disposal. The standards for this measurement are Plumbing and Drainage Institute (PDI) G101: *Testing and Rating Procedure for Grease Interceptors* and American Society of Mechanical Engineers (ASME) A112.14.6: *FOG (Fats, Oils, and Greases) Disposal Systems*. Separation can be effected by simple gravity flotation, in which case the device must be of sufficient volume to provide the proper retention time and quiescence to allow ascension of suspended FOG (see Chapter 8: "Grease Interceptors"). Separation also can be effected by coalescence, coagulation, centrifugation, dissolved air flotation, and skimming. In these instances, for a given flow, the device is typically smaller in dimension than in the gravity flotation design.

Because food particles generally have a specific gravity greater than one and are oleophilic, the presence of food particles materially interferes with the efficient separation of FOG from the waste stream. Food grinders typically are not used upstream of bioremediation systems for this reason and because of the increased biological oxygen demand (BOD) that the additional waste places on the system.

Retention

The retention of FOG in a bioremediation system is essential to its disposal by a reduction in its constituent elements. Retention is facilitated by baffles, compartmentalization, or sedimentation, depending on the system design. Because only 15 percent of suspended FOG (at a specific gravity of 0.85) is above the water surface, bioremediation systems that retain FOG a greater distance from dynamic flows generally have greater retention efficiencies and capacities than those that rely on suspension alone.

Disposal

The disposal of FOG by biochemical processes within an on-site system is the single most distinguishing feature of bioremediation systems. The organisms responsible for metabolizing the FOG may be endemic to the waste stream or, more likely, seeded by means of a timed or flow-sensitive metering device. Crucial to a disposal function equal to ongoing separation and retention rates is a sufficient population of organisms in contact with the FOG. While this is a function of sizing (see "Sizing Guidelines" later in this chapter), it is also a function of system design.

The mechanism typically utilized to provide a stable, structured population of organisms in a bioremediation system is a biofilm. Biofilms are controlled biological ecosystems that protect multiple species of organisms from washouts, biocides, and changing environmental conditions in the bioremediation system. Biofilm forms when bacteria adhere to surfaces in aqueous environments and begin to excrete a slimy, glue-like substance that can anchor them to many materials, such as metals, plastics, soil particles, medical implants, and tissue, according to the Center for Biofilm Engineering.

Biofilms are cultivated on structures of various configurations of the greatest possible surface area per given volume. The structure or structures generally are referred to as "media." The media may be fixed (i.e., stationary relative to the device and the waste flow); moved by mechanical movement, such as a series of rotating discs or small, ball-shaped elements; or moved randomly by the energy of the waste stream flow and/or pump or aerator agitation.

The organisms inhabiting biofilms reduce the FOG to carbon dioxide and water through a process called "beta oxidation," which is a catabolic process consisting of the shortening of fatty acid chains by the successive removal of two carbon fragments from the carboxyl end of the chain, according to the *Dictionary of Bioscience*. Bioremediation systems utilizing structured biofilms are much more resistant to the effects of biocides, detergents, and other chemicals frequently found in kitchen effluent than systems using planktonic application of organisms. The efficiency of bioremediation systems in terms of disposal depends on the total surface area of the media relative to the quantity of FOG separated and retained, the viability and species diversity of the biofilm, system sizing, and installation.

FLOW CONTROL

Flow control sometimes are used with bioremediation systems depending on system design. When flow control devices are prescribed by the manufacturer, generally they are best located near the discharge of the fixtures they serve. However, because bioremediation systems are engineered systems, the use and placement of system elements are prescribed by the manufacturer. In instances in which elements of a bioremediation system may be common to the plumbing industry, the manufacturer's prescription for the application of those elements to the system shall prevail over common practice or code requirements.

SIZING GUIDELINES

These guidelines are intended as a tool for the engineer to quantify the maximum hydraulic potential from a given facility. Typically, fixture unit equivalency prediction sizing methods and other estimation tools based on utilization rate weighted factors are not acceptable sizing tools for bioremediation systems. Bioremediation systems must be capable of accommodating maximum hydraulic events without experiencing upset, blockage, or pass-through.

The general sizing procedure contains the following steps:

1. Fixture inventory: Itemize each and every fixture capable of liquid discharge to the grease waste piping system including, but not limited to, sinks, hoods, ware washers, floor sinks and drains, and kettles. Grinder pulpers are generally not to be discharged to bioremediation systems. Review the manufacturer's requirements for each particular system.
2. Capacity calculation: Calculate the capacity (in gallons) of liquid-retaining devices such as sinks as follows:

   Length × Width × Depth = Capacity, in cubic inches (cubic centimeters)

   Capacity × Number of compartments = Total capacity, in cubic inches (cm^3)

   Total cubic capacity ÷ 231 = Gallons (liters) capacity

   Gallons capacity × 0.75 (fill factor) = Rated discharge, in gallons per minute (gpm) (liters per second [L/s])

   (Note: If a 2-minute drain duration is used, divide the rated discharge by two.)
3. Rated discharges: Fixtures such as ware washers with a manufacturer's rated water consumption or single discharge rate are calculated at the greater rate.
4. Floor sinks and drains: Floor sinks and drains generally are rated at 4.0 gpm. Count the number of floor drains and sinks not receiving indirect discharges from the fixtures calculated above and multiply by 4.0 to determine gpm potential. Should this number exceed the total supply to the facility, select the smaller of the two numbers.
5. Loading influences: Some manufacturers may prescribe multipliers for various facility characteristics such as cuisine to accommodate anticipated increased organic content per gallon of calculated discharge. Refer to manufacturer's requirements for specific systems.

DESIGN CONSIDERATIONS

Each manufacturer of a bioremediation system has specific design elements to establish fitness for the purpose of its particular design. Certain fundamental materials and methods utilized in the design and manufacture of bioremediation systems are indicated by the following standard designations:

- ASME A112.14.6

- American Society for Testing and Materials (ASTM) C33: *Standard Specification for Concrete Aggregates*
- ASTM C94: *Standard Specification for Ready-mixed Concrete*
- ASTM C150: *Standard Specification for Portland Cement*
- ASTM C260: *Standard Specification for Air-entraining Admixtures for Concrete*
- ASTM C618: *Standard Specification for Coal Fly Ash and Raw or Calcined Natural Pozzolan for Use in Concrete*
- PDI G101
- American Concrete Institute (ACI) 318: *Building Code Requirements for Structural Concrete*
- International Association of Plumbing and Mechanical Officials (IAPMO) PS 1: *Tank Risers*
- Underwriters Laboratories (UL) 5085-3: *Low Voltage Transformers—Part 3: Class 2 and Class 3 Transformers*
- American Association of State Highway and Transportation Officials (AASHTO) H20-44
- U.S. Environmental Protection Agency (EPA) Test Method 1664: *Guidelines Establishing Test Procedures for the Analysis of Oil and Grease and Non-polar Material*

MATERIALS

Concrete

If concrete is used as a container for bioremediation systems, the concrete and reinforcement should be of sufficient strength to resist stresses caused during handling and installation without structural cracking and be of such corrosion-resistant quality to resist interior and exterior acids that may be present. Concrete should have a minimum compressive strength of 3,500 pounds per square inch (24,132 kilopascals [kPa]). Concrete should have a maximum water-cementing materials ration of 6 gallons per sack of cement. Concrete should be made with Type II or V, low-alkali Portland cement conforming to ASTM C150 and also should include sulfate expansion option as specified in Table 4 of ASTM C150 for Type II or V. Concrete should contain 4 percent to 7 percent entrained air utilizing admixtures conforming to ASTM C260. Concrete aggregates should conform to ASTM C33. If ready-mix concrete is used, it should conform to ASTM C94. Fly ash and raw or calcined natural pozzolan, if used as mineral admixture in Portland cement concrete, should conform to ASTM C618.

Stainless Steel

Stainless steel used in bioremediation systems should be of type 316 or of some other type with equal or greater corrosion resistance.

Fiberglass Reinforced Polyester

Bioremediation systems constructed principally of fiberglass reinforced polyester should comply with the minimum requirements expressed for septic tanks in Section 5 of IAPMO PS 1.

Polyethylene

Bioremediation systems constructed principally of polyethylene should comply with the minimum standards expressed for septic tanks in Section 5 of IAPMO PS 1.

STRUCTURAL CONSIDERATIONS

Bioremediation systems should be designed to handle all anticipated internal, external, and vertical loads.

Bioremediation systems containers, covers, and structural elements that are intended for burial and/or traffic loads should be designed for an earth load of not less than 500 pounds per square foot (24 kPa) when the maximum coverage does not exceed 3 feet (0.9 meters). Each system and cover should be structurally designed to withstand all anticipated earth or other loads and should be installed level and on a solid surface.

Bioremediation systems, containers, covers, and structural elements for installation in traffic areas should be designed to withstand an AASHTO H20-44 wheel load and an additional 3-foot (0.9-m) earth load with an assumed soil weight of 100 pounds per square foot (4.8 kPa) and 30-pound-per-square-foot (1.4-kPa) fluid equivalent sidewall pressure.

Internal construction of separations, coalescing surfaces, baffles, and structures that may compartmentalize fluids should be designed to withstand the maximum expected hydrostatic pressure. Maximum hydrostatic pressure should include the pressure exerted by one compartment at maximum capacity with adjacent compartments empty. The internal structures should be of suitable, sound, and durable materials consistent with industry standards.

In buried applications, bioremediation systems should have safe, reasonable access for prescribed maintenance and monitoring. Access could consist of horizontal manways or manholes. Each access opening should have a leak-resistant closure that cannot slide, rotate, or flip. Manholes should extend to grade, have a minimum size of 20-inch (0.5-m) diameter or 20 × 20-inch (0.5 × 0.5-m) square, and should comply with IAPMO PS 1 Section 4.7.1.

Bioremediation systems should be provided with drawings as well as application and disposal function details. Descriptive materials should be complete, showing dimensions, capacities, flow rates, structural and process ratings, and all application and operation facts.

DIMENSION AND PERFORMANCE CONSIDERATIONS

Bioremediation systems differ relative to type and operating method but should have a minimum volume-to-liquid ratio of 0.400 gallons per 1.00-gpm flow rating and a minimum retention ratio of 3.75 pounds of FOG per 1.00-gpm flow. The inside dimension between the cover and the dynamic water level at full-rated flow should be a minimum of 2 inches (51 mm). While the airspace should have a minimum volume equal to 10.5 percent of the liquid volume, air management and venting shall be prescribed by the manufacturer.

The bioremediation system's separation and retention efficiency rating should be in accordance with PDI G101. Bioremediation systems should show no leakage from seams, pinholes, or other imperfections.

Performance testing of bioremediation systems should demonstrate performance equal to or exceeding manufacturer claims and should have a minimum discharge FOG content not to exceed 100 milligrams per liter. Performance testing should be conducted only by accredited, third-party, independent laboratories in accordance with current scientific methods and EPA analysis procedures.

INSTALLATION AND WORKMANSHIP

Installation should be in accordance with the manufacturer's requirements. Bioremediation systems should be free of cracks, porosity, flashing, burrs, chips, and filings or any defects that may affect performance, appearance, or serviceability.

RESOURCES

Center for Biofilm Engineering, Montana State University.

Dictionary of Bioscience, 5th ed. New York: McGraw-Hill.

International Association of Plumbing and Mechanical Officials (IAPMO). 2000. *Uniform Plumbing Code*.

Plumbing and Drainage Institute. PDI G101: *Testing and Rating Procedure for Grease Interceptors With Appendix of Sizing and Installation Data.*

U.S. Environmental Protection Agency. *Code of Federal Regulations*, Title 40.

14 Green Plumbing

Plumbing engineers play some part in the grand scheme of things, but they are not the green police. Their primary responsibility is serving the client that hires them to design a specific set of plumbing systems. However, plumbing engineers can try to educate clients and help them appreciate the immediate and long-term benefits of sustainable design, and as a result, an increasing number of projects is going green. In fact, many code authorities already require some of the practices discussed in this chapter.

This chapter is designed to help plumbing engineers incorporate sustainable design practices in their designs, as well as to provide assistance in designing Leadership in Energy and Environmental Design (LEED)-certified projects. These are expansive subjects with a constant growth of emerging technologies. It is up to each individual to further investigate these concepts and technologies, as plumbing engineering continues its journey into this new era.

All benefit by increasing the efficiency of buildings. Also, it is essential to make efforts to preserve some of the natural resources that are being flushed away every day. Some of these design considerations are mandated by federal law. Some may be legislated in the future. Others provide immediate financial benefits, and many provide health benefits. Part of this learning process begins with some facts about the current state of affairs to further appreciate the need for these practices.

THE BIG PICTURE

Humanity is consuming the world's natural resources at an amazing rate.

Water Use Facts

According to the American Water Works Association (AWWA):

- Approximately 4,776 gallons of water are needed to raise a Christmas tree. For the 35 million Christmas trees that U.S. families enjoy each year, a total of 167 billion gallons of water is consumed.
- If all mothers refresh their floral arrangements and flowering plants after Mother's Day, they use a total of 2.8 million gallons of water. That's equivalent to the amount needed to supply a week's worth of water to 1,157 households.
- 1 inch of rainfall drops 7,000 gallons, or nearly 30 tons of water, on a 60 × 180-foot plot of land.
- On average, 50–70 percent of residential water is used outdoors for watering lawns and gardens.
- After a typical Thanksgiving dinner, 16.4 million Americans watch football. At halftime, American toilets flush 16.4 million times and use 48.5 million gallons of water. Using water-efficient toilets would save 22.3 million gallons of water, or the same amount of water needed to fill 1,476 swimming pools.
- The average five-minute shower uses 15–25 gallons of water.

Water and Sanitation

What about underdeveloped nations?

- An estimated 2.6 billion people lack adequate sanitation, and 1.1 billion people are without access to safe water, according to UNICEF.
- Globally, more than 125 million children under five years of age live in households without access to an improved drinking-water source, and more than 280 million children under five live in households without access to improved sanitation facilities, according to UNICEF.
- 90 percent of wastewater in developing countries is discharged into rivers and streams without any treatment, according to *World Resources 2000-2001: People and Ecosystems: The Fraying Web of Life.*
- Diarrhea can be reduced by 26 percent when basic water, hygiene, and sanitation are supplied, according to the World Health Organization (WHO).

Water and Disease

Major diseases transmitted by water include cholera, typhoid, bacillary dysentery, infectious hepatitis, and Giardia. Major diseases caused by lack of water include scabies, skin sepsis and ulcers, yaws, leprosy, trachoma, and dysentery. Some alarming facts about water and disease include the following:

- 4,000 children die each day as a result of water-related illnesses, according to WHO.
- In the past 10 years, diarrhea has killed more children than all the people lost to armed conflict since World War II, according to the Water Supply and Sanitation Collaborative Council (WSSCC).
- Water is implicated in 80 percent of all sickness and disease worldwide. 19 percent of deaths from infection and disease worldwide are water related, and waterborne diseases contribute to nearly 4 million child deaths, according to the Rehydration Project.
- At any one time, it is estimated that one-half of the world's hospital beds are occupied with patients suffering from water-related diseases, according to WSSCC.
- Diarrhea kills more than 3 million people each year, and chronic diarrhea is a leading killer of people with AIDS, according to the U.S. Agency for International Development (USAID).

Water and Economic Growth

According to Water for People,

- More than 40 billion work hours are lost each year in Africa to the need to fetch drinking water.
- Water-related illnesses cost the Indian economy 73 million working days per year.

Buildings pose both economic and environmental impacts. Buildings comprise:

- 65 percent of total U.S. electricity consumption
- 36 percent of total U.S. primary energy use
- 30 percent of total U.S. greenhouse gas emissions
- 136 million tons of construction and demolition waste in the United States (approximately 2.8 pounds per person per day)
- 12 percent of potable water in the United States
- 40 percent (3 billion tons annually) of raw materials used globally
- 40 percent of the world's energy, 75 percent of the world's wood, and 16 percent of the world's water

In addition, the U.S. Environmental Protection Agency (EPA) finds that people spend 90 percent of their time indoors, yet 30 percent of new and renovated buildings have indoor air quality problems.

WHAT IS SUSTAINABLE DESIGN?

Sustainable design is not a new concept. It has been done for years. In some cases, sustainable design actually returns to old technologies that were abandoned when petroleum products became so available and cheap. However, sustainable design has taken on new meaning with the popularity of green building. Plumbing engineers always should consider the efficiency of the systems they design for any project and utilize the sustainable technologies that are appropriate for each project's needs. While some sustainable practices help achieve LEED certification, many do not, but certification should not be the only objective.

The Brundtland Commission, also known as the U.N. World Commission on the Environment and Development, defines sustainability as the ability to meet the needs of the present, without compromising the needs of the future. Sustainability also might be described as design and construction practices that significantly reduce or eliminate the negative impact of buildings on the environment and occupants in five broad areas:

- Sustainable site planning
- Safeguarding water and water efficiency
- Energy efficiency and renewable energy
- Conservation of materials and resources
- Indoor environmental quality

Standards and Validation

Numerous organizations worldwide provide rating and accreditation processes for various types of construction. The Building Research Establishment Environmental Assessment Method (BREEAM) is the European equivalent and predecessor to the United States Green Building Council (USGBC), which offers the LEED program.

U.S. Green Building Council

The USGBC is a nonprofit coalition of leaders from across the building industry that works to promote buildings that are environmentally responsible, profitable, and healthy places to live and work. The purpose of this organization is to integrate building industry sectors and lead a market transformation. This includes the need to educate owners and practitioners.

HOW CAN LEED HELP?

LEED stands for Leadership in Energy and Environmental Design. A LEED AP is a LEED Accredited Professional.

The LEED certification process encourages a whole-building approach. This promotes and guides a collaborative approach toward integrated design and construction process. It includes a rating system that includes new construction, existing building renovations, core and shell, commercial interiors, and residential projects. It is expanding to encompass other categories, such as neighborhood development, as needs are identified. LEED helps plumbing engineers design systems that optimize environmental and economic factors, increasing efficiency in these areas.

LEED also provides recognition of quality buildings and environmental stewardship through:

- Third-party validation of achievement
- Federal, state, and local government incentives
- Contributing to a growing knowledge base
- LEED certification plaques to mount on buildings
- Official certificates
- Marketing exposure via the USGBC website, case studies, and media announcements

The LEED Certification Process

The LEED certification process is essentially a three-step process:

1. Project registration
2. Technical support
3. Building certification

The project team can register a building at www.leedbuilding.org. Someone on the team must be committed to overseeing the certification process. A LEED Accredited Professional would be ideal, but is not required.

After the project is registered, the team is entitled to two free credit interpretation rulings (CIRs). Anyone on the team can search and view previous CIRs on the USGBC website.

A review process starts 14 days after submittal. When the application is returned to the team leader, the team has a maximum of 30 days to correct application deficiencies and resubmit. The USGBC then performs a final review, concluding with a certification score. If problems with the application still exist, the client or design team must appeal within 30 days. The USGBC then has another 30 days to respond.

For the final submittal, the following items must be sent in a three-ring binder: a copy of the application, the scorecard, a project narrative, and documentation for each prerequisite and credit.

The LEED Rating System

The LEED rating system covers different types of buildings and construction, which are differentiated under the following LEED categories:

- LEED-NC: LEED for New Construction and Major Renovations
- LEED-EB: LEED for Existing Buildings: Operations and Maintenance
- LEED-CI: LEED for Commercial Interiors
- LEED-CS: LEED for Core and Shell
- LEED-H: LEED for Homes
- LEED-SC: LEED for Schools
- LEED for Homes
- LEED for Healthcare
- LEED for Neighborhood Development (in pilot in 2008)
- LEED for Retail (in pilot in 2008)

For the latest information on LEED categories, go to www.usgbc.org.

The program offers a total of 69 possible points to achieve certification. The four levels of LEED certification are:

- Certified: 26–32 points
- Silver: 33–38 points
- Gold: 39–51 points
- Platinum: 52 or more points

Note that the certification levels are subject to change and reflect the current system. For instance, LEED for Schools has a total of 79 points. Always double-check which system and version applies to each particular project.

The LEED program is broken into six categories:

1. Sustainable Sites
2. Water Efficiency
3. Energy and Atmosphere
4. Materials and Resources
5. Indoor Environmental Quality
6. Innovation and Design Process

Some of these credits are directly related to water use reduction, and some are related to other aspects of plumbing systems. Among those that are directly related to reduced water consumption are:

- Water Efficiency (WE) Credit 1.1: Water Efficient Landscaping: Reduce by 50 Percent

- WE Credit 1.2: Water Efficient Landscaping: No Potable Water Use or No Irrigation
- WE Credit 2: Innovative Wastewater Technologies
- WE Credit 3.1: Water Use Reduction, 20 Percent Reduction
- WE Credit 3.2: Water Use Reduction, 30 Percent Reduction
- Sustainable Sites (SS) Credit 6.1: Storm Water Design: Quantity Control
- SS Control 6.2: Storm Water Design: Quality Control
- Innovation and Design (ID) Credit 1: Innovation in Design

ID Credit 1 may be applied to water management design or may be related to some other aspect, such as reduced energy consumption in plumbing systems. Other applicable credits that may be obtained in plumbing system design include those relating to energy savings, third-party Commissioning, and recycled materials. This chapter focuses primarily on credits relating to water use reduction and wastewater management.

REAL LIFE FINANCIAL BENEFITS

Increased sustainability in plumbing system designs can have direct financial rewards. It is estimated that construction costs may increase 3 percent for a LEED-certified building. In fact, the construction cost of a typical office building has been shown to be about 2 percent of the total lifetime cost, assuming a 20-year lifespan, and about 5 percent for operation and maintenance, whereas the people inhabiting the building may account for as much as 92 percent of the total cost through salaries and benefits.

Some of the ways that sustainable design practices can provide tangible financial benefits are through reduced operating costs and reduced maintenance costs:

- Higher valuation of the building: The rule of thumb is to divide the reduction in annual operating costs by 10 percent to get the increased value of the building, which may be up to $4 in increased valuation for every $1 spent.
- Higher visibility and marketability
- Reduced insurance and risk of liability: Improved health of occupants, greater occupant satisfaction, improved performance of occupants, reduced absenteeism, lower environmental impacts, and streamlined regulatory approvals

Obstacles and Objections

According to some surveys, the most common objections to building green are:

- Perceived high cost of LEED documentation
- Design and construction costs
- Resistance to change
- Lack of financial resources

DOMESTIC WATER USE REDUCTION FOR IRRIGATION

Credits WE 1.1 and WE 1.2 are related to irrigation. A building can receive one point if the project team demonstrates that the domestic water required for irrigation and landscaping was reduced by 50 percent. By eliminating domestic water use for landscaping altogether, the building receives an additional point.

How to accomplish this? Methods for earning these credits include many deign choices, such as:

- Utilizing plantings that do not require watering other than the rain that they receive naturally
- Using rainwater to sustain the landscaping
- Capturing and reusing various wastewater from the building, such as condensate waste, for landscaping needs

DOMESTIC WATER USE REDUCTION FOR FIXTURES

The water reduction credits related to plumbing fixture specifications are WE 3.1 and WE 3.2. The project team must demonstrate that the domestic water required for plumbing fixtures was reduced by 20 percent to qualify for one point. The total domestic water used for fixtures must be reduced by 30 percent to qualify for an additional point.

Low-flow Fixtures

A number of low-consumption fixtures facilitate this task. Specifying these fixtures in lieu of conventional fixtures can easily accomplish this objective for most projects. The standards used as the reference, or baseline, are per the requirements of the Energy Policy Act of 1992. This includes 1.6-gallon-per-flush (gpf) toilets, 1.0-gpf urinals, 2.5-gallon-per-minute (gpm) faucets, and 2.5-gpm showerheads. Note that flush fixtures are rated in gpf, and flow fixtures are rated in gpm. These fixture types have different characteristics and need to be addressed relative to their functionality.

Some of the reduced-consumption fixtures include:

- 1.28-gpf toilets
- 0.5-gpf urinals
- 0.125-gpf urinals
- Waterless urinals
- 0.5-gpm faucets
- 1.6-gpm kitchen faucets

- 2.0-gpm, 1.8-gpm, 1.5-gpm, and even 1.0-gpm showerheads

Which fixtures are best? It depends on the project. This is a decision that must be made by the plumbing designer in conjunction with the architect, taking into consideration the needs of the owner. Some of the considerations may be site-specific. For instance, waterless urinals may be a good choice for areas that have little or no water supply. 0.125-gpf urinals may be more appropriate for other projects.

Another water-saving technique is vacuum-operated waste transport systems. They are used on cruise ships and in some prisons. The water closets require only 0.5 gpf, but additional energy is required to operate the vacuum pumping systems. This drainage system relies on a mechanical device requiring power to operate, which adds another potential weak point to the system.

WASTEWATER MANAGEMENT

Wastewater management must be part of a total sustainable building strategy. This must include consideration for environmental aspects relative to waste. The quality, quantity, and classification of wasted matter must be taken into account. The wastewater expelled from buildings is a combination of biodegradable waste, reusable waste, storm water runoff, and non-degradable waste. The biodegradable waste can be considered a source of nutrients that can go back into nature by bioremediation methods. Many non-degradable wastes can be recycled. Some by-products may require handling as hazardous materials. Storm water runoff can be recycled and used to reduce domestic water consumption.

Wastewater reclamation and reuse systems can be categorized into levels (see Table 14-1).

- Level 1: Nonpotable systems needing limited treatment: Rainwater and condensate waste collection systems shall be provided for irrigation and cooling use. Provide a collection tank, circulating pump, and point of connection for landscaping, coordinating with the landscape and heating, ventilating, and air-conditioning (HVAC) contractors. Recovery and delivery systems should include redundant tanks and other equipment to facilitate cleaning and maintenance. Domestic water makeup also should be included for emergency use and when supplementary water is required. Excess water production from Level 1 shall be conveyed to Level 2.
- Level 2: Low-level potable systems: Level 2 systems shall collect water from graywater processing, as well as from Level 1 production surpluses. Each system should include redundant tanks and other equipment to facilitate cleaning and maintenance. Domestic water makeup also should be included for emergency use and when supplementary water is required. Each graywater system shall include filters, an ultraviolet (UV) system, tanks, pumps, etc., all of which must be indicated on the plumbing drawings. The graywater reuse

Table 14-1 Treatment Stages for Water Reuse

Level 1	Components
Nonpotable systems needing limited treatment • Catchment flushing • Large contaminate removal • Sediment filtration	• Screen • First Flush • Vortex/Centrifugal
Level 2	**Components**
Low-level potable systems • All of the previous steps • Treatment for odor control • Increased level of filtration • Limited treatment for disease-causing pathogens	• Everything above • Cartridge filters • Automated sand filters • Ultraviolet (UV) light • Ozone
Level 3	**Components**
Potable water for human consumption • All of the previous steps • Automated system testing of pre-potable incoming water • Increased level of filtration • Increased level of disinfection processes • Automated system of testing the water after treatment to confirm water quality meets the standards for human consumption	• Everything above • Membrane filtration • Reverse osmosis (RO) • Nanofiltration • Chlorination as required
Level 4	**Components**
Black water for nonpotable systems • All of the previous steps • Bio-remediation with membrane system and air injectors • Post-recovery filtration similar to Level 3: RO, O3, UL, etc. • Additional testing with strict manual and electronic monitoring • Biosludge disposal • On-site technician, 24/7	• Everything above. • Manmade wetlands • Additional filtration • Additional testing and monitoring. • 24-hour technician on site • 24-hour technician on site • Proper disposal plan and systems
Level 5	**Components**
Black water for potable systems • All of the previous steps • Additional filtration similar to Level 3: RO, O3, UL, etc. • Additional testing with strict manual and electronic monitoring • On-site technician, 24/7	• Everything above • Additional filtration • Additional testing and monitoring • Proper disposal plan and systems

fixtures may return their waste to a black water treatment system. This type of system typically treats suspended solids, odors, and bacteria in water to be reused for toilet flushing.

- Level 3: Potable water for human consumption: Level 3 consists of both public domestic water and water from Level 1 and Level 2 systems, with additional treatment. Water shall be collected from the public water utility, as well as from Level 1 and Level 2 production surpluses. The Level 1 and 2 water must be processed with UV, reverse osmosis (RO), ozone, and filtering systems similar to Level 2, but monitored to EPA or National Sanitation Foundation (NSF) standards or local equivalents. Each system shall include filters, a UV or similar system, tanks, pumps, etc., all of which must be indicated on the plumbing drawings.
- Level 4: Black water for nonpotable systems: Level 4 includes water not meant for human consumption without further processing. It can be used for toilet flushing and laundry facilities. This system must include redundancy. Water shall be collected from the graywater system, as well as from Level 1 and Level 2 production surpluses. Each system shall be provided with emergency domestic water makeup. Each system shall include filters, a UV system, tanks, pumps, etc., all of which must be indicated on the plumbing drawings.
- Level 5: Black water for potable systems: Level 5 includes water not meant for human consumption or contact without additional treatment. It consists of black water that has been collected and treated. Each system shall include membrane filters, bio-chambers, a UV system, tanks, pumps, etc., as indicated on the plumbing drawings. Sludge accumulation shall be conveyed to a suitable site for further processing and disposal, based on analysis of sludge components.

Rainwater Capture and Reuse

Rainwater reuse can help earn more than one credit: water use reduction, innovative wastewater, storm water management, and innovation in design. The captured water may be used for irrigation, flushing toilets, cooling tower makeup, or other uses. Various filtration methods may be necessary, depending on the final use of the water. Ideally, the storage tanks should be elevated, such as on the top floor of the building, to reduce or eliminate pumping requirements. Remember that tanks store water, but also can store pressure by permitting the stored water to flow by gravity. Static head increases with height. If the building is high enough to require multiple water pressure zones, multiple tanks can be located at varying levels, possibly with one tank cascading down to another. As with all aspects of design, the approach must be customized relative to each individual project. Figure 14-1 shows a typical small cistern system diagram.

Many jurisdictions require rainwater detention to control the release rate into the sewer systems. Many municipal systems are overloaded and cannot process the storm water entering the system during times of significant rain events. Some cities have combined storm and sanitary sewer systems, which can make the problem even worse. One of the causes of this problem is increased impermeable surface features due to increased density, a result of urban sprawl. This effect can be reduced through the use of green roofs, permeable paving materials, storm water detention, and other innovative approaches.

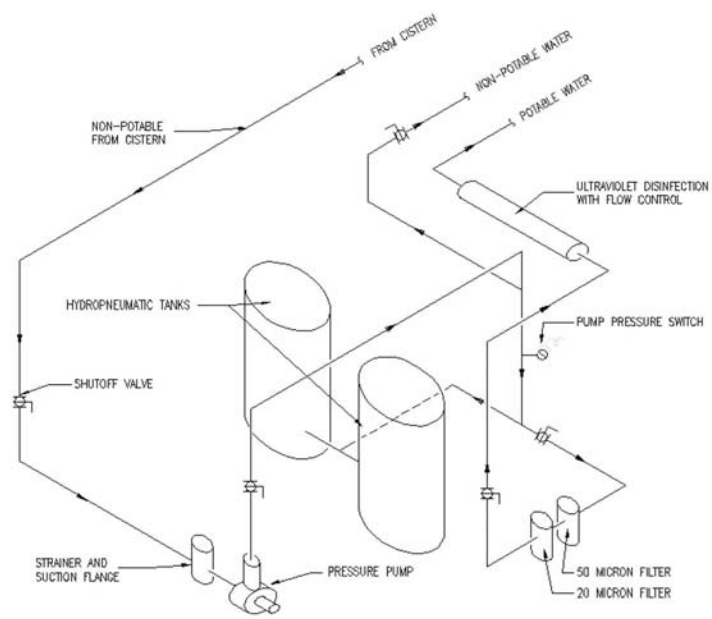


Figure 14-1 Typical Small Rainwater Cistern System Diagram

Table 14-2 outlines some types of treatment for rainwater systems. Many options are available, for different purposes. Most systems require some combination of these treatment options. Table 14-3 compares the cost, maintenance, and effectiveness of these filtration and disinfection methods.

Storage Tanks

Storage tanks come in many shapes, sizes, and materials. They can be located below grade, above grade, near the roof, or in many other locations. Table 14-4 compares the different storage tank options for rainwater collection.

Graywater and Black Water

About 68 percent of household wastewater is graywater. The other approximately 32 percent is black water. Figure 14-2 and Table 14-5 compare the two types of wastewater.

Wastes from dishwashers and kitchen sinks can be piped to automatic grease separators. These separators automatically siphon off the fats, oils, and greases, which can be used for bio-diesel fuel. The remaining wastewater then is processed as black water. It's a good idea to locate these facilities on the truck dock or another location that provides plenty of external venting to reduce odors indoors.

Biosolids Technology

Biosolids can be a by-product of graywater, but they primarily come from blackwater processing. Biosolids

Table 14-2 Rainwater Treatment Options

Treatment Method	Location	Result
Screening		
Leaf screens and strainers	Gutters and downspouts	Prevents leaves and debris from entering tank
Settling		
Sedimentation	Within tank	Settles out particulates
Activated charcoal	Before tap	Removes chlorine*
Filtering		
Roof washers	Before tank	Removes suspended material
Inline multistage cartridge	After pump	Sieves sediment
Activated charcoal	After sediment filter	Removes chlorine* and improves taste
Slow sand filters	After tank	Traps particulates
Microbial Treatment/Disinfection		
Boiling/distilling	Before use	Kills microorganisms
Chemical treatment (chlorine or iodine)	Within tank or at pump (liquid, tablet, or granular) before activated charcoal	Kills microorganisms
Ultraviolet light	After activated charcoal filter and before tap	Kills microorganisms
Silver ionization	After activated charcoal filter and before tap	Kills microorganisms
Ozonation	After activated charcoal filter and before tap	Kills microorganisms
Nanofiltration	Before use, polymer membrane (10^{-3}–10^{-4} pores)	Removes molecules
Reverse osmosis	Before use, polymer membrane (10^{-3}–10^{-4} pores)	Removes ions (contaminants) and microorganisms

*Should be used if chlorine has been used as a disinfectant.

Source: *Texas Guide to Rainwater Harvesting,* 2nd edition, Texas Water Development Board

Table 14-3 Filtration/Disinfection Method Comparison

Treatment Method	Cost	Maintenance	Effectiveness	Comments
Cartridge filters	\$20–60	Change filters regularly	Removes particulates > 3 microns	Disinfection treatment also is recommended
Reverse osmosis	\$400–1,500	Change filter when clogged (depends on turbidity)	Removes particulates > 0.001 microns	Disinfection treatment also is recommended
Ultraviolet light	\$350–1,000 (\$80 bulb replacement)	Replace bulb every 10,000 hours or 14 months; clean protective cover regularly	Disinfects filtered water provided (< 1,000 coliforms per 100 millimeters)	Water must be filtered prior to exposure for maximum effectiveness
Ozonation	\$700–2,600	Monitor effectiveness with frequent testing or monitoring equipment (about \$1,200)	Less effective in high turbidity; should be prefiltered	Requires pump to circulate ozone molecules
Chlorination	\$1/month manual dose or \$600–3,000 for automatic dosing system	Include monitoring with automatic dosing	Less effective in high turbidity; should be prefiltered	Excessive chlorine levels have been linked to health issues and damage to copper piping systems

Source: *Texas Guide to Rainwater Harvesting,* 2nd edition, Texas Water Development Board

Table 14-4 Storage Tank Options

Material	Features	Cautions	Cost	Weight
Plastics				
Polyethylene/polypropylene	Commercially available, alterable, and moveable	UV-degradable; must be painted	$.035–1.00/gallon	8 lbs/gallon
Fiberglass	Commercially available, alterable, and moveable	Must be sited on smooth, solid, level footing	$0.50–2.00/gallon	8 lbs/gallon
Metals				
Steel	Commercially available, alterable, and moveable	Prone to rust and corrosion	$0.50–2.00/gallon	8 lbs/gallon
Welded steel	Commercially available, alterable, and moveable	Possibly prone to rust and corrosion; must be lined for potable use	$0.80–4.00/gallon	8 lbs/gallon
Concrete and Masonry				
Ferrocement	Durable and immovable	Potential to crack and fail	$0.50–2.00/gallon	8 lbs/gallon
Stone, concrete block	Durable and immovable	Difficult to maintain	$0.50–2.00/gallon	8 lbs/gallon
Monolithic/poured in place	Durable and immovable	Potential to crack and fail	$0.30–1.25/gallon	8 lbs/gallon
Wood				
Redwood, fir, cypress	Attractive, durable, can be disassembled and moved	Expensive	$2.00/gallon	8 lbs/gallon

are the remaining sludge and also what is skimmed from the surface. It consists of different components requiring a variety of handling methods and technologies.

A compostable material is one that undergoes physical, chemical, thermal, and/or biological degradation in a mixed municipal solid waste (MSW) composting facility such that it is physically indistinguishable from the finished compost. The final product ultimately mineralizes (biodegrades to carbon dioxide, water, and biomass as new microorganisms) at a rate like that of known compostable materials in solid waste such as paper and yard waste.

A compost-compatible material is one that disintegrates and becomes indistinguishable from the final compost and is either biodegradable or inert in the environment.

A removable material is one that can be removed (not to be composted) by existing technologies in MSW composting (such as plastics, stones, or glass).

Biosolids are categorized as Class A and Class B biosolids. To ensure that biosolids ap-

Figure 14-2 Graywater versus Black Water

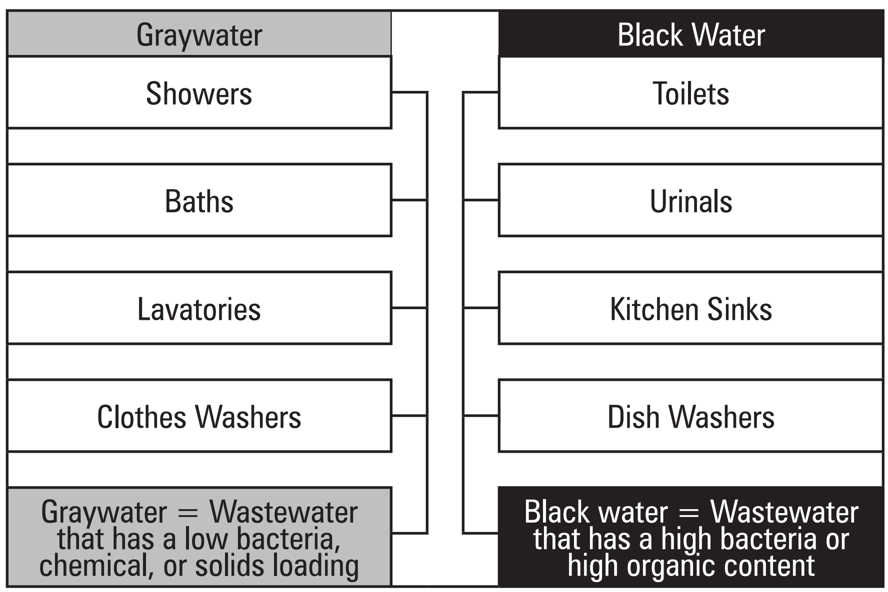


Table 14-5 Comparison of Graywater and Black Water

Parameter	Graywater	Black Water	Grey + Black
BOD5[1] (g/p/d[2] and mg/l)	25 and 150-300	20 and 2,000–3,000	71
BOD5 (% of UOD[3])	90	40	–
COD[4] (g/p/d and mg/l)	48 and 300	72 and 2,000–6,000	–
Total P (g/p/d and mg/l)	2 and 4–35	1.6	4.6
Total N (g/p/d)	1 (0.6–5 mg/l)	11 (main source urine)	13.2
TSS (g/p/d)	18	> 50	70
Pathogens	Low	Very high	Very high
Main Characteristic	Inorganic chemicals	Organics, pathogens	Inorganics, organics, and pathogens

[1] BOD5 = Oxygen required for the decomposition of the organic content in graywater during the first five days, determined as BOD after a five-day period of incubation under standard conditions

[2] g/p/d = grams/person/day

[3] UOD = Ultimate (total) oxygen demand in a sample taken

[4] COD = Oxygen demand for all chemical (organic and inorganic) activities; a measure of organics

Sources: Haug 1993; Droste 1997; Dixon et al. 1999b; Hammes et al. 2000; Lindstrom 2000a, 2000b plied to the land do not threaten public health, the EPA created 40 CFR Part 503. This rule categorizes biosolids as Class A or B depending on the level of pathogenic organisms in the material and describes specific processes to reduce pathogens to these levels. The rule also requires vector attraction reduction (VAR)—reducing the potential for spreading of infectious disease agents by vectors (i.e., flies, rodents, and birds)—and spells out specific management practices, monitoring frequencies, recordkeeping, and reporting requirements. Incineration of biosolids also is covered in the regulation.

Class A biosolids contain minute levels of pathogens. To achieve Class A certification, biosolids must undergo heating, composting, digestion, or increased pH that reduces pathogens to below detectable levels. Some treatment processes change the composition of the biosolids to a pellet or granular substance, which can be used as a commercial fertilizer. Once these goals are achieved, Class A biosolids can be applied to land without any pathogen-related restrictions at the site. Class A biosolids can be bagged and marketed to the public for application on lawns and gardens.

Class B biosolids have less stringent standards for treatment and contain small but compliant amounts of bacteria. Class B requirements ensure that pathogens in biosolids have been reduced to levels that protect public health and the environment and include certain restrictions for crop harvesting, grazing animals, and public contact for all forms of Class B biosolids. As is true of their Class A counterpart, Class B biosolids are treated in a wastewater treatment facility and undergo heating, composting, digestion, or increased pH processes before leaving the plant. This semi-solid material can receive further treatment when exposed to the natural environment as a fertilizer, where heat, wind, and soil microbes naturally stabilize the biosolids.

The biosolids rule spells out specific treatment processes and treatment conditions that must be met for both A or B classifications.

Class A Technologies

Technologies that can meet Class A standards include thermal treatment methods such as composting, heat drying, heat treatment, thermophilic (heat generating) aerobic digestion, and pasteurization. Class A technologies are known as PFRP, or processes that can further reduce pathogens. The technologies must process the biosolids for a specific length of time at a specific temperature.

Composting This is an environmentally friendly way to recycle the nutrients and organic matter found in wastewater solids. Composting systems turn wastewater biosolids, sawdust, yard waste, and wood chips into high-quality compost. As the material decomposes, oxygen filters through the compost site, releasing water, heat, and carbon dioxide. This process helps dry the organic material, while the generated heat increases the rate of decomposition and kills pathogens.

Heat drying This process applies direct or indirect heat to reduce the moisture in biosolids. It eliminates pathogens, reduces volume, and results in a product that can be used as a fertilizer or soil amendment. Because dryers produce a 90 percent dry material, additional VAR is not required.

Digestion In autothermal thermophilic aerobic digestion (ATAD) systems, biosolids are heated from 131°F to 140°F (55°C to 60°C) and aerated for about 10 days. This autothermal process generates its own heat and reduces volume. The result is a high-quality Class A product acceptable for reuse as a liquid fertilizer.

Pasteurization Pasteurization produces a Class A material when the biosolids are heated to at least 158°F (70°C) for 30 minutes. This extreme heat kills pathogens in the organic matter. When followed by anaerobic digestion, the VAR is attained, and the biosolids can be applied to land with minimal restrictions. The majority of the energy used in the pasteurization process is recovered with an innovative heat exchanger system and used to maintain the proper temperature in downstream anaerobic digesters.

Class B Technologies

The EPA regulations list a number of technologies, which, under certain operating conditions, can treat and reduce pathogens so that the material qualifies as Class B biosolids. These processes are known as processes that can significantly reduce pathogens, or PSRP. Class B technologies include anaerobic digestion, aerobic digestion, composting, air-drying, and lime stabilization.

Digestion Several EPA-approved stabilization technologies are available for anaerobic and aerobic digestion, including:

- Heaters, heat exchangers, digester covers, gas, and hydraulic mixing systems, all important components in conventional anaerobic digestion systems
- Temperature-phased anaerobic digestion (TPAD) systems, which optimize anaerobic digestion through a heat recovery system that pre-heats raw material and simultaneously cools the digested biosolids
- Membrane gas storage systems, which include an expandable membrane cover that provides variable digester gas storage, optimizes digester gas utilization for heating and electrical generation, and increases storage capacity

- Hydraulic mixers, which use a multi-port discharge valve to greatly improve biosolids mixing in the digestion process
- Air diffusers and aerators, which can be incorporated in any aerobic digester configuration

Lime stabilization Adding lime can stabilize biosolids by raising the pH and temperature. While adding sufficient amounts of lime to wastewater solids produces Class B biosolids, adding higher amounts yields Class A biosolids. Combining low amounts of lime with anoxic storage also can yield Class A biosolids.

Energy Requirements

Rainwater and condensate collection systems use minimal electrical power. Graywater systems for a large project may be estimated to require up to 10,000 kilowatt-hours per year. Blackwater systems for the same project may be estimated to require as much as 20,000 kilowatt-hours per year. These numbers are subject to the building systems for the particular project and vary greatly from project to project.

As an example, the power consumption ratios of a typical bioremediation system may consists of:

- 38 percent for membrane aeration blowers
- 35 percent for other blowers
- 16 percent for recirculation pumps
- 5 percent for process pumps
- 4 percent for mixers
- 2 percent for controls, monitors, and other equipment

This does not include pumping the water throughout the building, which may require additional power.

ENERGY EFFICIENCY AND ENERGY-SAVING STRATEGIES

Energy consumption within plumbing systems can be reduced using several methods, such as variable-frequency drive domestic booster pump systems. The energy savings are difficult to define precisely and vary for every project.

Water heaters offer a potential area for energy savings, as plumbing engineers are specifying more high-efficiency equipment these days. If required to specify a minimum efficiency of 84 percent for gas-fired boilers, specifying 98 percent efficient units can save 14 percent of energy costs, theoretically.

One problem in quantifying these savings lies in the fact that efficiencies vary with several factors, including incoming water temperature and return temperature. These factors apply to all types of heaters, but the numbers typically are jaded. Thus, it might be reasonable to assume that the system is still 14 percent more efficient. Using low-flow fixtures, with their related reduced hot water consumption, saves as much as 40 percent of the energy required to heat the domestic hot water.

The expected energy savings can be calculated using gallon-per-day (gpd) figures and extrapolating an estimated savings. These numbers, combined with energy consumption and reduction figures for other aspects of the building, can indicate the percentage of total energy saved. These savings may be applied to LEED Energy and Atmosphere credits.

High efficiency does not always come from high-efficiency equipment alone. The efficacy must be considered relative to the application. 98 percent efficient water heaters do not necessarily save energy on every system. All designs require an integrated approach and a balance of the correct elements relative to the needs of the project and the goals of the client.

SOLAR WATER HEATING

Solar water heating is an excellent way to reduce energy consumption. The average solar system for a typical home (see Figure 14-3) can save about two-thirds of the home's yearly cost for providing domestic

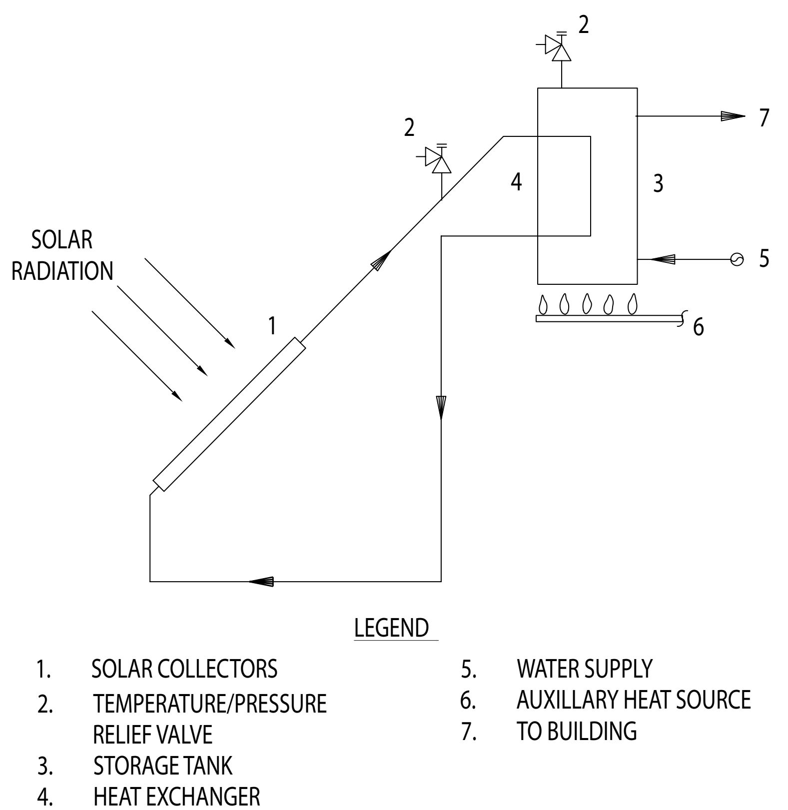


Figure 14-3 Simple Solar Domestic Water Heater Diagram

hot water. The energy savings for a commercial application are more difficult to precisely quantify, but they may be in the same range, depending on a variety of factors.

One important factor in any system involving heat transfer is the loading of the system. Other than when they are shut down and using no energy, heat exchangers, like pumps, are most efficient when they are running at 100 percent capacity. Oversizing equipment leads to reduced efficiencies and maybe even premature failure of the equipment.

Refer to other *Plumbing Engineering Design Handbook* chapters for additional information, including Volume 3, Chapter 10: "Solar Energy" and Volume 2, Chapter 6: "Domestic Water Heating Systems," as well as the resources listed at the end of this chapter.

GEOTHERMAL SYSTEMS

Geothermal energy can be used for homes, as well as industrial and commercial buildings. They even are used by some utility companies to generate steam to spin turbines, creating electrical power for municipalities. They can be used for radiant heat, as well as radiant cooling.

Refer to other *Plumbing Engineering Design Handbook* chapters for additional information, including Volume 4, Chapter 10: "Water Treatment," as well as the resources listed at the end of this chapter.

RESOURCES

LEED Green Building Rating System: www.leedbuilding.org

U.S. Green Building Council: www.usgbc.org

American Water Works Association: www.awwa.org

American Rainwater Catchment Systems Association: www.arcsa.org

Water for People: www.waterforpeople.org

U.S. Environmental Protection Agency: www.epa.gov

Texas Manual on Rainwater Harvesting, Third Edition. Texas Water Development Board, 2005.

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