
CHAPTER 2

PIPING

This chapter will describe the materials used most often for piping networks and systems described in this handbook. This chapter includes information on pipes, fittings, valves, jointing methods, hangers, and supports.

PIPE AND COMPONENT SELECTION CRITERIA

CODE ACCEPTANCE

Plumbing Systems

When selecting a piping material for any component of plumbing-related systems, the applicable plumbing code is of primary importance. Here, the allowable piping materials will be listed as well as any restrictions for their use. In addition, the code will also stipulate various accepted standards that govern the manufacture, tolerances, and installation of all components.

When renovating an existing facility or where circumstances require a unique design, it may be necessary to request a deviation from the accepted list of materials in order to match existing piping or obtain special design characteristics. The authorities reviewing such requests require enough information to determine that the intent of the applicable code provisions is followed in terms of safety and suitability of materials for the purpose intended.

Applicable plumbing and model building codes are discussed in Chap. 9, “Plumbing Systems.”

Other Code Requirements

Codes required for systems other than plumbing are generally the following:

1. ANSI B31.1-9 series
2. FDA requirements, such as cGMP
3. Sanitary 3-A Standards for the food and pharmaceutical industries

PRESSURE AND TEMPERATURE RATINGS

The pressure rating for a wide range pipe and other components is provided by the ANSI Pressure Classification System, which publishes qualitative performance standards. The design pressure is the maximum sustained (steady-state) pressure that a piping system must contain without exceeding its code-defined stress limits.

The design temperature of a component must be equal to or greater than the maximum sustained temperature that will be experienced during any normal or abnormal mode of operation. Normal operating temperature is the temperature maintained by the system while it is operating at steady-state, full-load, nontransient operation. It is the temperature at which the allowable stress is calculated.

COST

The total installed cost of the network includes the piping material cost, assembly of the joint selected, handling due to the weight of the material, physical damage allowance, and the support system required.

CORROSION RESISTANCE

Corrosion is the thinning of a pipe wall (usually) caused by a chemical reaction from a corroding fluid or agent and is limited almost exclusively to metal products. Corrosion resistance is the ability of a pipe to resist the internal corrosive effects of the fluid flowing through it, as well as the external corrosive forces on the pipe, for example, soils (if underground) or surrounding atmospheric conditions (when installed above ground). Corrosion can be reduced or eliminated with the application of suitable coatings, linings, and cathodic protection, depending on the nature of the problem. Since there is no universal corrosion-resistant material, the selection of a specific grade or class of pipe material with specific alloys to resist expected corrosion resulting from specific fluids within a pipe is a matter of tradeoffs unique to each project.

Corrosion is separated into two basic types: general and localized. General corrosion describes the potential dissolution of pipe over its entire exposed surface. Localized corrosion affects only a small area of the pipe surface.

General Corrosion

This is a breakdown of the pipe material at a uniform rate over its entire surface by direct chemical attack. It is caused by the loss of the protective passive film that forms on the surface of the pipe coupled with a chemical reaction occurring between the pipe material and the chemical in the fluid.

Galvanic Corrosion. This type of corrosion occurs in a liquid medium (called an electrolyte) when a more active metal (anode) and a less active metal (cathode) come in contact with one another and form an electrode potential. When this occurs, the more active (noble) metal will tend to dissolve in the electrolyte and go into solution. This is shown in the galvanic series of metals (Table 2.1).

Intergranular Corrosion. This type of corrosion occurs in the pipe wall when material in the grain boundary of some alloys is less resistant to the corroding agent than the grains themselves, and the bond between the grains is destroyed.

Erosion Corrosion. This is caused by a wearing away of the pipe wall, usually as a result of excessive fluid velocity or impingement by suspended solids.

Localized Corrosion

This takes place on small areas of the surface, usually at high rates, and takes various forms:

TABLE 2.1 Galvanic Series of Metals and Alloys

Corroded end (anodic, or least noble)
Magnesium alloys
Zinc
Beryllium
Aluminum alloys
Cadmium
Mild steel, wrought iron
Cast iron, flake or ductile
Low-alloy high-strength steel
Nickel-resist, types 1 & 2
Naval bronze (CA464), yellow bronze (CA268), aluminum bronze (CA687), red bronze (CA230), admiralty bronze (CA443), manganese bronze
Tin
Copper (CA102, 110), silicon bronze (CA655)
Lead-tin solder
Tin bronze (G & M)
Stainless steel, 12–14% chromium (AISI Types 410, 416)
Nickel silver (CA732, 735, 745, 752, 764, 770, 794)
90/10 Copper-nickel (CA706)
80/20 Copper-nickel (CA710)
Stainless steel, 16–18% chromium (AISI Type 430)
Lead
70/30 Copper-nickel (CA715)
Nickel-aluminum bronze
Inconel alloy 600
Silver braze alloys
Nickel 200
Silver
Stainless steel, 18 chromium, 8 nickel (AISI Types 302, 304, 321, 347)
Monel alloys 400, K-500
Stainless steel, 18 chromium, 12 nickel-molybdenum (AISI Types 316, 317)
Carpenter 20 stainless steel, Incoloy alloy 825
Titanium, Hastelloy alloys C & C276, Inconel alloy 625
Graphite, graphitized cast iron
Protected end (cathodic, or most noble)

Stress-Corrosion Cracking. This type of corrosion is the physical deterioration and cracking of the pipe wall caused by a combination of high operating temperature, tensile stress on the pipe, and chemicals in the fluid stream.

Pitting. This is characterized by deep penetration of the metal at small areas of the surface, concentrating in small cells, without affecting the entire surface.

Crevice Attack Corrosion. This occurs at junctions between surfaces (often called crud traps) where a crack exists that allows an accumulation of a corroding agent.

Corrosion failure occurs if any pipe material is reduced to a minimum thickness mandated by code.

Manufacturers of pipes and fittings publish corrosion-resistance tables concerning chemical resistance and compatibility with fluids carried by the piping they produce. These relate to temperature, concentration, and specific chemicals. These tables should be used for selection of a specific pipe to transport any specific chemical.

PHYSICAL STRENGTH

Physical strength is the capability of any pipe to resist the damage that might occur either during the construction phase or after the pipe is placed in service.

FIRE RESISTANCE

Fire resistance is the capability of a piping system to simply remain intact and not fall during a fire or, in some cases, to also retain the ability to carry water. Where this is a factor, pipes, joints, and supports strong enough for this purpose should be selected.

AVAILABILITY

Any pipe is considered available when it can be supplied at a competitive price to the area where the project is under construction. In addition, obtaining the mechanics and special tools needed to assemble the piping system must also be possible.

METALLIC PIPE AND PIPING MATERIALS

ALUMINUM (AI)

Aluminum pipe is manufactured in various wall thicknesses similar to copper and in sizes ranging from 1/8 to 12 in. Sizes above 3 in are not readily available. Aluminum is manufactured in various alloys; the most commonly used for facilities conforms to ASTM B-210. Joints are made using brazing or welding with special aluminum alloy filler metals.

Aluminum tubing is light in weight and generally used for specialty services, such as cryogenics (where ductility and strength are necessary) and for carrying compressed specialty gases (because of its corrosion resistance). It also resists many specialty chemicals and is resistant to atmospheric corrosion. It is not suitable for acids, mercury, and strong alkalis. It has a high rate of expansion.

For a list of various alloys, refer to Table 2.2.

BRASS (BR)

Brass is an alloy of copper and zinc. The proportion varies from 85% copper to 67% copper. Pipe with a high copper content is known as red brass, and that with a lower content is known as yellow brass. When used for drainage systems, it is obtained plain end. Joints for this pipe can be either threaded, flanged, brazed, or soldered. Brass pipe for utility piping systems shall conform to ASTM B 43: Red Brass Tube, Seamless.

Brass is generally used for local branch drainage lines, where this alloy will resist specific corrosive drainage effluent and, in larger sizes, for potable and other water supply lines and to match existing work for alterations. Its advantages and disadvantages are the same as for copper.

Brass castings for pipe fittings and components of plumbing fixtures are not made with the same alloy as pipe and often contain lead. Pipe is lead free and brass fittings with lead are no longer permitted by code to be used for potable water.

TABLE 2.2 Aluminum Alloys

Alloy number	UNS number series	Major alloying elements
1XXX	A91NNN	Aluminum with 99.00% minimum purity
2XXX	A92NNN	Copper
3XXX	A93NNN	Manganese
4XXX	A94NNN	Silicon
5XXX	A95NNN	Magnesium
6XXX	A96NNN	Magnesium plus silicon
7XXX	A97NNN	Zinc
8XXX	A98NNN	Miscellaneous

CAST IRON SOIL PIPE (CI)

Technically known as gray cast iron, this pipe is a ferrous material alloyed with carbon in the form of free graphite flakes, silicon, and other impurities. It is available in three classifications: service (standard) weight, extra heavy, and hubless. The pipe is commonly lined internally with cement or coal tar enamel, and coated externally with a variety of materials to reduce corrosion by soils.

Joints require two types of pipe ends: hub and spigot or hubless. The hub and spigot ends can be joined either by caulking or by the use of an elastomeric compression gasket. Hubless pipe is joined by an external compression coupling.

Cast iron soil pipe should conform to the following standards:

1. ASTM A 74: Hub and Spigot Cast Iron Soil Pipe and Fittings
2. CISPI 301: Hubless Cast Iron Soil Pipe
3. CISPI 310: Hubless Cast Iron Fittings for Soil Pipe

Cast iron is well suited for sanitary effluent and can be used in any part of a gravity drainage and vent system. Advantages include an ability to withstand moderate external pressure (such as direct burial in soil), good fire resistance, good flow characteristics, and good corrosion resistance in most natural soils. Piping in use for over 100 years has been documented. Disadvantages are that the pipe is brittle and subject to breakage when roughly handled, it is subject to corrosive attack by aggressive soils and highly septic effluent, it is heavy, and it has a high initial material cost.

Cast iron pipe is manufactured with both inside and outside coated for corrosion resistance. A PE wrapping is often used to eliminate external corrosion of cast iron pipe buried underground on a site.

ACID-RESISTANT CAST IRON (AR)

Commonly referred to as high silicon iron pipe, acid-resistant CI is an alloy of gray cast iron containing between 14.25 and 15% silicon, and small amounts of manganese, sulfur, and carbon. It is available only in extra heavy pattern, with the same dimensions as CI piping.

Joints require two types of pipe ends: hub and spigot or hubless. The hub and spigot ends can be joined by caulking. Hubless pipe is joined by a compression coupling.

Acid-resistant cast iron pipe shall conform to ASTM A 861 and ASTM A 518.

This specialty piping material is used for drainage of various corrosive liquids, and since it is stronger than glass, is recommended for exposed or underground applications where there is a possibility of physical damage.

CARBON STEEL (ST)

Steel is a very broad category of piping because of the large number of alloys that have been produced. It is divided into two broad categories according to the method

of manufacture: mill pipe and fabricated pipe. Mill pipe is produced to meet finished pipe specifications. Fabricated pipe is manufactured from steel plate with spiral or straight welded seams.

Steel pipe is manufactured by either the seamless (extruded) or welded method, and is available either plain (black) or galvanized (zinc plated inside, outside, or both). Wall thickness is expressed as “schedule,” and ranges from schedule 5 (lightest) to schedule 160. The wall thickness varies with the size of the pipe. The larger the schedule number, the thicker the pipe wall for a specific pipe size.

Steel pipe, depending upon type, can be obtained with threaded ends for screwed fittings, plain ends, and flanged and beveled ends for welding.

There is an extremely large number of steel pipe alloys available. The selection depends on the intended service. The steel pipe alloys most commonly used for service and utility systems conform to ASTM A 53: Steel Pipe, Welded or Seamless, Black or Galvanized and ASTM A-106: Steel Pipe, Welded or Seamless, Black or Galvanized.

Steel pipe is generally used for pressure piping. Its advantages are long laying lengths, high internal and external strength, and the availability of varying pipe thickness to meet almost any design pressure. It has good flow characteristics and fire resistance and is low in initial cost. The most serious disadvantage is low corrosion resistance. This requires internal and external protection, with galvanizing the most commonly used method.

COPPER

Copper tubing is seamless, made from almost pure copper (99.9 percent), and is available in hard (annealed) and soft (drawn) form. It is manufactured in sizes ranging from $\frac{1}{8}$ to 12 in, but sizes over 6 in are not generally available. All tubing is manufactured with plain ends only. Joints are made by soldering, and brazing, and with flared and flanged fittings.

The six types of copper tubing used most often are:

1. ASTM B-88 is the grade used most often for potable water, and also for compressed gases and vacuum systems where high purity is not a factor. It is seamless, available in nominal pipe sizes from $\frac{3}{8}$ to 12 in, in hard and soft temper, and in three wall thickness grades—K (thickest wall), L, and M (thinnest wall). If patented flare fittings are used, the pipe must be obtained without outside diameter embossing, which would interfere with the sealing of the pipe wall against the side of the fitting.

2. ASTM B-819 is similar to B-88, except that it is available only in grades K and L and, in addition, the pipe is factory cleaned, capped, and specially marked. This pipe is required to be used for medical gas systems in health-care facilities. It should also be considered as the primary copper pipe for gases in laboratories as well.

3. ASTM B-75 is seamless, available as either hard or drawn, and in nominal sizes from $\frac{1}{8}$ to 2 in O.D. The smaller sizes are often referred to as capillary tubing. This is the grade most often used for very small diameter pipe [$\frac{1}{4}$ in O.D. (6 mm)

or less] connecting instruments to the distribution piping. This pipe is commonly joined by patented flare joints, which require temper 060 to seal correctly.

4. ASTM B-280, type ACR (air conditioning and refrigeration), is available cleaned and capped for field refrigeration piping and could also be considered for laboratory use. It is available only in hard temper, and its size is the actual O.D. of the pipe. This requires that all non-ACR fittings used in the system, which are manufactured in nominal pipe size, be dimensionally compatible with the ACR pipe, which is manufactured in actual pipe size.

5. ASTM B-306, copper drainage tube, is known as DWV (drainage, waste, and vent). This designation applies to copper tube used for nonpressure drainage systems. This tube has the thinnest wall of any copper product. The preferred jointing method is soldering, which is adequate in strength and the least costly. Primary use is in residential construction as indirect waste lines and in larger projects for local branch lines where human waste is not discharged. Advantages are its light weight, ease of assembly, and smooth interior. Disadvantages include corrosive attack by ordinary sewage, poor fire resistance, and the need for dielectric connections to eliminate galvanic corrosion where this material is connected to any iron piping.

6. ASTM B-837 Type G is seamless tube, available in either hard (drawn) or soft (annealed) temper, and in nominal sizes from $\frac{3}{8}$ to $1\frac{1}{8}$ -in O.D. This tubing is identified by the O.D. rather than nominal size. This grade is manufactured specifically for natural gas and LP fuel gas systems. Fittings shall be similar to those used with type ACR copper. The pipe is joined by either brazing or flare type joints. Brazed joints are required for system pressures above 14 in WC where installed in inaccessible locations. Brazing alloys shall contain less than 0.05 percent phosphorus.

DUCTILE IRON PIPE (DI)

Ductile iron is a cast ferrous material alloyed with free nodular or spheroidal graphite in lieu of the flakes that are present in cast iron. This is achieved by the addition of a magnesium inoculant. It is used either as a gravity sewer or pressure pipe. Sizes available range from 3 to 54 in. There are eight pressure ratings—class 50 (125 psi) to class 56 (350 psi), and gravity sewer pipe. A cement or bituminous lining can be provided to resist internal corrosion. This pipe can be assembled with mechanical, gasketed, or flanged joints. Ductile iron pipe shall conform to ASTM A 518 and ASTM A 861.

The advantages of ductile iron are the same as those for CI pipe, except that it is far stronger in terms of allowable pressure ratings and external load-bearing capacity. It is also not as brittle, allowing rougher handling. It has a higher initial cost than CI.

LEAD (LD)

Lead pipe is made from 99.7% pig lead with various alloys available for special applications. Joints for this pipe are either wiped, burned, or mechanically flanged. Lead pipe shall conform to WW-P-325a: Lead Pipe, Bends and Traps.

Uses of lead pipe include existing connections to floor-mounted water closets, radioactive wastes, and special laboratory corrosive wastes. It has very limited use in modern drainage systems.

STAINLESS STEEL (SS)

The term *stainless steel* encompasses a wide variety of alloys containing 11 to 30% chromium (Cr), 0 to 35% nickel (Ni), and 0 to 6% molybdenum (Mo) in various combinations as well as small amounts of other elements such as titanium, manganese, niobium, and nitrogen. It is widely used in the chemical, pharmaceutical, and food processing industries.

Pipe is available in sizes ranging from $\frac{1}{8}$ to 48 in, and is manufactured in plain end, prepared end for welding, and flanged. Joints can be welded, threaded, or flanged. Wall thickness is expressed as a "schedule," and ranges from schedule 5 (lightest) to schedule 160. The wall thickness varies with the size of the pipe. The larger the schedule number, the thicker the pipe wall for a specific pipe size. Stainless steel pipe is also available as tubing with wall thickness designated as a decimal.

The composition of a stainless steel alloy determines its metallurgical structure or grade, and therefore its properties. There are five groups of stainless steel based on metallurgical structure: ferritic, austenitic, superaustenitic, martensitic, and duplex.

1. Ferritic stainless steels contain 12 to 30% (more typically 16 to 18%) Cr, 0 to 4% Ni, and 0 to 4% Mo with a low carbon content. This material is magnetic and has good ductility and cold formability but is not hardenable by heat treatment. This class is generally less vulnerable to chloride-induced stress corrosion cracking. Its primary use is in transport of strong oxidizing fluids (such as nitric acid) in process environments, machinery, and kitchen equipment. This class is exemplified by type ASTM grade 430.

2. Austenitic stainless steels contain 17 to 27% Cr, 8 to 35% Ni, and 0 to 6% Mo. This material is typically nonmagnetic and readily weldable, and has good ductility (even at cryogenic temperatures) and cold formability but is not hardenable by heat treatment. This class is more generally corrosion resistant, but is generally vulnerable to chloride-induced stress corrosion cracking. Regular carbon grades are susceptible to corrosion around welded joints due to migration of Cr away from the weld site. These problems are overcome by using a low carbon grade, indicated by an L suffix, that reduces carbon to below 0.035 percent. Grades within this class are the most commonly used stainless steels. This class is exemplified by type ASTM grades 304 and 316 (304L and 316L). A superaustenitic grade is also available with superior resistance to chloride pitting.

3. Superaustenitic stainless steel alloys were created to better withstand corrosion in a more severe environment than conventional stainless steel. They are alloys of Ni, Cr, Mo, copper, and iron typified by UNS (Unified Numbering System) alloys N08020, N08024, and N08026.

4. Martensitic stainless steels contain 11 to 18% Cr, 0 to 6% Ni, 0 to 2% Mo, and 0.1 to 1% C. This class is magnetic, oxidation resistant, and hardenable by heat treatment. Little used in piping applications, its primary uses are in cutlery, turbine blades, and high-temperature parts. This class is exemplified by type ASTM grade 410.

5. Duplex stainless steel is characterized by a microstructure containing both ferritic and austenitic types with different grades, having a mixture of 40 to 60% of each for various alloys. Its advantages are good resistance to chloride-induced stress corrosion cracking and high mechanical strength properties along with good ductility and impact strength. Disadvantages include corrosion of pipe by reducing acids and weld site corrosion by oxidizing acids.

Stainless steel is available in various wall thicknesses. Pipe is commonly available from schedule 5 to 80, and tubing from 0.028 to 0.188.

Stainless Steel Finishes

For stainless steel piping used in pharmaceutical, food-processing, chemical, and electronics applications, the interior and exterior of the piping are often required to be finished as required by FDA, EPA, USDA, or other applicable codes. Finishing the exterior makes it easier to keep clean. Finishing the interior will prevent the adherence of any solids, increase corrosion protection, and shorten pipe interior cleaning procedures. Finishing can be abrasive, electropolished, or both.

Abrasive finishes are mechanically produced by polishing and wearing away of the surface. This is often specified by a particular size or "grit" of the abrasive used, such as a 220 grit. This signifies the size of the abrasive passing through a specific size mesh. The larger the number, the finer the finish. Electropolishing is an electrochemical process using an electrical current to deposit metal from an anode to a cathode. Electropolishing, which is the opposite of electroplating, removes surface metal from microscopic high points faster than from low points. The metal to be polished is the sacrificial anode. Surface ions of iron are removed leaving a chromium-rich surface resulting in a smooth, corrosion-resistant pipe interior. Another method used to specify standard sheet and pipe exterior finishes uses numbers 1 to 8. An explanation of sheet finishes is given in Table 2.3. Table 2.4 gives the grit equivalent of microinch measurement.

Finishes are often indicated as Ra (arithmetic mean roughness average, or roughness average) and Rq, the equivalent of RMS (root mean square). Both of these are measured in microinches and denote the smoothness of the surface. The smaller the number, the finer the finish. The Ra reading is approximately 87.5 percent of the Rq (RMS) reading. Other methods of expressing smoothness are centerline average (CLA) and arithmetic average (AA).

Passivation

When the interior surface of stainless steel piping is required to have a very low rate of corrosion, it must be made passive. This is accomplished by the formation of a thin surface film that acts as a barrier to corrosion. The surface film (or passive film) is made thicker by exposing it to oxidizing and chelant solutions or electropolishing. Oxidizing solutions frequently used are nitric acid, ammonium persulfate, hydrogen peroxide, and citric acid. Chelants are nontoxic organic acids or their viable salts and nontoxic synergizing agents. ASTM A 380 suggests other passivation chemical combinations that have proven successful.

TABLE 2.3 Table of Standard Sheet Finishes

	Number	Description
Unpolished (as rolled) finishes	1	A rough, dull finish that results from hot rolling to the specified thickness, followed by annealing and descaling.
	2D	A dull finish that results from cold rolling, followed by annealing and descaling, and perhaps a final light roll pass through unpolished rolls. This finish is used where appearance is of no concern.
	2B	A bright cold-rolled finish resulting from the same process as that for number 2D finish, except that the annealed and descaled sheet receives a final light roll pass through polished rolls. This is the general-purpose, cold-rolled finish that can be used as is or as a preliminary step to polishing.
Polished finishes	3	An intermediate polished surface obtained by finishing with a 100-grit abrasive. This finish is generally used where a semifinished polish surface is required and usually receives additional polishing during fabrication.
	4	A polished surface obtained by finishing with a 120- to 150-grit abrasive, following initial grinding with coarser abrasives. This is a general-purpose bright finish with a visible "grain" that prevents mirror-like reflection.
	7	A highly reflective finish obtained by buffing finely ground surfaces, but not to the extent of removing the scratch pattern.
	8	A reflective surface obtained by polishing with successively finer abrasives and buffing extensively until all scratch patterns from preliminary grinding are removed.

Source: Data from *Finishes for stainless steel*, Publication SS201-683-14M-EB, American Iron and Steel Institute.

TABLE 2.4 Grit to Microinch Conversion

Grit	Microinch (μin)
120	45–48
150	30–33
180	20–23
240	15–18
320	9–11

CORRUGATED STEEL PIPE

Corrugated steel pipe is available from 6 in (125 mm) to 96 in (2.66 m). It is fabricated from flat steel that has been rolled into various shapes and impressed with grooves around the circumference of the pipe, generally described as circular arcs connected by tangents. Corrugations are measured by pitch (the dimension from crest to crest at right angles to the corrugations) and depth.

Longitudinal pipe seams are riveted, welded, bolted or have helical lock seams. Joints are generally steel bands with a gasket under the sleeve and tightened by bolts inserted in an integral angle. Fittings are usually made from straight piping and shop fabricated into the desired shape.

Corrugated steel pipe shall conform to different AASHTO standards depending on the actual pipe material specification.

OTHER METALLIC PIPING MATERIALS

The chemical compositions of various metal piping materials selected for special corrosion-resistant characteristics are given in Table 2.5.

TABLE 2.5 Alloy Composition of Miscellaneous Metallic Piping

Material	C, %	Cr, %	Cu, %	Fe, %	Mn, %	Mo, %	Ni, %	Si, %	Other elements, %
Admiralty metal	—	—	70	—	—	—	—	—	Zn, 29; Sn, 1
Aluminum 2S	—	—	—	—	—	—	—	—	Al, 99.5+
Aluminum 3S	—	—	0.1	0.5	1.25	—	—	0.5	Al, 97.7
Brass, admiralty	—	—	71	—	—	—	—	—	An, 28; Sn, 1
Brass, aluminum	—	—	76	—	—	—	—	—	Al, 2; Zn, 22
Bronze, silicon	—	—	96	—	—	—	—	3	
Carpenter 20 alloy	—	20	4	44	—	3	29	—	
Copper, arsenical	—	—	99.9+	—	—	—	—	—	As, 0.04
Croloy 2¼ alloy	0.15	2.25	—	96.1	—	1.0	—	0.5	
Cupro-nickel, 70-30	—	—	69.3	0.75	—	—	30	—	
Cupro-nickel, 90-10	—	—	88.8	1.25	—	—	10	—	
Durimet 20 alloy	0.07	20	3.5	45.7	—	1.75	29	—	
Duriron	0.85	—	—	84.7	—	—	—	14.5	
Hastelloy B alloy	0.1	—	—	5	—	28	62	—	
Hastelloy C alloy	0.1	16	—	5	—	16	55	—	W, 4
Incoloy alloy 800	0.04	21	0.3	45.3	1	—	32	0.4	
Inconel alloy 600	0.04	15.8	0.1	7	0.20	—	76	20	
Iron, cast	3.4	—	—	94.3	0.5	—	—	1.8	
Lead	—	—	—	—	—	—	—	—	Pb, 99.95
Monel alloy 400	0.12	—	31.5	1.4	1	—	66	0.15	
Monel alloy K-500	0.15	—	29.5	1.0	0.60	—	65	0.15	
Nickel 200	0.06	—	0.05	0.15	0.25	—	99.4	—	
Nickel silver, 18%	—	—	65	—	—	—	18	—	Zn, 17
NI-Hard alloy	3.4	1.5	—	89.5	0.5	—	4.5	0.6	
NI-Resist, Type I	2.8	2.5	6.5	69.6	1.3	—	15.5	1.8	
NI-Resist, Type II	2.8	2.5	—	71.9	1.0	—	20.0	1.8	
Steel, carbon-molybdenum	0.15	—	—	99.4	—	0.5	—	—	
Steel, low-carbon, electric-resistance-welded, ASTM A587-68	0.1	—	—	99.5	0.4	—	—	—	P, 0.01; S, 0.02; Al, 0.05
Steel, mild (SAE 1020)	0.2	—	—	99.1	0.45	—	—	0.25	
Steel, Ni-Cr (SAE 3140)	0.4	0.65	—	96.7	0.8	—	1.25	0.25	
Tantalum	—	—	—	—	—	—	—	—	Ta, 99.9+
Titanium (Ti-50A)	0.08 max.	—	—	0.20 max.	—	—	—	—	N, 0.05 max.; H, 0.015 max.
Worthite alloy	0.07	20	1.75	46.7	—	3	25	3.5	

PLASTIC PIPE AND PIPING MATERIALS

This section will discuss various commercially available plastic piping materials and their properties.

Plastics, because of their unique chemical resistance and other characteristics, are widely used as raw material for both piping and elastomeric sealing and gasketing compounds. It is no longer justifiable to think of plastic pipe as merely a cheap substitute for other piping materials. Plastic has become the material of choice for piping systems used to convey various liquids, chemicals, pharmaceuticals, liquid fuels, and fuel gases, and those used for underground sewer water.

Plastic pipe is available in a great variety of compositions. When used for plumbing systems, the restrictions imposed by the applicable code will be the single most important determining factor in the use and selection of any plastic pipe material.

Plastic pipe is manufactured in two types: thermoset (TS) and thermoplastic (TP). Thermoset piping is permanently rigid; examples are epoxy and phenolics. Thermoplastic material will soften when subject to any degree of heat and rearden upon removal of the heat. This will affect the strength of the pipe. Therefore, extreme care must be used when selecting the material type and support system for the material.

In general, the advantages of plastic pipe are excellent resistance to a very wide range of sanitary and chemical effluent and aggressive soils, long laying lengths, good flow characteristics, and economical initial system costs. Disadvantages are poor structural stability requiring close support, susceptibility of some materials to changes resulting from exposure to ultraviolet rays or sunlight, poor fire resistance, lowering of pressure ratings with elevated temperature, and production of toxic gases released by some materials when burning.

KEY PROPERTIES OF PLASTIC PIPE

The advantages of plastic pipe include:

1. Resistance to a very wide range of sanitary and chemical effluents
2. Resistance to aggressive soils
3. Availability in long lengths
4. Light weight
5. Low resistance to fluid flow
6. Generally low initial cost

Disadvantages include:

1. Poor structural stability requiring additional support
2. Susceptibility of some types of plastics to physical changes resulting from exposure to sunlight
3. Generally low resistance to solvents
4. Poor fire resistance

5. Lowered pressure ratings at elevated temperature
6. Production of toxic smoke and gases, which are released upon combustion of some types of plastic pipe

DESCRIPTION AND CLASSIFICATION

Plastic pipe is as descriptive a phrase as metallic pipe. The properties of various plastic materials are obtained from the basic chemical composition of the polymer resin, additives, and the manufacturing process itself. In order to better understand the material called "plastic," definitions of the basic terms and ingredients used by the plastic piping industry are necessary. Please understand that these are simplified definitions.

Plastic is a material whose essential ingredient is an organic substance of large molecular weight which at some stage in its manufacture can be shaped by flow and becomes solid in its finished state.

A *polymer* is a material consisting of molecules with a high molecular weight. A *monomer* is a chemical compound capable of reacting to form a polymer. *Polymerization* is a chemical reaction in which molecules of a monomer are linked together to form a polymer. When two or more monomers are used, the process is called *copolymerization*.

The following are common additives used in the manufacture of plastic piping: flame retardants, plasticizers to increase flexibility and workability, antioxidants to retard degradation from contact with air, stabilizers to retard degradation at higher temperatures, lubricants to aid in the extrusion process, pigment or dyes to color the final product and protect against ultraviolet light, fillers to modify strength or lower cost, and modifiers to produce a special property response.

Another type of plastic is an *elastomer*. Used mostly for gaskets, an elastomer is a material that is capable of being repeatedly stretched to at least twice its original length at room temperature and which will return to its approximate original length upon release.

The following is a partial list of plastic pipe and elastomer materials available from all sources. The names in parentheses are trade names patented by various manufacturers. Only those piping materials that are commonly available will be discussed. Elastomers, indicated as (E), are listed only for reference since they are outside the scope of this chapter:

ABS = acrylonitrile butadiene styrene; also (Buna-N) (E)

BR = butadiene (E)

CAB = cellulose acetate butyrate (Celcon)

CIIR = chlorinated isobutene isoprene (E)

CPE = chlorinated polyethylene (E)

CPVC = chlorinated polyvinyl chloride

CR = chloroprene rubber (Neoprene) (E)

CSP = chlorine sulphonyl polyethylene (Hypalon) (E)

ECTFE = ethylenchlorotrifluoroethylene

EP = epoxide, epoxy

EPDM = ethylene propylene-diene monomer (E)

- EPM = ethylene propylene terpolymer (E)
- FEP = fluorinated ethylene propylene
- FPM = fluorine rubber (Viton) (E)
- HDPE = high-density polyethylene
- IIR = isobutene isoprene (butyl) rubber (E)
- IR = polyisoprene (E)
- PA = polyamide
- PAEK = polyaryl etherketone
- PB = polybutylene
- PC = polycarbonate
- PCTFE = polychlorotrifluoroethylene (Halar)
- PE = polyethylene
- PEX = cross linked polyethylene
- PF = phenol-formaldehyde
- PFA = perflouralkoxy
- PP = polypropylene
- PPS = polyphenylene sulfide
- PTFE = polytetrafluoroethylene (Teflon)
- PEEK = polyether etherketone
- PFA = perfluoroalkoxy
- PS = polysulfone
- PVC = polyvinyl chloride
- PVDC = polyvinylidene chloride
- PVDF = polyvinylidene fluoride
- SBR = styrene butadiene (E)

Plastic materials used for piping are divided into two basic groups, thermoplastic and thermosetting. Thermoplastics soften upon the application of heat and rearden upon cooling. This permits pipe to be extruded or molded into shapes. The most common piping materials are thermoplastic. Thermosetting plastics form permanent shapes only when cured by the application of heat or the use of a curing chemical. Once shaped, they cannot be reformed.

There are subclassifications of pipe based on the material used for the pipe itself. The two most common are polyolefins and fluoroplastics. Polyolefins, which are plastics formed by the polymerization of certain straight chain hydrocarbons, include ethylene, propylene, and butylene. Piping includes PP, PE, and PB. Fluoroplastics are polymers containing one or more atoms of fluorine. Piping includes PTFE, PVDF, CTFE, ETFE, PFA, and FEP.

PLASTIC PIPE STANDARDS AND NOMENCLATURE

A variety of standards and nomenclature is used to designate pressures and standard dimensions used for the procurement and identification of plastic pipe. Some are

used to match existing metallic pipe specifications and others are unique to the plastic pipe industry. The following is an explanation of the terms used in various standards:

SDR. The standard dimensional ratio is the most commonly accepted measure for providing a pipe wall thickness category and constant mechanical properties for many plastic pipe materials. Used for solid homogeneous pipe, the SDR is found by dividing the average outside diameter of a pipe by the wall thickness. This designation has resulted in a series of preferred industry standard numbers that are constant for all sizes of pipe. It is possible for a pipe to have different SDRs depending on whether the I.D. or O.D. is the controlling factor.

DR. The dimensional ratio is often incorrectly used interchangeably with SDR. The DR is found in the same manner as above and means the same thing, but is used when the product does not have the preferred SDR number established by other prevailing standards. Pipe manufactured to pressure ratings for AWWA C-900 series standards uses this designation.

O.D. controlled. This designation is used when the outside diameter of the pipe is the controlling factor in the selection of the pipe.

I.D. controlled. This designation is used when the inside diameter of the pipe is the controlling factor in the selection of the pipe.

P.R. Pressure rated is used when the pressure rating is the controlling factor in the selection of the pipe rather than the dimensions of the pipe itself.

PS. Pipe stiffness is used only for sewer pipe. This designation is in PSI. The higher number has a thicker pipe wall.

Schedule. This designation is used to match the standard dimensions for metallic pipe sizes. The pressure rating of the pipe varies with pipe size. Some standards use iron pipe size (IPS) instead of schedule to keep the wall thickness consistent with iron pipe.

PSM. This is an arbitrary designation for products having certain dimensional characteristics unique to a very specific product.

The AWWA has several proprietary dimensional standards that are used to specify plastic pipe used only for pressurized potable and fire water main distribution and transmission systems. The composition of the plastic piping material is referenced to ASTM standards. Since plastic pipe connects to or replaces cast iron and ductile iron pipe, these standards are O.D. controlled for use with O-ring gasketed joints only and are dimensionally compatible with these joints. These standards are:

AWWA C-900 = 4 to 12 in PVC

AWWA C-901 = ½ to 3 in PE

AWWA C-902 = ½ to 3 in PB

AWWA C-903 = Deleted

AWWA C-904 = Fittings for C-900 pipe

AWWA C-905 = 14 to 36 in PVC

AWWA C-906 = Larger diameter PE pipe

Trade laws allow import of Canadian pipe materials into the United States. The Canadian Standards Association (CSA) has standards of their own, but many of

them have not been completely coordinated with the United States standards for similar products. At this time, using CSA standards as reference for plastic products is not recommended.

There are three designations used in plastic drainage pipe standards: DWV, sewer, and drain. All standards are O.D. controlled and are non-pressure-rated. The only differences between identical materials with different designations are dimensions. Different materials with the same designations have the same dimensions.

For the most part, the codes are very specific about acceptable materials for use in plumbing systems, such as potable water and drainage, where approval of the authorities is required. Regarding uses such as draining chemicals from laboratories or industrial work, the codes are vague. When the chemical waste will be treated inside the project boundary, usually the materials (and design) used for the waste system do not fall under the jurisdiction of the plumbing code. In these cases, the engineer has the most latitude in the selection of materials used for drainage piping.

ELEMENTS FOR SELECTION

Due to the differences in manufacture, grade, and chemical composition of the pipe, test data must be obtained from the local supplier or manufacturer. Properties of similar materials from different manufacturers are often not the same. Very often, a range of values for properties such as tensile strength, maximum operating temperature, and hardness is given.

Elevated Temperature Considerations

Service temperatures in plastic piping systems depend on the type of plastic used. A maximum service temperature is generally fixed for thermoplastics, and identifies the upper limit to which the pipe may be heated without damage. When heated above this temperature, the pipe will soften and deform. Upon cooling, it will harden to the deformed shape and dimensions.

Long-Term Hydrostatic Strength

The design pressure for plastic pipe is based on long-term hydrostatic strength, which is determined by finding the estimated circumferential stress that, when applied continuously, will produce failure of the pipe after 100,000 h at a specified temperature. In addition, a service factor is included in the design calculations. This factor takes into account certain variables together with a degree of safety appropriate to the installation. The service factor is usually selected by the design engineer, and referenced to a service design life of about 50 years. This design method does not include the fittings, joints, or cyclic effects such as water hammer.

Most pressure ratings for thermoplastic pipes are calculated assuming a water environment. As the temperature rises, the pipe becomes more ductile and loses strength, and therefore the rating of thermoplastic pipe must be decreased to allow for safe operation. These factors are different for each pipe material.

Fatigue Behavior

When surges and water hammer are likely to be encountered, additional allowance should be made or protective devices installed in the piping system to reduce the pressure.

Aging and Long-Term Degradation

Aging is the change in physical and chemical properties during storage or use, and is generally dependent on temperature. These changes can occur naturally through normal atmospheric or building temperature fluctuations, or can be developed artificially due to elevated temperatures of the fluid in the pipe. The origin of these changes within the pipe are in the molecular or crystallographic structure of the pipe. Plastics and elastomers experience chemical changes due to the influence of light, heat, oxygen, humidity, and radiation, all of which cause breaks in their molecular chains. One criterion for determining the onset of aging is the measurement of thermal stability (oxygen induction time) using differential scanning calorimetry.

Ultraviolet Radiation (UVR)

UVR is a known source of degradation to plastic pipe. The effects can be reduced by adding pigments or covering the installed pipe with a jacket.

Flammability

During fire conditions, the degradation of plastics is greatly accelerated. In the early stages of a fire, most plastics melt and lose their structural shape and strength. As heat is added at a rising rate, plastics undergo a series of typical changes, which include chemical decomposition often releasing toxic chemicals. This decomposition occurs at a lower temperature than ignition. By the time ignition occurs or is possible, a relatively long period of chemical emission has elapsed.

When thermoplastic pipe burns, it releases smoke and toxic gases, provides heat that increases the intensity of a fire, and may provide a path for flame to spread along its length. In addition, open holes may develop at wall or ceiling penetrations which could provide a route for the passage of gases between rooms.

All organic materials are flammable, but this is particularly true of polyolefins. It is well proven that many polymers are as a result of their chemical composition difficult to ignite. Polymers can also be made much more difficult to ignite by the addition of flame retardants.

Acoustic Transmission

Because of its light weight, thermoplastic piping does little to reduce airborne sound. An appropriate thickness of insulation must be used to reduce noise.

Thermal Expansion

The amount of movement resulting from thermal effects is relatively high, thus requiring special attention to installation. As a general rule, runs in excess of 20 ft should be checked for the necessity of expansion offsets.

Corrosion Resistance

Corrosion occurs in two ways, as chemical and stress corrosion. There are two general types of chemical attack on plastic piping. The first is called solavation, which is the solubility, or absorption, of chemicals into the piping material from the fluids inside the pipe. This causes swelling and softening. The second type of attack occurs where the polymer or base resin molecules are somehow changed by a chemical agent, and the original properties of the plastic pipe cannot be restored upon removal of that chemical. Stress (or strain) corrosion weakens the pipe due to constant and repetitive movement and/or pressure surges.

The chemical resistance of the various types of plastics varies greatly not only among different types of plastic, but among different grades of the same type of plastic. Achieving full resistance is a function of the resistance of the compound used to make the pipe and the processing of the plastic.

The factors that determine the suitability and service life of any specific plastic pipe are

1. The specific chemicals and their concentrations
2. The jointing method
3. Dimensions of the pipe and fittings
4. Pressure inside the pipe
5. Ambient temperature and temperature of the fluid
6. Period of contact
7. Stress concentrations in the pipe and fittings

Abrasion

If a material such as sand, gravel, or slurry is transported in the piping system, or frequent cleaning with mechanical equipment is anticipated, resistance to abrasion should be investigated. Mechanical cleaning equipment manufacturers have data available from tests on various piping materials. Pipe manufacturers are also a source of information regarding various effluents. Additives can be used to increase the abrasion resistance of any pipe.

Biological Resistance

Very few types of plastic pipe can be degraded and/or deteriorated by the action of micro- or macroorganisms. For the most part, plastic pipe shows negligible or no susceptibility to bacterial attack. Refer to manufacturers for specific data.

Electrical Properties

Because plastic pipe is nonconductive, electrostatic charging of a pipeline is possible if dry, electrically nonconductive material is transported. All pipe materials with a specific resistance of 106 ohms per centimeter (Ω/cm) are considered nonconductive. Plastic pipe is generally not recommended to carry ignitable mixtures or electrically nonconductive dry substances due to potential electrostatic charging and possible damage to the dry material inside the pipe.

Static electrical charges can be prevented by providing the pipe with a conductive coating of metallic powder or lagging the pipe with metallic foil that has been grounded.

Permeability

Permeation is a process where fluids pass either into or out of a piping system through the walls of a pipe. Permeation can occur through the walls of a susceptible plastic pipe, through gaskets or other jointing material, and through defects or inappropriately or incorrectly sealed pipe.

Organic matter that migrates from soil through the plastic pipe is called permeate, and the process is called permeation. Until additional scientific work is completed on permeation through plastic pipe, it is not recommended that plastic pipe be used to carry potable water in areas of contaminated soil.

Leaching

Leaching is a process where substances sometimes called extractables are released from the walls of the pipe material into the fluid, but not through the pipe walls. The most common extractables are inorganic chemicals and volatile organic compounds (VOCs).

Tests have shown that the rate of leaching from plastics in contact with high purity water usually decreases with time. The time it takes for any specific plastic to reach a steady state after being subject to immersion in the fluid (elution) in dynamic systems is a function of the water temperature and velocity. Experience has shown that leach-out in the first five days is considered a burn-out period. The release of VOCs from various plastic pipes in contact with high purity water at 74°F is shown in Fig. 2.1. Figure 2.2 shows calculated lengths of thermoplastics that will increase total organic compound (TOC) level of high purity water by 1 ppt when used as a transfer medium (assuming 4-in pipe and a water velocity of 6 ft/s).

Creep

When a load is continuously applied on a plastic material, it creates an instantaneous initial deformation that further increases at a decreasing rate. This further deformation is called creep. If the load is removed at any time, there is partial immediate recovery followed by a gradual creep recovery. If, however, the plastic is deformed (strained) to a given value that is maintained, the initial load (stress) created by the deformation slowly decreases at a decreasing rate. This is known as the stress relaxation response. The ratio of the actual values of stress to strain for

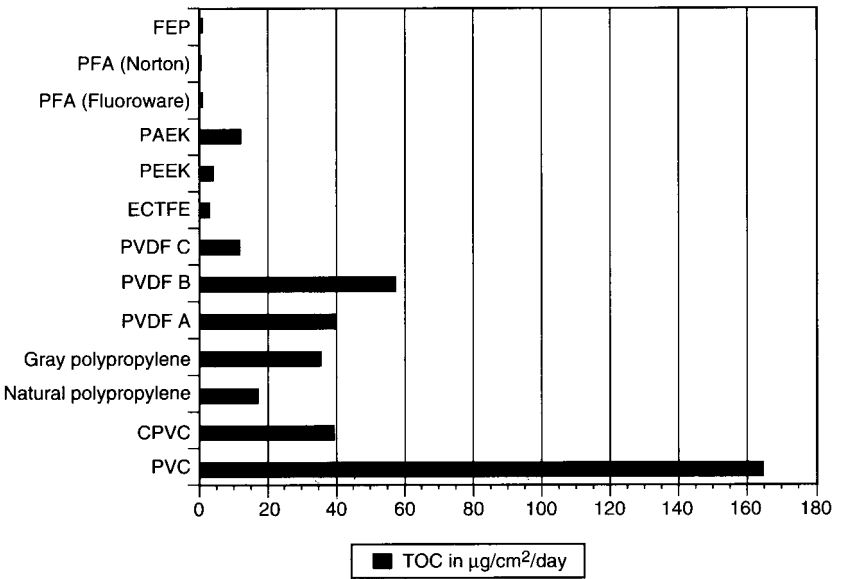


FIGURE 2.1 Release of VOCs from plastic pipe.

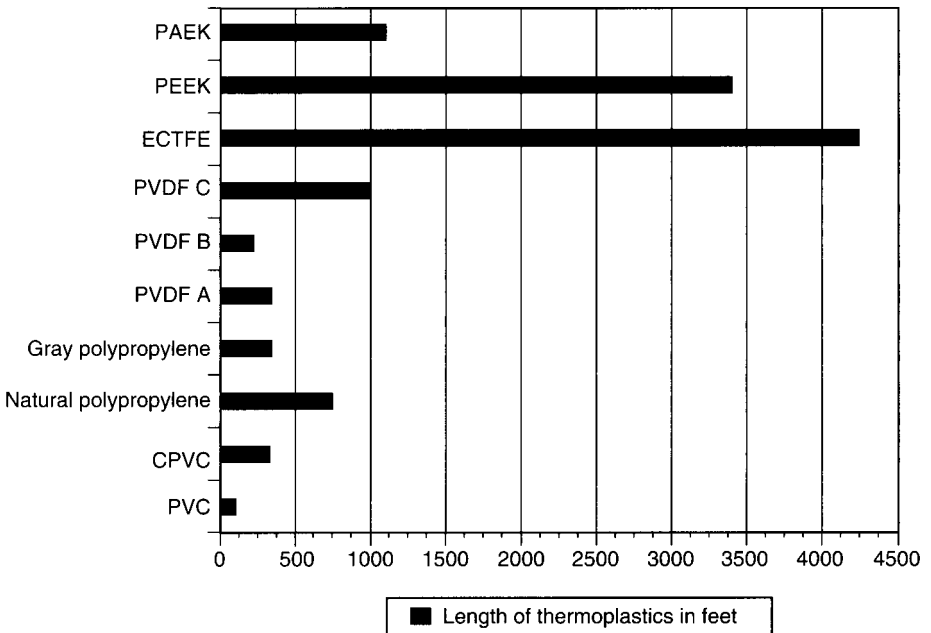


FIGURE 2.2 Leaching from 4-in plastic piping.

a specific time under continuous stressing or straining is commonly referred to as the effective creep modulus, or the effective stress-relaxation modulus. This modulus is significantly influenced by time. Most pipe manufacturers are willing to provide values of effective moduli for specific materials and loading conditions. Experience has shown that all plastic pipe will creep.

The properties of plastic pipe are influenced by time of loading, temperature, and environment. Therefore, standard data sheet values for mechanical properties may not be satisfactory for design purposes. The stress-strain responses of plastic reflect its viscoelastic nature. The viscous, or fluidlike, component tends to dampen or slow down the response between stress and strain.

PLASTIC PIPE MATERIALS

Polyvinyl Chloride (PVC)

PVC is the strongest and the most widely used plastic pipe. It has very poor resistance to solvents. It is used for both pressure and nonpressure applications and is approved by the NSF for potable water systems. Principal uses are for potable water, other fluids, and all types of drainage applications within chemical and temperature limits. A generally accepted upper service temperature limit is 150°F.

Pipe is made only from compounds containing no plasticizers and a minimum amount of other materials. Piping is referred to as rigid in the United States and unplasticized in Europe. Neither designation is required today if ASTM classifications are used. Pipe is available in schedule 40 and 80 and in diameters up to 20 in (500 mm). Fittings for water piping are available in diameters up to 6 in (150 mm). Drainage fittings are made in diameters up to 8 in (200 mm). Schedule 80 pipe can be joined by threading, solvent cement, or elastomeric seals. Schedule 40 pipe cannot be threaded. Underground water-main pipe generally uses push-on gaskets for jointing. PVC pipe is self-extinguishing and will not burn. However, when subject to conditions of a fire, a toxic gas is emitted.

Pipe used for exterior water mains may be required to have special approval if used to supply fire protection water.

PVC pipe should conform to the following ASTM standards:

1. D-2241, D-1785, and D-272: interior water pipe pressure. Fittings shall conform to D-2665.
2. Pipe used for exterior water mains shall conform to AWWA standards.
3. D-2665, D-3034, F-679, and F-769: drainage pipe and fittings.
4. CS 272: PVC plastic DWV pipe and fittings.

Chlorinated Polyvinyl Chloride (CPVC)

CPVC is a chemical modification of PVC, with an extra chlorine atom in its structure that extends its service temperature limitations to about 200°F, 50°F more than PVC pipe. Available sizes and other properties are very similar.

CPVC pipe should conform to the following ASTM standards: ASTM D-2846, F-441, and F-442 for piping and F-437, F-438, and F-439 for fittings.

Polypropylene (PP)

PP is a polyolefin available in two types, type 1, homopolymer, and type 2, copolymer. It has superior resistance to sulfur-bearing compounds and is capable of withstanding a wide range of both corrosive and sanitary effluents. It is the most resistant to organic solvents of all the common plastic pipe materials, and is only slightly less rigid than PVC. Its principal use is for laboratory drainage purposes. It is superior to PE at higher temperatures. When manufactured with no pigment, it is widely used for pure water system distribution.

PP is available in schedule 40 and 80 and in diameters up to 12 in (300 mm). Joining methods include solvent-welded socket joints, heat-fused socket-welded joints, heat-fused butt-welded joints, threaded joints, or proprietary mechanically threaded joints. Only schedule 80 can be threaded.

PP pipe does not have any ASTM standards for dimensions or wall thickness of pipe or fittings. Each manufacturer provides exact dimensions. Some joints refer to D2657 for heat-fused socket joints and ASTM 2.1 for threaded joints.

Polyethylene (PE)

PE is probably the best known polyolefin. It is widely used because of its superior toughness, ductility, flexibility, and ability to dampen water shock. The upper service temperature limit is around 140°F. It is used for underground fuel gas distribution piping and site irrigation systems and it has NSF approval for potable water piping. It is also used for all types of gravity and pressure drainage applications within chemical and temperature limits where flexibility is an advantage, particularly in foundation drains. It has the least mechanical strength of all the common plastic pipe materials, and is only moderately resistant to solvents.

There are four types of PE manufactured, rated by the density of the natural resin used, types 1, 2, 3, and 4. Types 3 and 4 have the highest density and have been given the abbreviation HDPE. The most commonly used pipe is composed of types 3 and 4. It is available in schedule 80 in diameters up to 6 in (150 mm). It is joined by socket and butt heat-fusion and insert fittings for water irrigation systems.

PE pipe should conform to the following ASTM standards:

1. D-2513: underground fuel gas pipe, D-2683 and D-2513: fittings
2. D-2239, D-2447, and CS-255: pressurized water piping
3. D-2609: fittings
4. D-3350: PE pipe material

Acrylonitrile Butadiene Styrene (ABS)

ABS is used for interior and exterior sanitary and industrial drainage and vent systems and pressurized liquid lines such as those used for salt water, irrigation, crude oil, and pumped waste. NSF has approved this material for potable water systems. It is slightly more rigid than PVC and is the least resistant to solvents of all the popular plastic materials. The generally accepted upper service temperature limit is 175°F. ABS is available in schedule 40 and 80, and in diameters up to 12

in (300 mm). Drainage fittings are available only in diameters up to 6 in (150 mm). Joints are made by solvent cement, threaded, or compression joints. Only schedule 80 can be threaded.

ABS pipe should conform to the following ASTM standards:

1. D-2751 and F-628: sewer pipe and fittings
2. D-2661 and D-275 1: pressurized water pipe
3. ASTM D-2661: fittings

Polybutylene (PB)

PB is a polyolefin having slightly less stiffness than regular PE, but with a higher strength than HDPE. It has good abrasion resistance, is resistant to creep, and retains its strength at elevated temperatures. This material is resistant to soaps, most acids and bases, and polar solvents at lower temperatures. It is attacked by some aromatic hydrocarbons and chlorinated solvents. PB pipe is used mainly for water and, to a lesser degree, for pressurized liquids, gases, slurry lines, and chemical waste lines. Its maximum temperature is around 200°F

Pressure piping is available in coils in sizes up to 2 in (50 mm) or in straight lengths in sizes up to 18 in (450 mm). Joining methods include butt and socket heat-fusion, insert fittings with hose clamps, flared joints, and compression fittings with sleeve inserts.

PB pipe should conform to the following ASTM standards:

1. D-2666: coiled tubing, F-845: fittings
2. D-2662 and D-3000: pipe and fittings
3. F-809: large diameter pipe and fittings

Fluoroplastics

Fluoroplastics are a broad class of thermoplastics that have some or all of their hydrogen replaced by fluorine. Their useful temperature range is from -100 to 300°F.

Polytetrafluoroethylene (PTFE) piping is a fully fluorinated fluorocarbon polymer. This family of piping material is known as "Teflon," and includes PFA and FEP. It is resistant to fats and oils, fuels, aromatic compounds, amines, ketones, and esters. It is attacked by sodium, potassium, and fluorine gas. It is used for standard and high purity pressurized water distribution systems, drainage systems for many chemical effluents, and liquid chemical systems. Joining methods include butt and socket heat fusion and threaded and triclamp fittings for ultrapure water systems. The piping is pressure rated and manufactured in sizes up to 4 in, and tubing up to 1 in. The initial cost of this class of pipe is among the highest of all the plastic pipe materials.

Polyvinylidene fluoride (PVDF) piping is a thermoplastic partially fluorinated fluorocarbon polymer that is resistant to most inorganic acids and bases, aliphatic and aromatic hydrocarbons, halogens (except fluorine), alcohol, and halogenated solvents. It is attacked by alkalis, ketones, and some amines. The PVDF family of piping includes ETFE, CTFE, ECTFE, and Kynar. It is manufactured in several grades for specific uses. It is used for standard and high-purity pressurized water

distribution systems, drainage systems for many chemical effluents, and liquid chemical systems. Joining methods include butt and socket heat fusion and threaded and triclamp fittings for ultrapure water systems. The piping is pressure rated and manufactured in sizes up to 10 in. The initial cost of this pipe is among the highest of all the plastic pipe materials.

Fluoroplastic pipe does not have any dimensional standards except those established by individual manufacturers. The piping shall be composed of materials and tested by the manufacturer as specified by the ASTM. The pressure rating is referenced to the schedule rating. Heat-fused socket joints shall be referenced to ASTM D-2657.

Reinforced Thermosetting Resin Pipe (RTHP)

RTHP is a class of composite pipe that consists of a reinforcement either imbedded in, or surrounded by, cured thermosetting resin. The most common reinforcement is fiberglass. This type of pipe is known as fiberglass reinforced pipe (FRP). Reinforcement can be composed of any mineral fiber. RTHP is also available in a variety of resins, liners, and wall construction. It has a high strength-to-weight ratio. The generally accepted maximum temperature rating is 250°F.

Pipe is available in sizes from 1 to 48 in and is used for pressure and gravity drainage purposes. Because of its construction, the piping is capable of withstanding much higher temperatures than most plastic pipe, and is much stronger both physically and mechanically while being resistant to a wide variety of chemicals. Joints are bell and spigot secured with adhesive, threaded and secured with adhesive, butt and wrapped, and mechanical joints. Adhesives selected depend on the specific service intended and type of pipe.

The resin is the binder that holds the composite structure together. It supplies the source of temperature and chemical resistance. There are four resin types: epoxy, polyester, vinyl ester, and furans. Furans are difficult to work with and are rarely used. Epoxy and vinyl ester are the most widely used. Epoxy resin is stronger than vinyl ester. The curing agent (or catalyst) also has an effect on the chemical resistance of the pipe. Aromatic amine-cured epoxy has better chemical resistance than polyamide-cured epoxy.

The various combinations of materials are resistant to a great variety of chemicals and suitable for many services. Consult manufacturers' information to select the appropriate pipe material combination.

RTHP pipe should conform to the following ASTM standards:

1. D-3262: sewer pipe, D-3840 and D-4160: fittings
2. D-3754 and D-3517: pressure pipe
3. D-2996: filament wound pipe
4. D-299: centrifugally cast pipe

OTHER PIPING MATERIALS

ASBESTOS CEMENT PIPE (ACP)

Asbestos cement pipe is manufactured by mixing portland cement (with or without silica) and asbestos fiber. This pipe is widely used for pressurized systems such as potable water mains and noncorrosive, nonpressurized sewer systems. Piping is available in sizes ranging from 4 to 42 in (100 to 1000 mm), and in pressure ratings ranging from nonpressure (gravity) pipe to 100-, 150-, and 200-psi pressure-rated pipe and fittings. Gravity pipe is made in five strength classes, each denoting the three edge-bearing strengths regardless of size. These strength classes are 1500, 2400, 3300, 4000, and 5000 lb per linear foot.

Joints are made using compression gasket joints or asbestos-cement/rubber-gasket joints.

Asbestos cement pipe shall conform to the following standards:

1. AWWA C-400, 401, 402, and 403: pressure pipe
2. ASTM C-428: gravity pipe

GLASS (GL)

Glass pipe is made from a low expansion borosilicate glass with a low alkali content. It is used for laboratory gravity waste service and is available in sizes up to 6 in. The pipe is joined by an elastomeric compression gasket secured by a sleeve. Glass pipe conforms to the following standards: ASTM C 599 and Federal Specification DD-G-541B.

This pipe is primarily used for drainage of various corrosive liquids. It is considered very brittle, and should be used where it has some measure of protection, such as in pipe spaces or behind laboratory furniture.

VITRIFIED CLAY (VC)

Vitrified clay pipe is made from selected clay and shale mixed together with water, formed into pipe, and fired (baked) at 2000°F. At this temperature the material fuses together (vitrifies) to form a homogeneous mass.

VC pipe is suitable for gravity underground service only. Sizes range from 3 to 54 in. The pipe is made in two grades—standard and extra strength. It is available only in bell and spigot ends, with compression gaskets used for joint assembly. A new development is a pipe with the joints flush with the pipe exterior, thus gaining superior strength to resist jacking and external damage as the pipe is pushed through the soil. This pipe has not yet received approval from all authorities and its use has been limited.

Vitrified clay pipe shall conform to the following standards:

1. ASTM C 4
2. ASTM C 700
3. ASTM C 1208: Vitrified clay pipe and joints for use in jacking, sliplining, and tunnels

Its primary advantage is the ability to accept a broad range of effluent with a diverse chemical and acid content, especially where the generation of hydrogen sulfide gas could result in the formation of sulfuric acid in the piping system. It has excellent resistance to scour and corrosion from soil. The disadvantages are that the pipe is very brittle and has a high initial cost due to the intensive labor involved in the installation.

CONCRETE PIPE

Concrete pipe is manufactured from either nonreinforced or reinforced concrete. Concrete pipe is suitable for underground (clear water) gravity drainage systems and pressurized water service, typically for nonpotable cooling or process water from surface sources. Sizes for concrete pipe range from 4 to 36 in. Reinforced concrete pipe is available in 12- to 144-in sizes. Concrete pipe is manufactured in two strengths, standard and extra strength. Reinforced pipe is manufactured in five pressure ratings, classes I-V, increasing in strength from low to high. Concrete pipe is not manufactured to nationally accepted dimensional standards. Refer to individual manufacturers.

Joints are tongue and groove or bell and spigot. Tongue and groove joints are sealed with rubber gaskets and are generally used for gravity systems. Bell and spigot joints use compression gaskets and are generally used for pressurized systems. There is no standard for fitting dimensions. When dimensions are required, they must be obtained from the proposed manufacturer.

Concrete pipe shall conform to the following standards:

1. ASTM C 76: Reinforced Concrete Culvert, Storm Drain and Sewer Pipe
2. ASTM C 14: Concrete Culvert, Storm Drain and Sewer Pipe
3. ASTM C 443: Joints for Circular Concrete Sewer and Culvert Pipe Using Rubber Gaskets
4. ASTM C 361: Reinforced Concrete Low Head Concrete Pressure Pipe
5. AWWA C 301: Prestressed Concrete Cylinder Pipe and Fittings

FITTINGS

Fittings are used to connect pipes to one another and to change the direction of straight runs of pipe. An alternative to fittings is bending the pipe to allow changes in direction.

CODE CONSIDERATIONS

Codes require that any change in direction of plumbing piping in a drainage system be made with fittings. The fittings shall have long radius bends so as not to allow solids any place to accumulate and to provide good hydraulic flow characteristics. These are known as drainage pattern fittings, and they are required to be used for drainage systems. Threaded drainage fittings shall be of the recessed type. Drainage pattern fittings are not required to be used for vent piping. Pressure systems can use any fitting type.

FITTING TYPES

A small number of fittings used either singly or in combination with one another are the most commonly used.

1. Bends or sweeps are used to change the direction of a pipe. These fittings come in various angles. A $\frac{1}{4}$ bend is a 90° fitting, and comes either as a short or long sweep (or radius). A $\frac{1}{8}$ bend is a 45° angle and a $\frac{1}{16}$ bend is a 22.5° angle.
2. The wye is used to connect a branch pipe into a straight run of piping at a 45° angle. These fittings are available with either all similar sizes or various combinations of pipe sizes in any connection.
3. The tee fitting is used to connect a branch pipe into a straight run of piping at a right angle, where the flow characteristic of liquid is not a factor. These fittings are available with either all similar sizes or various combinations of pipe sizes in any combination.
4. The elbow is a 90° change of direction with a very short radius. They are available with either all similar sizes or combinations of pipe sizes.

Refer to Fig. 2.3 for an illustration of these four basic types of fittings. In addition to those discussed here, there is a large variety of special combination drainage fittings manufactured for use either where space considerations are of primary importance or where combination fittings will result in considerable savings in time and labor.

FITTING MATERIALS

Cast Iron

Fittings of this material can be used with CI or steel pipe. They are available with screwed, hub and spigot, no hub, or flanged ends. These fittings should conform to the following standards:

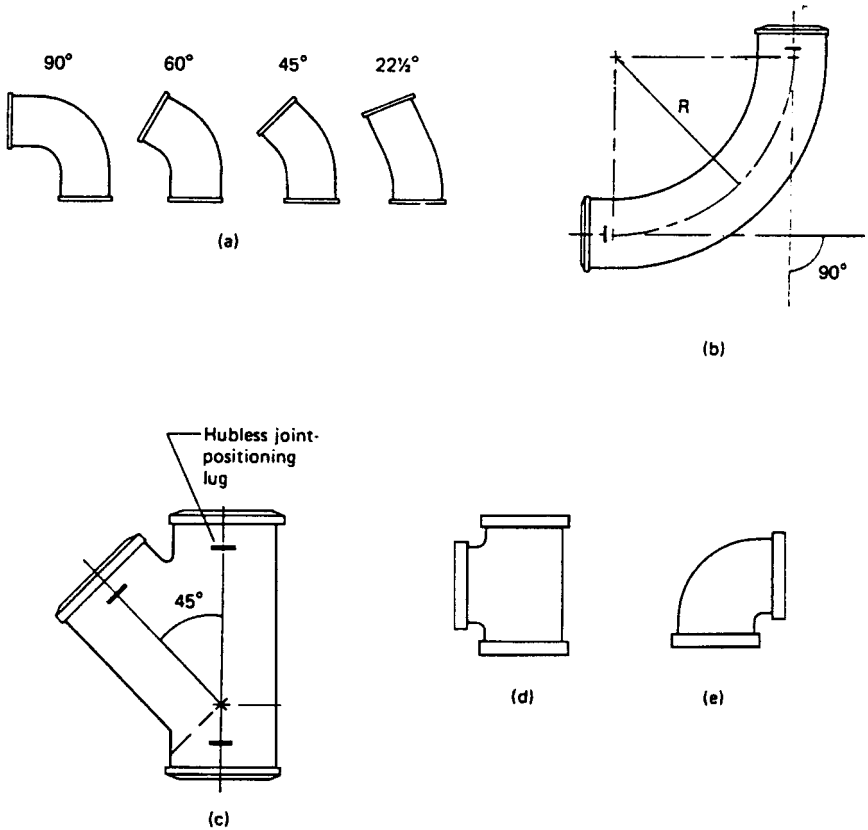


FIGURE 2.3 Typical fitting shapes. (a) 90°, 60°, 45°, and 22½° bends; (b) 90° sweep; (c) 45° sanitary wye; (d) standard tee; (e) elbow.

1. ANSI B 16.12: cast iron drainage fittings, threaded
2. ASTM A 74: cast-iron drainage fittings, hub and spigot
3. CISPI 310: cast-iron soil pipe and fittings, hubless

Malleable Iron

Fittings of this material can be used with ST or CI pipe. They are available with screwed ends. These fittings should conform to ANSI B 16.3: Malleable Iron Screwed Fittings.

Cast Copper Alloy

Fittings of this material can be used with any copper or brass pipe. They are available with solder ends only. These fittings should conform to the following standards:

1. ANSI B 16.18: Cast Copper Solder Joint Pressure Fittings
2. ANSI B 16.23: Solder Joint Drainage Fittings
3. ANSI B 16.26: Cast Copper Alloy Flared Fittings

Wrought Copper and Copper Alloy

Fittings of this material can be used with any copper or brass pipe. They are available with solder ends only. These fittings should conform to the following standards:

1. ANSI B 16.22: Wrought Copper and Copper Alloy Solder Joint Pressure Fittings
2. ANSI B 16.29: Solder Joint DWV Drainage Fittings

Acid-Resistant CI

Acid-resistant fittings are of the same material as the pipe and conform to the same standards.

Glass

Glass fittings are of the same material as the pipe and conform to the same standards.

Stainless Steel

Stainless steel fittings are of the same material as the pipe and conform to the same standards.

Bronze

Cast bronze fittings shall conform to ANSI/ASME B 16.15 and are available in class 150 and class 250 threaded ends. Flanges conforming to ANSI B 16.24 are available in sizes 2½ in (65 mm) and larger.

Dielectric

Dielectric fittings are actually adapters used to connect any pipe containing copper with any pipe containing iron to prevent the galvanic action between these dissimilar metals from causing corrosion failure. The fitting itself is constructed so that insulation prevents either connecting pipe from coming into direct contact with the other.

Plastic Fittings

Plastic fittings can only be used with the individual plastic pipe materials from which they are made. Nationally recognized standards are not available for many

plastic fitting materials and should be obtained from individual manufacturers. Those that are available shall conform to the following standards:

1. ASTM D-2665: PVC Fittings
2. ASTM D-2852: Styrene Fittings
3. ASTM D-2661: ABS Fittings
4. ASTM D-2609: PE Fittings

Unions

Unions are fittings used when it is necessary to easily separate piping, usually for the purpose of removing a piece of equipment (such as a pump) without having to take apart a joint. A union is a screwed fitting. These fittings should conform to the following standards:

1. ANSI B 16.39: Unions, Steel or Malleable Iron
2. ANSI B 16.41: Unions, Brass or Bronze

JOINTS

A joint is required each time it is necessary for piping to be connected either to itself, a fitting, or a piece of equipment. It must be able to withstand the greatest possible pressure exerted upon it by either the design or test pressure of the individual system. Piping systems use both pressure and nonpressure piping. The same joints may be utilized for similar piping on any system.

Most plumbing codes refer to recognized standards that govern the methods and materials used to fabricate each type of joint. The selection of the jointing methods will be determined by the type of pipe used, the type of fittings available for the pipe, the highest pressure expected in the system, and the possible need for disassembly.

METALLIC PIPE JOINTS

Caulked

The caulked joint is used only for piping with hub and spigot ends. After the spigot end is placed inside the hub, a rope of oakum or hemp is packed into the annular space around the spigot end, until it reaches 1 in from the top. (For AR pipe, the packing is hydrous magnesium aluminum silicate reinforced with fiberglass.) Then, a 1-in thickness of molten lead is poured into the annular space on top of the rope. The lead is then pounded further into the joint by a caulking iron until it is at a level $\frac{1}{8}$ in below the rim of the hub. In use, the hemp or oakum swells when it absorbs water and further increases the joint's ability to resist leaking.

There are no widely recognized standards that govern the fabrication of caulked joints. Requirements controlling installation are often provided in plumbing codes.

This rigid, nonpressure joint is suitable for all above-ground and underground drainage installations. Because they are very labor intensive, gasketed and coupling joints have replaced caulked joints for most CI joint applications. Refer to Fig. 2.4 for an illustration of a caulked joint.

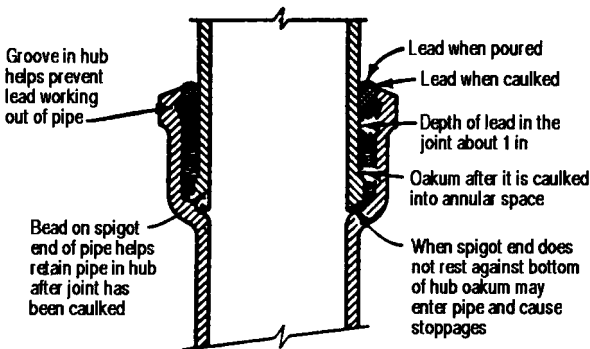


FIGURE 2.4 Caulked joint.

Compression Couplings

Often referred to as a sealing sleeve, this joint is used to connect hubless CI, AR, and GL piping. The same sleeve assembly is used for CI pipe with either plain ends (cut) or factory ends. A separate assembly is required for the two different end types of GL pipe.

Compression couplings depend on the friction between the sleeve and the pipe exterior for sealing and resistance to being pulled apart. The coupling assembly consists of an inner elastomeric gasket and an outer metallic sleeve with an integral bolt used for tightening. The two ends of the pipe to be joined are butted together, the entire sleeve assembly is placed over both ends, and the bolt is securely tightened according to the torque requirements established by the manufacturer.

Standards governing the fabrication of this joint are: ASTM C 564 and CISPI 310 for cast iron pipe.

The compression coupling is a rigid, nonpressure joint preferred for above-ground installations because of its ease of assembly and strength. Underground, the metallic sleeve often fails after years of service due to corrosion of the bolts by surrounding soil or fill. Dresser couplings are accepted for use in pressurized fuel gas systems.

Refer to Fig. 2.5 for an illustration of a compression coupling.

Screwed

A screwed joint can be used for any plain end pipe that has the necessary wall strength to have threads cut into it. A screwed joint requires that threads be cut on the outside of a pipe (male threads) and the inside of a fitting (female threads). The threads used for pipes are known as American Tapered Pipe Threads (APT), and may be referred to as internal (APTI) or external (APTE). The joint is assembled by placing the male thread inside the female thread and turning the fitting or pipe until the joint is tight. The male thread is sealed prior to assembly by pipe joint compound or Teflon tape in order to prevent water from seeping past the threads. It is important to clear the pipe of any burrs or chips resulting from the cutting process.

The standard governing the fabrication of this joint for service and utility systems is ANSI B 2.1: American Standard Tapered Pipe Threads.

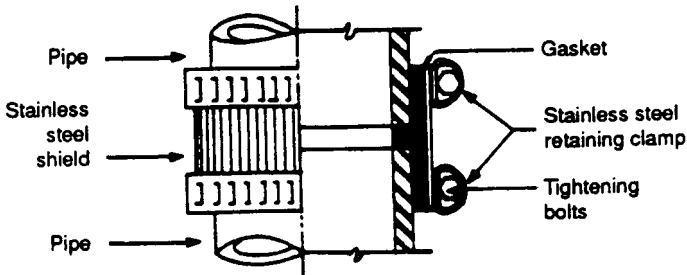


FIGURE 2.5 Compression coupling joint.

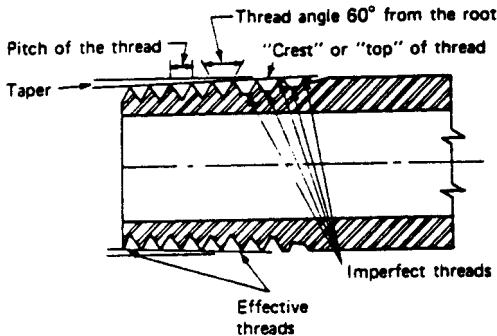


FIGURE 2.6 Tapered thread screwed joint.

This type of joint is inexpensive and easy to fabricate. It is generally restricted to piping 3 in or smaller, because of the great effort required to turn larger sized pipe when making up the joint.

Refer to Fig. 2.6 for an illustration of a tapered thread screwed joint.

Soldered

Also known as a "sweat joint," soldering is a process used to join metallic pipe below its melting point using an alloy that produces a metal solvent action between pipe and solder at a relatively low temperature.

Solder is an alloy that melts at a temperature of 840°F or less. Nonpotable water lines can use a solder of 50-50 tin-lead. The Safe Drinking Water Act banned the use of lead in solder and flux, requiring the use of lead-free solder. A commonly used lead-free filler alloy is tin and antimony (95% tin, 5% antimony) and other filler metals, often with proprietary alloys. Solder comes in the form of a flexible roll approximately $\frac{1}{8}$ in in diameter. The joint is fabricated by placing flux on the clean male pipe and inserting it fully into a clean socket end on a fitting. The assembly is heated enough to melt the solder. The solder is then applied completely around the perimeter. Capillary action draws the solder throughout the entire joint. When the solder cools, it adheres to the walls of both the pipe and fitting, creating a leakproof joint.

Flux is a material with a consistency of paste, spread over the entire pipe end and used to remove an oxide film and eliminate oxidation during the heat generated by the jointing process. It also aids in the drawing of solder into the joint by producing a "wetting" action.

Soldering shall conform to standard ASTM-B8Z8. Solder alloy shall conform to standard ASTM B 32. It is a rigid, pressure joint suitable for any type of installation for which the piping itself is acceptable. Refer to Fig. 2.7 for an illustration of a solder joint.

Brazed

Also known as a "silver solder," brazed joints are used to join plain end copper or copper alloy pipe with solder end fittings. They are also used to join aluminum

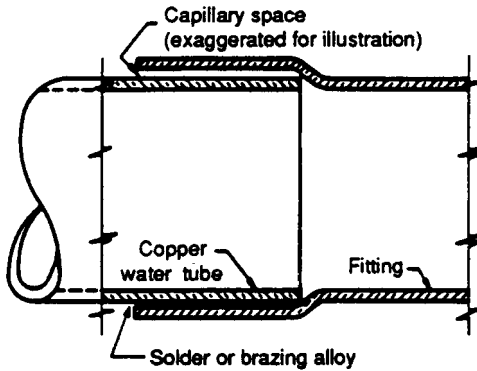


FIGURE 2.7 Soldered and brazed joint.

pipng with special filler metals. The brazed joint is far stronger than the soldered joint and produces joints in copper tube stronger than the pipe itself.

Similar to a solder joint, brazing alloy is available in a variety of compositions that melt at a temperature of 850°F or more. It is commonly used for medical and specialty gas applications and other systems that require a high working pressure when using copper tube or copper alloy piping.

Brazing alloys are available in two classes. Those containing 30 to 60% silver are in the BAG class, those with copper alloy and phosphorus fall in the BCuP class. Flux is also required for some alloy metals but not all. When joints are made up for medical gas and other pipelines that require a high degree of cleanliness, the use of flux is prohibited. This requires the use of appropriate BCuP alloys and wrought copper fittings containing phosphorus normally provided in the flux.

Brazing alloys shall conform to ANSI/AWS A 5.8. Refer to Fig. 2.7 for an illustration of a brazed joint.

Flared

The flared joint, illustrated in Fig. 2.8, is a rigid, pressure joint used only with soft (annealed) piping. It is made by first placing a loose, threaded coupling nut on one end of the pipe, then cold-forming that end with a mandrel that enlarges the pipe end to fit a mating end on a threaded coupling shank. The screwed coupling nut and shank are then turned in opposite directions drawing the pipe together to form a leakproof seal.

Compression Gasket

Sometimes erroneously referred to as a mechanical type of joint, compression gaskets are used to join CI soil pipe, DI and FRP sewer and pressure pipe, and VC pipe. Each pipe requires a specific type of end suitable for the individual joint type.

Although the shape of the gasket differs according to the application, the fabrication is the same. The gasket is a ring or sleeve of elastomeric material of the required shape to fit the bell end of the specific pipe. First, the gasket is inserted

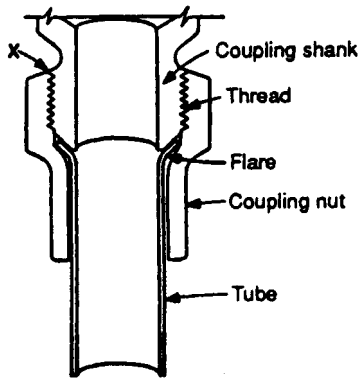


FIGURE 2.8 Flared joint.

into the bell end of the fitting. An approved lubricant is spread on the male pipe which is then inserted into the fitting by use of a mechanical assist. The barrel of the pipe compresses the gasket forming a leakproof joint.

Standards governing the fabrication of this joint are:

1. ASTM C 564: metallic pipe
2. ASTM D 3212: plastic pipe
3. CISPI HSN: gaskets for hubless cast iron soil pipe

This flexible joint allows some deflection of the pipe' during installation. For soil pipe, it is not considered a pressure fitting, but when used on DI pipe, it is acceptable for a pressurized system. It is well suited for both above-ground and underground installations, and has replaced caulked joints for underground piping because of its ease of fabrication and the inert nature of the gasket that prevents corrosive attack. Refer to Fig. 2.9 for an illustration of a gasketed joint.

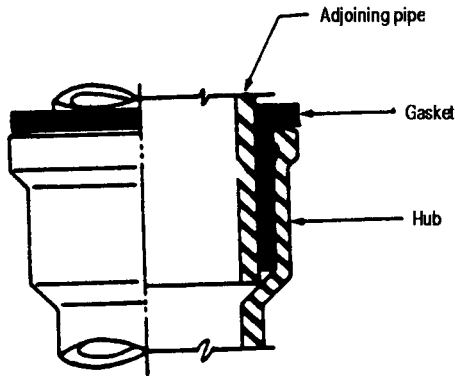


FIGURE 2.9 Compression gasket joint.

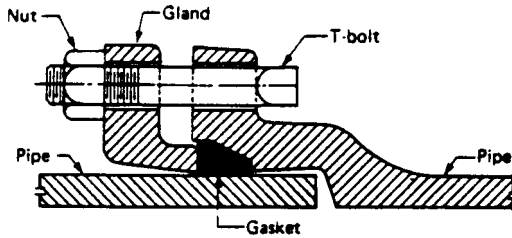


FIGURE 2.10 Typical mechanical joint.

Mechanical Joint

The mechanical joint is used for DI pressure or drainage pipe. There are many different kinds of joints. All mechanical joints, no matter what shape, are similar in principle. Refer to Fig. 2.10 for an illustration of a typical mechanical joint.

Grooved

There are two pipe-end preparations acceptable for a grooved joint: roll grooving (shoulder) and cut grooving. Roll grooves are used when the pipe is too thin to have a groove cut into it.

The coupling assembly consists of an inner elastomeric gasket and an outer split metallic sleeve with an integral bolt used for tightening. The outer sleeve has extensions at each end that fit into grooves cut or formed around the perimeter near the ends of the pipes to be joined. The two ends of the pipe are butted together. The coupling assembly is then placed over both the ends and the extensions are mated with the grooves in the pipe. The bolt is tightened to the torque requirements established by the manufacturer to form a watertight joint.

Standards governing the fabrication of this joint are:

1. AWWA C 606: couplings
2. ASTM D 735: gaskets
3. ASTM D 183: bolts

This rigid, pressure joint is well suited for both pressure and nonpressure lines. The cut grooving method is stronger but cannot be used on some pipe judged to have thin walls. Refer to Fig. 2.11 for an illustration of a grooved joint.

Wiped

The wiped joint is used only to connect lead pipe with itself or any other adapter for lead pipe used in drainage systems. The joint is assembled by first placing the ends of the lead pipe and other pipe together. Molten lead is then poured onto the joint and spread evenly, or wiped, around the pipe with a hand-held pad until the minimum thickness is reached. There shall be a minimum covered surface on each

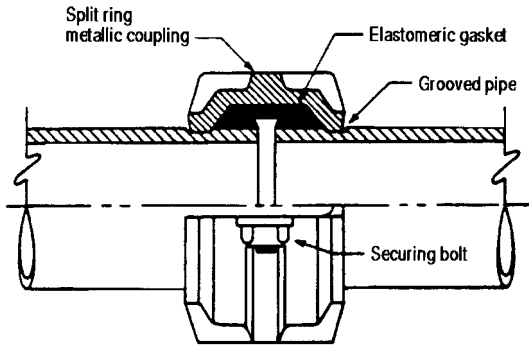


FIGURE 2.11 Grooved joint.

side of the joint of not less than $\frac{3}{4}$ in, and the added lead shall be a minimum of $\frac{3}{8}$ -in thick at the thickest part.

There are no recognized standards that govern the fabrication of the wiped joint. Requirements are usually provided in plumbing codes.

This is a rigid, nonpressure joint. Since lead pipe is rarely encountered in modern drainage systems, there are few experienced mechanics capable of making up this joint.

Burned

The burned joint is used only to connect lead pipe to itself. It is made by flaring one end of a pipe larger than the outside diameter of the other pipe to be joined. The two pipes are then brought together with the ends overlapping. Heat is applied evenly around the perimeter, melting the overlapping edges and fusing them together.

There are no recognized standards that govern the fabrication of the burned joint. This is a rigid, nonpressure joint. Since lead pipe is rarely encountered in modern drainage systems, there are few experienced mechanics capable of making up this joint.

WELDING

In the welding process, both pipe walls, at the joint, are brought to the melting point and fused together with the addition of filler metal to allow for correct wall thickness and strength. The necessary amount of heat for welding is produced by either a high temperature flame or an electric arc formed between the welding electrode and the pipe. Refer to Fig. 2.12 for illustrations of welded joints.

Because oxidation causes poor weld quality, an inert gas displacing the air, or a coated electrode that creates such a gas when heated, is used to keep air away from the molten metal. In order to properly weld pipe, the pipe ends must be specially prepared according to pipe thickness, composition, and welding method. The proper weld end preparation is critical to proper welding and must be diagrammed or described in the specifications.

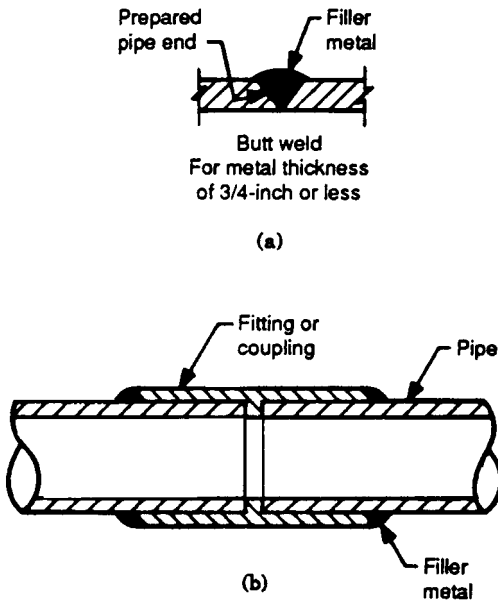


FIGURE 2.12 Typical welded joints. (a) Butt weld; (b) socket weld.

Types of Welding

Shielded Metal Arc Welding (SMAW). This is the standard electric arc welding. This process uses a coated rigid metal stick electrode of the proper composition. The stick electrode is an anode (+) and the pipe is the cathode (ground). The electrode is used to produce the arc and is also consumed as filler metal in the process of welding the joint. This electrode is coated with a substance that, when heated by the electric arc, creates a shielding gas and, in addition, makes a flux for a protective slag over the cooling weld metal of the joint. The coated electrode forms a flux on top of the weld that must be removed before the next pass can be made.

This process is widely used because it is the least expensive, requires the least clearance between obstructions, and is the easiest to manipulate the actual welding tool in the field.

Gas Metal Arc Welding (GMAW). This process, also known as metallic inert gas (MIG) welding, uses a metal electrode wire of the proper composition to produce the arc. The electrode wire also becomes the filler metal in the process of welding the joint. Inert gas, usually argon, is piped to the weld area from a remote tank and is delivered to the weld site through the electrode holder. This process is the next least expensive method and produces a better quality weld faster than SMAW.

Gas Tungsten Arc Welding (GTAW). Also known as tungsten inert gas (TIG) welding, the electrode is long-lasting tungsten which is not consumed during the welding process. The inert gas, usually argon, is piped to the weld area from a remote tank through the electrode holder. Filler metal is added to the joint either

automatically through the electrode holder or separately by hand. This process is the most costly and slowest method, but produces the finest weld quality of all. This is used most commonly as an automated shop-welding process.

Oxy-fuel Torch Welding. This process uses oxygen in combination with another fuel gas (usually acetylene, but propane, MAPP, and natural gas are also used) to produce the heat needed to melt the metal of the pipe and filler metal. The filler metal is added to the joint by hand. This process is mostly used for welding pipe in the field.

Orbital Welding. Orbital welding is a welding process used to join stainless steel tubing, mainly in the pharmaceutical and food-processing industries. It is a TIG process that uses a welding rig that automatically welds the pipe and produces welds with little or no obstruction to the pipe interior.

Welded Joint Types. There are two types of joints used for welding, butt joint and socket joint. Butt welding is the term used to describe two pipes placed end to end and joined with no overlapping. Socket welding describes one pipe being placed on top of the other when only one end of the exposed pipe is actually welded to the bottom pipe. This is like a coupling, but with the joint on the outside of the pipe. In general, only pipe 2 in or less (called small bore pipe) can be socket welded.

In butt welding, the pipe ends must be separated by a fixed distance. This can be done either with short pieces of wire or a ring called an insert placed between the two ends of the pipe before the weld is started. Because incorrectly placed wire may extend into the pipe after the weld is completed, the insert should be the only method specified for welding drainage pipe. This insert melts and becomes part of the joint, and so is called a consumable insert.

Since metal that is too thick does not make a proper weld, several thin welds on a single pipe may have to be made. Each weld is called a pass. Multiple passes are usually required.

Welded joints can be made in the shop or in the field. Shop welding is the least expensive and highest quality because there is more control over the entire welding process by the use of automated welding machines. As many pieces of pipe are assembled that can fit on a truck (usually about 40 ft long and about 16 ft wide) or that will fit into the building site. The whole assembled pipe is called a spool. Doing as much work in the shop as possible will limit the number of field welds.

In general, the following welding processes are recommended for the specific types of work: TIG welding, with a consumable insert for the first pass of shop-welded joints done by machine, because it gives the smoothest interior; MIG welding, to weld the rest of the joint when done in the shop by machine; electric arc welding, the most common method used in the field to join piping, with consumable inserts used when a smooth interior is desired.

Welder Qualification

Specifications for and approval of the entire welding process are necessary for both shop welding and field welding. It is also necessary to qualify welding personnel to ensure that they have sufficient training and knowledge to produce a weld of the required quality. Qualifications of welding personnel are difficult to assess. High-temperature, high-pressure pipe is covered by ASME codes that specify the selection of successive welding type passes, filler metal composition, joint preparation,

movement and handling of the pipe, tack welding and clamping, welding currents, metal deposit rates, and weld inspection. None of these code requirements apply to welded nonpressure drainage pipe. If the engineer does not have the knowledge to specify the minimum requirements for welders and the welding process, it could be left up to the contractor to determine the correct specifications for the project and recommend them to the engineer for approval. When this is done, the contractor establishes minimum criteria that will qualify any individual for welding on this particular project. It is now up to the contractor to test a welder's ability to make sound welds under the actual working conditions and using the same equipment expected to be used on the job and certify that person as being qualified. These criteria should be reviewed by the engineer for acceptability. It is common practice to use an outside, knowledgeable third party for this review process and to establish welding criteria.

Weld Testing

Defects in welded piping must be found and corrected. Defects occur because the weld does not actually create a monolithic piece of pipe. The flaws are cracks or voids in the joint. Nondestructive testing (NDT) methods are:

1. *Visual inspection of the weld.* This is the least expensive and the least informative. It is the most widely used, and coupled with hydrostatic tests of the completed system, will find most defects.
2. *Dye penetration.* This requires the use of two liquids. The first, which is a super-wetting agent, is applied to the weld, allowed to find its way into any defects, and then wiped off. The second fluid is a developer, which when applied, changes the color of the first liquid, creating a red mark where any defect occurs. This is used to check flaws that may not be visible to the eye.
3. *Magnetic testing.* First, an electrical current is passed through a pipe to induce a magnetic field in the pipe. Colored metal chips are then applied to a pipe joint. Since the magnetic field is strongest where the voids and defects occur, an accumulation of them indicates a flaw. Since stainless steel is nonmagnetic, this method is not used for lines made of this material.
4. *Ultrasonic testing.* This method uses an ultrasound generator and a screen to display reflected images from the weld. The most difficult part of this technique is to find well-trained and qualified operators. This is a costly procedure and not used for drainage lines.
5. *X-ray testing.* This technique uses an x-ray picture of the weld to disclose defects. This is the best of the various types but the most costly. Due to its cost, it is not used for drainage lines. This is the most commonly used when a record of the weld is required, but this is rarely required for drainage piping.

FLANGED

Sometimes referred to as a bolted joint, a flange is a perpendicular projection of a pipe. This projection is sufficiently long to allow holes drilled in the projection to secure to another mating surface. Often, a gasket is required to assure proper seating

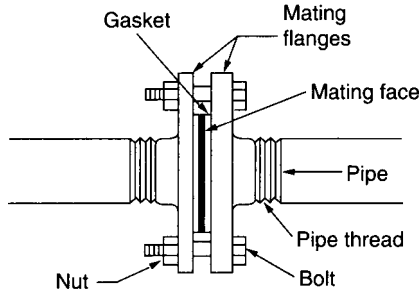
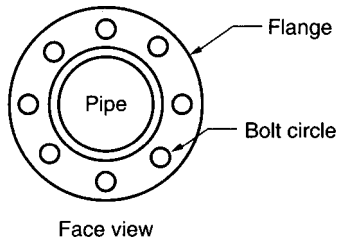


FIGURE 2.13 Flanged joint.

of the mating surfaces. Bolts through each projection secure the pipe ends together. A typical flanged joint is illustrated in Fig. 2.13.

Piping can be manufactured with flanges cast or forged to the pipe end or attached to the pipe in a separate operation. Attachment can be made by welding, threading, or brazing, depending on the pipe material. Flange dimensions shall comply with ANSI/ASME B 16.5.

Flanged joints are available in a large variety of mating surfaces (plain, serrated, grooved, seal welded, or ground and lapped for metal-to-metal contact) and in either flat-face or raised-face configurations. Gasket materials must be capable of resisting temperature, pressure, and fluid in the pipe. Bolting material is also available in various alloys and sizes.

HINGED CLAMP

The hinged clamp fitting is made by using pipe ends having small flanges that, when aligned, are secured with a hinged joint placed over both flanges and tightened to form a watertight joint. It is easily disassembled. A gasket can be used if desired for specific service requirements. This joint can be used for both pressure and nonpressure systems. There are several proprietary types of similar fittings using the same principle. A typical hinged clamp joint is illustrated in Fig. 2.14.

This type of fitting is generally used on stainless steel tubing in the food and pharmaceutical industries where a high degree of cleanliness is required; it conforms to Sanitary 3-A standards. This joint leaves no crud traps and permits piping to be easily disassembled for cleaning.

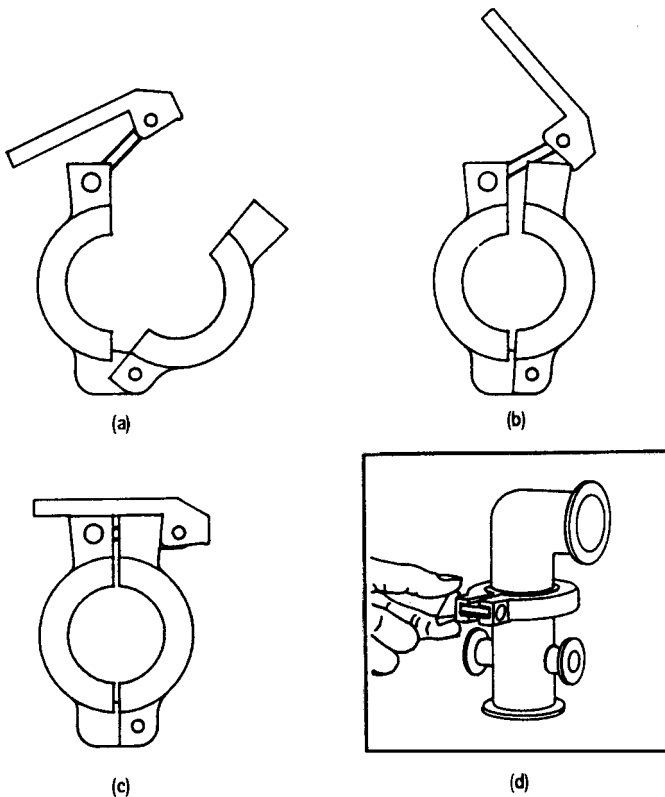


FIGURE 2.14 Hinged clamp joint. (a) Clamp open; (b) part closed; (c) closed; (d) completed joint.

Mechanically Pressed Joint

This is a proprietary joint called “Pressfit” and is used to connect schedule 5 or lighter carbon steel and stainless steel, plain end, small bore pipe, $\frac{1}{2}$ in (DN15) to 2 in (DN50) in size.

Pressed joints depend on the friction between the housing and the pipe, along with an indent to resist being pulled apart. The addition of a compressed O-ring seal provides a pressure seal. Refer to Fig. 2.14.1(a) for an illustration of a pressed joint.

There are no codes or standards governing the fabrication of this joint.

Compression Sleeve Coupling

The compression sleeve coupling is a rigid, pressure-type joint often used to connect plain end fuel gas, air, oil and water piping. This is a proprietary joint also known as “Dresser” couplings, after the manufacturer of the joint.

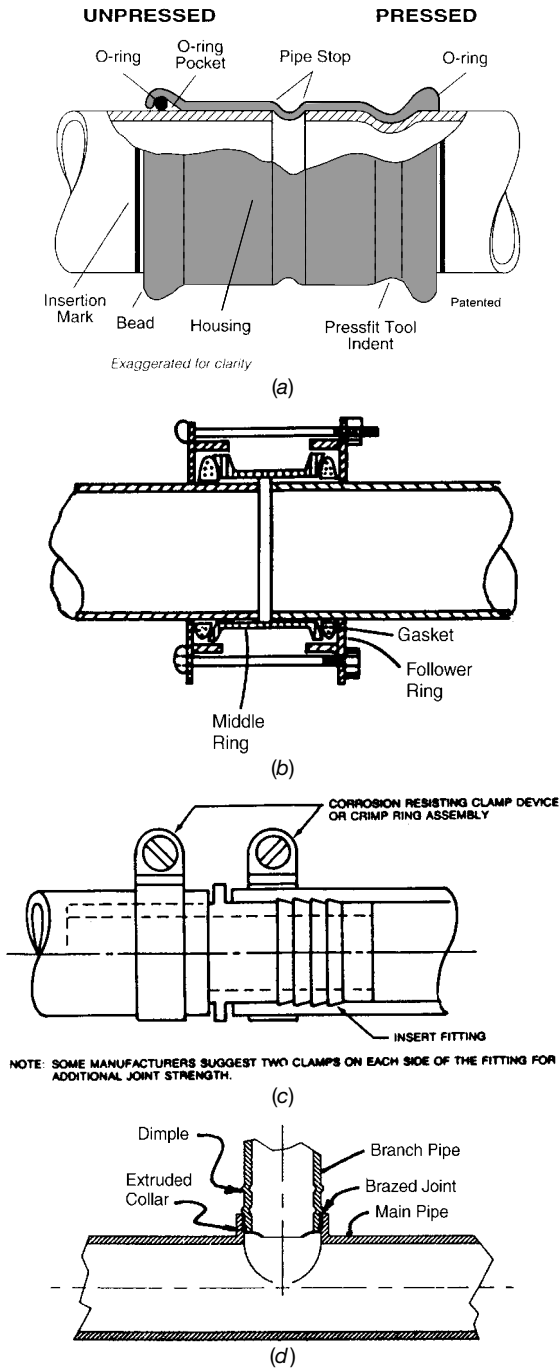


FIGURE 2.14.1 (a) mechanically pressed joint; (b) compression sleeve coupling; (c) plastic insert joint; (d) mechanically formed joint.

This coupling uses a metallic middle ring with a gasket placed at each end. The gaskets are compressed by means of a separate metallic gland placed over the gaskets and bolted to each other across the joint.

This is a proprietary joint that has no standards governing fabrication. Refer to Fig. 2.14.1(b) for an illustration of a compression sleeve coupling

Plastic Insert Joint

The plastic insert joint is a rigid, pressure-type joint used to connect plain end, flexible plastic tubing such as PEX for potable water service.

The joint is fabricated by placing an insert into both ends of the pipe to be connected, bringing the ends together and securing the insert to each pipe end by means of a clamping device or crimp assembly. For added strength, two clamping devices on each end are often used. Refer to Fig. 2.14.1(c) for an illustration of a plastic insert joint.

Mechanically Formed Fittings

The mechanically formed joint is a rigid, pressure-type joint commonly used to provide a branch connection in copper water piping. This joint shall only be brazed. This is a proprietary joint also known as “T-Drill”, after the manufacturer of the joint.

These joints are formed using a proprietary tool that first drills a pilot hole in the main pipe and upon withdrawal extrudes a collar. The branch pipe to be inserted shall be dimpled to form a depth stop preventing the branch from being inserted too far into the main pipe collar and restricting flow.

This is a proprietary joint that has no standards governing fabrication. Refer to Fig. 2.14.1(d) for an illustration of a mechanically formed joint.

ADAPTERS

Adapters are required when joining pipes with different dimensions or different joint types. Most plumbing codes require the use of approved adapters when joining two different pipe materials or piping with dissimilar joint ends.

JOINTS FOR PLASTIC PIPING

Plastic piping can be joined by a variety of methods. All of the joints except the solvent cement type are similar to those used for metallic pipes.

1. Solvent cement
2. Heat fusion
 - a. Buttjoints
 - b. Socket joints

3. Flanged
4. Insert-type mechanical fittings
5. Threaded
6. Threaded-type mechanical fittings
7. Grooved joints
8. Dresser type joints
9. Mechanical stab-type coupling
10. Elastomeric compression couplings
11. Adapter fittings from plastic pipe to other piping
12. FRP piping
 - a. Tapered adhesive joint
 - b. Butt and strap joint

Solvent Welding

Also known as solvent cementing, this process can be used only with specific types of plastic pipe and fittings with plain and socket ends. Specific solvents and cements can be used only with specific plastic pipe types.

The cement used to fabricate the joint reacts chemically with the pipe and fitting and dissolves the material it contacts. It is spread on the male section, which is then inserted in the female portion of the joint. The dissolved portions in contact with each other flow together and, when dry, are fused into a single mass, producing a leakproof joint.

There are different standards governing the solvent cement depending on the pipe used. They are:

1. No standard: PVDF
2. ASTM D 2235: ABS
3. No standard: PP
4. ASTM D 2855: PVC
5. ASTM D 2846 or ASTM F 493: CPVC

This process produces a rigid pressure joint that is suitable for any type of installation for which the piping itself is acceptable. Refer to Fig. 2.15 for an illustration of a solvent welded joint.

Heat Fusion

This joint can be used only with specific types of plain end thermoplastic plastic pipe and fittings manufactured for this purpose. The socket joint is fabricated by first placing a fitted wire with multiple loops around the outside of the plain end of the pipe. The wire will conduct electricity and has two leads, called pigtailed, about 2 ft long. The pipe and wire are then placed into the socket of a fitting. These leads are connected to a carefully controlled source of electricity provided by the pipe manufacturer for this purpose. When the electricity is turned on, the wires inside the joint are heated, causing those portions of the pipe and the fittings

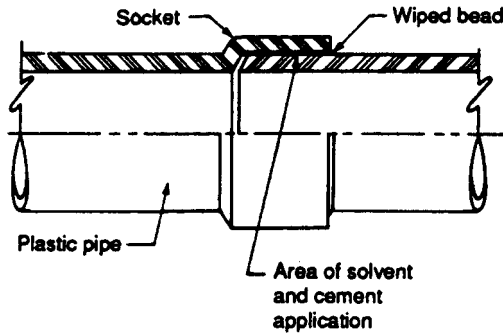


FIGURE 2.15 Solvent cement joint.

contacting each other to melt and fuse together. After the electricity is turned off, the plastic hardens, creating a watertight joint. The embedded wires become part of the joint. The leads are cut off to complete the process. The fused butt joint is made by separately heating the pipe ends to the melting point and then bringing them together. When the joint hardens a leakproof seal is formed.

There are no widely recognized standards that govern the fabrication of this joint. The manufacturer's instructions must be carefully followed.

This rigid pressure joint is suitable for all above-ground and underground installations. Refer to Fig. 2.16 for illustrations of heat-fused joints.

JOINTS FOR FRP PIPING

Tapered Adhesive Joint

This type of joint, illustrated in Fig. 2.17, is made by machine tapering the outside of the male pipe and inserting it into a matching bell-shaped female end. An adhesive spread on the male section secures the joint. A coupling with tapers at each side is used to join two lengths of tapered male pipe ends. A straight coupling (used with straight pipe ends) with no taper is also available.

Butt and Strap Joint

This type of joint, illustrated in Fig. 2.18, is made by squaring and deburring each end of the pipes to be joined. The ends are aligned and then the outside is wrapped with layers of glass mat and cloth saturated with resin. The width of the wrapping depends on the pressure rating of the pipe.

Elastomeric Compression Joint

The joint shall conform to ASTM D-3212.

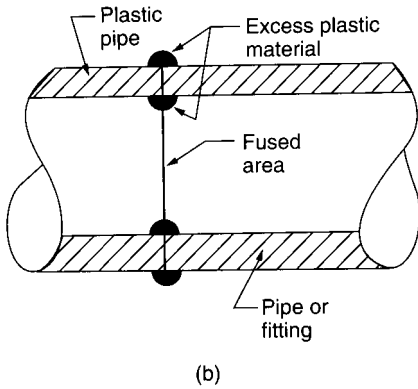
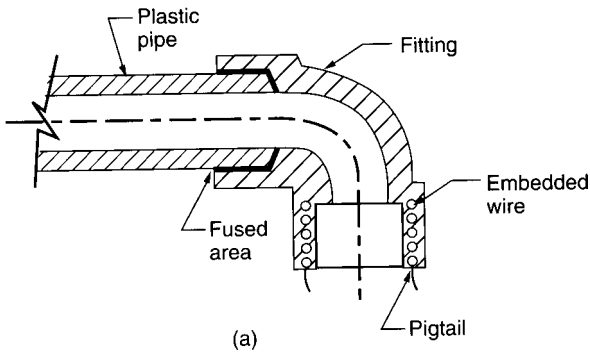


FIGURE 2.16 Heat-fused joints. (a) Socket-fused joint; (b) butt-fused joint.

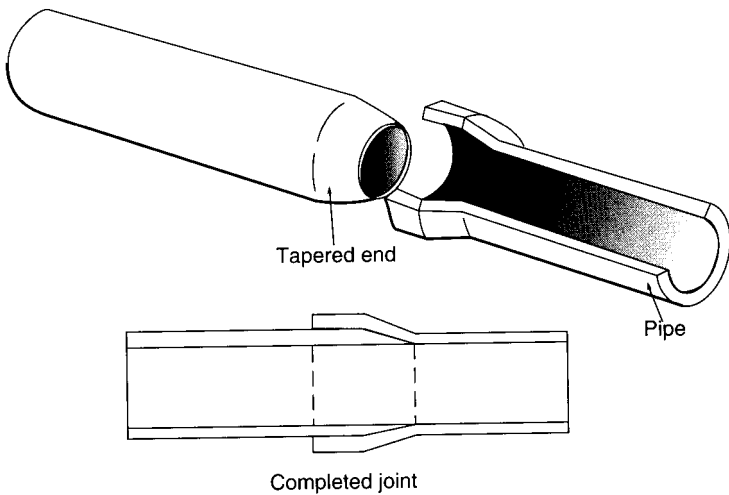


FIGURE 2.17 Tapered adhesive joint.

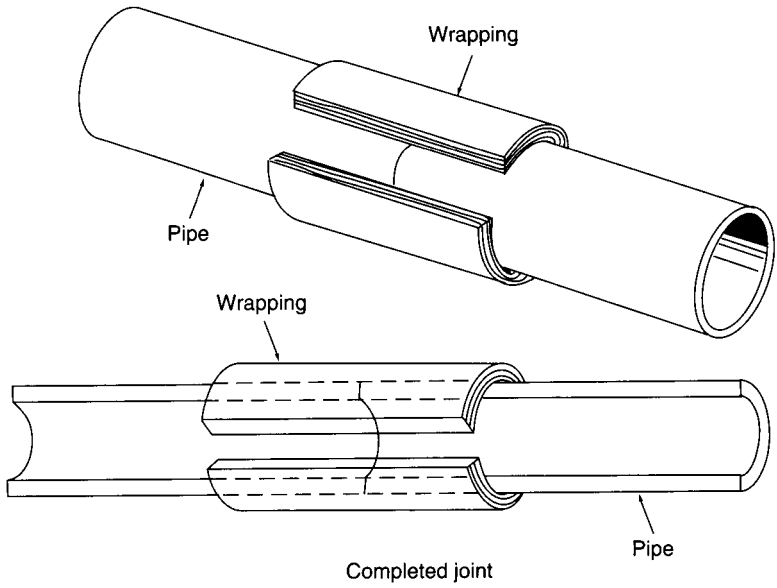


FIGURE 2.18 Butt and strap joint.

DOUBLE-WALL PIPING

Installing an outer pipe around an inner pipe has been found to prevent the release of hazardous liquids being transported in the inner pipe. This system as a whole is called a secondary contained piping system, or double-walled pipe. A major use for these systems is for transporting liquid fuel. The use of double-wall piping for this purpose appears in Chap. 12, Liquid Fuel Systems. There are no generally recognized codes for dimensions.

The interior pipe transporting the liquid is called the carrier or primary pipe. The outer pipe around the carrier pipe is called the containment pipe or secondary containment. A detail of a typical double-contained pipe is schematically illustrated in Fig. 2.19. The two pipes are kept apart by spacers, often called frogs or spiders by manufacturers. Figure 2.20 illustrates a cross section through the double-contained pipe.

Double-wall systems are manufactured from many different piping materials. There is no requirement for the primary and secondary pipe to be made of the same material except where a possible incompatibility may exist. Because the secondary containment pipe does not have to be in contact with the fluid, it is very cost-effective to have the secondary containment pipe made from a different, less costly material. This is possible because the selected outside pipe will not have to be in constant contact with the fluid and, therefore, may be acceptable for only limited contact at a lower temperature and pressure.

The major problem in the design of double-wall systems is thermal expansion and contraction of the primary and secondary pipes. If transporting hot liquids, the primary and secondary pipes will expand at different rates, even if they are made of the same materials, since the secondary pipe is at a lower temperature. Compensation methods for expansion and contraction include expansion loops between restraints with oversize containment, changes of direction with oversize containment

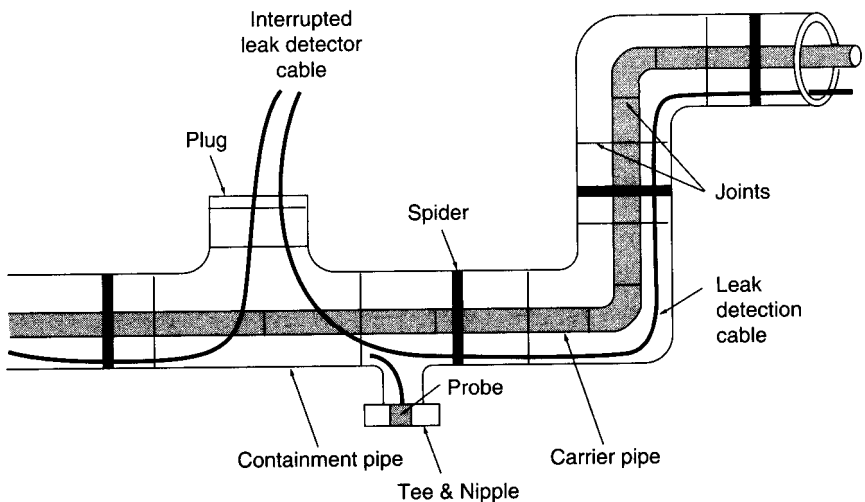


FIGURE 2.19 Typical double-contained piping.

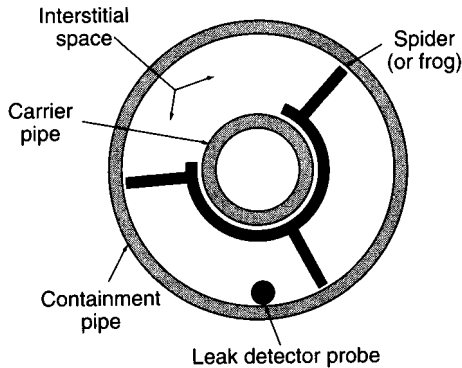


FIGURE 2.20 Section through double-contained pipe.

elbows, expansion offsets between restraints, expansion joints, and proprietary fittings to keep the containment pipe in alignment if the temperature difference is not too large. Since each manufacturer uses different materials and jointing methods, expansion compensation methods for each specific system must be obtained from specific manufacturers.

With the potential for polluting the environment if any product leaks from the piping system, a leak detection system is mandatory to detect leaks from the primary pipe. For facilities, the two methods used most often are (1) an electronic resistance or capacitance cable with sensing panel and (2) capped tees with a probe installed so that any product leaking into the containment will spill into the tees and be detected by an immersion probe. In the first method, a cable is installed throughout the pipe run and is located at the bottom of the pipe. If the cable cannot be correctly routed through changes of direction, it must be interrupted (illustrated in Fig. 2.19). The cable has the ability to detect moisture anywhere along its length and the sensing panel will indicate where the leak is located along the cable. In the second method, a probe in the tee is connected by cable to a panel that will show which tee probe detected the liquid. Experience has shown that the cable is difficult to install and is prone to false annunciation due to condensation in the pipe. Because of this, the second method (the probes installed in a tee) is preferred as of this writing. The tees are generally spaced from 20 to 50 ft apart depending on economics and, often, on distances established by client preference.

VALVES

GENERAL

Valve functions can be defined as ON/OFF service, throttling service (flow control), prevention of reverse flow (or back flow), pressure control, regulation and pressure relief. Valves can be classified as either linear (gate valve) or rotary (ball valve) based on the action of the closure member. They are also classified by the shape of their closure member such as gate, globe, butterfly, ball, plug, diaphragm, pinch, and check.

Their primary function, however, is to control the flow of liquids and gases, including plain water, corrosive fluids, steam, toxic gases, or any number of fluids with widely varying characteristics. Valves must also be able to withstand the pressure and temperature variations of the systems in which they are used. Some valves on combined water service mains, and those handling flammable material, may be required to be fire safe or approved for fire protection use.

Pressure regulating valves for water service are discussed in Chap. 9, Plumbing Systems, in the section entitled Water. Pressure regulating valves are discussed in their respective chapters. Pressure relief valves are outside the scope of this handbook.

CODES AND STANDARDS

The following standards apply to valve construction:

1. AWWA C 500: gate valves for water and sewage systems
2. AWWA C 504: rubber seated ball valves
3. MSS SP 67: butterfly valves
4. MSS SP 80: bronze gate, globe, angle, and check valves

VALVE COMPONENTS

The following are the primary components of a valve.

1. A valve body is the housing for all the internal working components of a valve and it contains the method of joining the valve to the piping system.
2. The closure element, known as the disk or plug, is a valve component that, when moved, opens or closes to allow the passage of fluid through the valve. The mating surface of the disk bears against the seat.
3. The actuator is a movable component that, when operated, causes the closure element to open or close.
4. The stem is a movable component that connects the actuator to the closure element.

5. The bonnet is a valve component that provides a leakproof closure for the body through which the stem passes and is sealed.
6. The seat is a component that provides a surface capable of sealing against the flow of fluids in a valve when contacted by a mating surface on the disk. The seat is attached to the valve body.
7. The stuffing box is the interior area of the valve between the stem and the bonnet that contains the packing.
8. Packing is the material that seals the stem from leaking to the outside of the valve. The packing is contained by the packing nut on the bonnet.
9. The backseat is a seat in the bonnet used in the fully open position to seal the valve stem against leakage into the packing. A bushing on the stem provides the mating surface. Backseating is useful if the packing begins to leak and it provides a means to prevent the stem from being ejected from the valve. Backseating is not provided on all valves.
10. The stroke of a closure member is the distance the member must travel from the fully opened to the fully closed position.

VALVE BODY MATERIALS

Valves are manufactured in both metallic and nonmetallic materials. Nonmetallic materials consist primarily of thermoplastics.

Metallic

Valve bodies are manufactured of the following materials:

1. Bronze valves are usually limited to the smaller sizes and are used in water service up to 450°F. Different alloys are available for higher temperature and pressure applications.
2. Cast iron is a commonly used material for water and steam up to 450°F and is generally limited to smaller size castings. High tensile strength iron may be used in large sizes.
3. Malleable iron is characterized by pressure tightness and resistance to stress and shock.
4. Ductile iron casting has high tensile strength, good ductility, and good corrosion resistance.
5. Steel is available in a wide variety of alloys that are recommended for high temperature and pressure applications and conditions that may be too severe for iron and bronze bodies.
6. Stainless steel is available in a wide variety of alloys and is often used for pure water and other services requiring noncorrosive materials.

Thermoplastics

Thermoplastics are rapidly gaining popularity in many utility systems. They have proven very successful for carrying corrosive fluids where conventional valves are

not suitable or special alloy metals are very costly. It is estimated that they are suitable for use in 85 to 90 percent of all utility services.

There are many different types of thermoplastic materials capable of carrying most chemicals. All standard valve types are available. The valve materials often have additives different from those used for manufacturing piping. Generally available valve types and their sizes are given in Table 2.6. In general, plastic valves are limited to a maximum temperature of 250°F and pressure of 150 psig (1035 kPa). General properties of plastic material used for valves are given in Table 2.7.

VALVE ACTUATORS

Valve Categories

There are three operating methods for valve actuators: multiturn (used for gate, globe, and diaphragm valves), quarter-turn (used for plug, ball, and butterfly valves), and linear (used for gate, diaphragm, and globe valves). The valves can either operate manually or be power actuated. There is no generally recognized code or standard for valve operators outside of those concerned with specific, high-risk industries, for example, nuclear work.

Manual Operation

Manually operated valves are usually used when the valve is easily accessible, does not require automatic operation or is operated infrequently. Multiturn valves use hand-wheels, gears, or levers. The most common is the handwheel. If the operating effort is too high for a handwheel, a gear box could be installed. A less common gear arrangement is the impact gearbox. This consists of a free-wheeling handwheel for part of its rotation that then imparts a hammer blow to the stem to break loose

TABLE 2.6 Thermoplastic Materials and Valve Types

Valve design	Materials	Size range, in
Ball (union design)	PVC, CPVC, PP, PVDF	1/4–4
Ball (compact design)	PVC, CPVC	1/2–3
Ball, multiport	PVC, CPVC, PP, PVDF	1/2–3
Diaphragm	PVC, CPVC, PP, PVDF	1/2–10
Butterfly	PVC, CPVC, PP, PVDF	1 1/2–24
Globe	PVC, CPVC, PP	1/2–4
Gate	PVC	1 1/2–14
Ball check	PVC, CPVC, PP, PVDF	1–4
Swing check	PVC, PP, PVDF	3/4–8
Labcock	PVC	1/4
Foot	PVC, CPVC, PVDF	1/2–4
Pressure relief	PVC, CPVC, PP	1/2–4
Solenoid	PVC, CPVC, PP	1/2–1

TABLE 2.7 General Properties of Thermoplastic Materials Used for Valves

Properties	Unit	PVC	CPVC	PP	PPG	PVDF
Specific gravity	—	1.43	1.45	0.92	1.03	1.76
Tensile strength	psi	7,000–7,800	8,500–9,200	4,300–5,000	9,950–11,000	7,000–7,800
Elongation	%	60–120	20–40	150–200	3–5	30–50
Tensile modulus	10 ³ psi	455–485	485–510	130–170	12,800–14,220	170–200
Flexural strength	psi	14,220–15,560	14,220–17,060	7,820–9,240		13,510–14,930
Flexural modulus	10 ³ psi	384–412	426–455	213–228	540–570	227–256
Compressive strength	psi	12,800–14,220	14,220–15,560	8,530–9,950		12,800–14,220
Compression modulus	10 ³ psi	242–256	256–284	120–156		14–199
Poisson's ratio	—	0.37	0.35	0.44		0.28
Hardness (Rockwell R)	degree	115	118	95	107	110
Impact strength (Izod) w/V-notch	kg-cm/cm ²	4–5	4–5	4–7	6–8	10–12
Resistance to heat (continuous)	°F	140	194	194	221	248
Deflection temperature (at 66 psi)	°F	165	250	230	302	302
Thermal conductivity	kcal/mh°C	0.13	0.12	0.08		0.11
Dielectric strength	kV/m	0.90	0.90	1.02	1.18	1.18
Volume resistivity	ohm-in	2.0×10 ¹⁵	2.3×10 ¹⁵	1.9×10 ¹⁵	0.4×10 ¹⁵	1.95×10 ¹⁵
Dielectric constant						
10 Hz		2.8–3.0				
60 Hz		3.15	2.93	2.42		9.8
103 Hz		3.14	2.92	2.41		9.5
106 Hz		2.85	2.69	2.41	2.2	7.5
Dissipation factor						
60 Hz	10 ⁻²	1.18	1.09			0.05
10 ³ Hz	10 ⁻²	1.91	1.10	0.044		0.048
10 ⁶ Hz	10 ⁻²	1.72	0.92	0.063	0.02	0.160
Water absorption 24 h, 1/8 in thickness	%	0.07	0.15	0.01	0.02	0.03

Note: For thermal expansion, see Table 2.15.

a stuck gate or globe valve. For the torque necessary to open a gate valve against an unbalanced force, refer to Fig. 2.21. This is generally referred to as "breakaway torque."

Quarter-turn and linear valves use a lever.

Power Actuators

Power actuators are used where valves are remotely located, frequent operation is required, or automatic operation is necessary due to system considerations.

Depending on the type of valve, the actuator will be required to deliver output for rotary or linear motion. This may be for ON/OFF (fully opened to fully closed) service, or stroke functions such as those required to keep a valve partially open, or a combination of both. The power source must be capable of exceeding the torque requirements needed by the actuator by an adequate safety factor. In the case of throttling, a detailed analysis may be required. The worst case is in providing the breakaway torque. Valve-operating torque is never constant, varying with closure member position. Typically, the peak torque is required at breakaway, reduces to about 30 percent of breakaway in the half-open position and increases to about 90 percent of breakaway at closure.

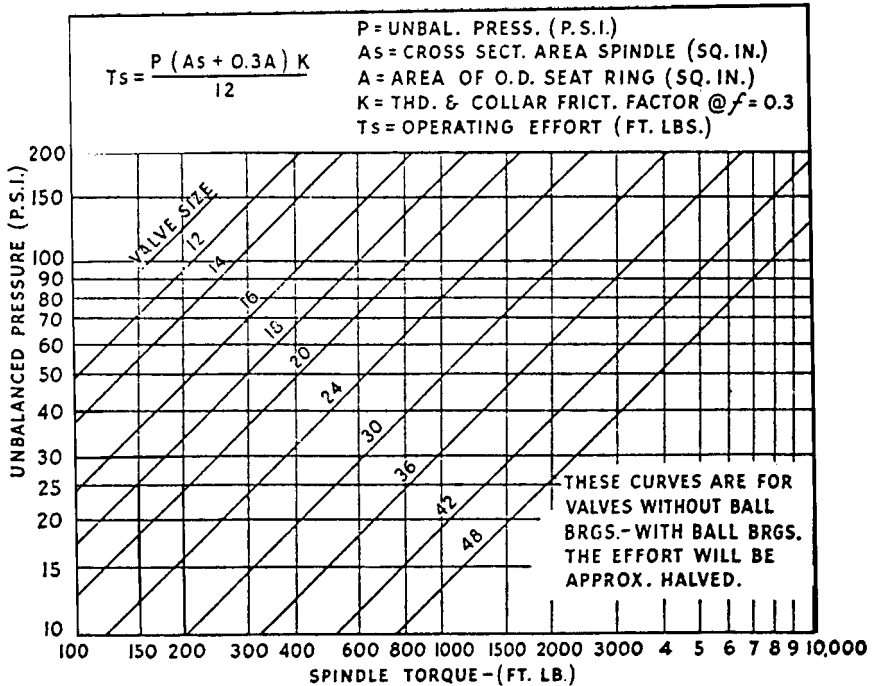


FIGURE 2.21 Force required to open a gate valve against unbalanced pressure. (Data compiled by The Chapman Valve Manufacturing Company.)

Actuators are classified by their source of power: electric, pneumatic, or hydraulic.

Electric Actuators. These are the most commonly used power source. They can be solenoid or motor operated. They usually have the least total installed cost because the source of electricity is generally available throughout a facility and the wiring and control instrumentation is relatively simple. Solenoid operation is generally limited to smaller lines, ON/OFF service, and systems in which the water hammer produced by quick closing can be easily attenuated because of the systems' low pressure and velocity requirements. Motor-operated actuators tend to be bulky and slow, particularly when large gear reduction is used to increase torque. Their advantage is that the torque output is constant throughout their stroke, and their response is linear. For critical systems, there must be an emergency power supply.

The speed at which a valve closure member is operated is important. The figure generally used for a gate valve closure member is 12 in (300 mm) per min and for a globe valve closure member, 4 in (100 mm) per min. Higher rates are available, but exceeding the maximum specified speed will damage the seat and disk. Gate and globe valves are torque-seating valves when closed. In the open direction, a limit switch is often provided to protect the seat against backseat overtightening. Quarter-turn valves are position-limited open and closed because seating is based on position, not force.

Electric motors do not stop instantaneously, but coast to a stop. The use of a solenoid brake to prevent the motor from overtightening the closure member should be ascertained from the manufacturer of the valve on which the actuator is installed.

Unless an emergency power source is available, electric motors should not be used where cycling to a fully opened or fully closed position is a requirement in the event of a power failure. Motor operators should be limited to moderate cycling functions. They are not recommended for service where severe cycling is necessary. Generally, 2-in (50-mm) valves do not have sufficient strength for a standard electric motor actuator. Electric motor actuators have been extensively tested in seismic and harsh ambient environments.

Pneumatic Actuators. Depending on the system selected, these air-driven devices generally operate in a range of between 30 and 120 psig (210 and 830 kPa), with 30 to 60 psig (210 to 415 kPa) being the most common. The compressed air supply should be a dedicated one, conforming to ISA requirements, and preferably supplied from a control air compressor assembly. An alternative, but less desirable means, would be to obtain the air supply from the facility system, using additional compressed air-conditioning filters, dryers, and PRVs as required.

Pneumatic actuators are well suited for frequent operation and fast response times. There are two types of actuators, piston and diaphragm. The piston actuator is generally used for ON/OFF operation. The piston stroke can be long, making it suitable for large valves. The diaphragm actuator is appropriate for modulating service but because the travel is short, the valve size on which it can be used is limited.

The fail-safe mode is usually accomplished by using either an internal spring or a secondary accumulator tank to provide the necessary power to cycle to an opened or closed position. The internal spring may cause the assembly to be flexible, which may be a problem for seismic installation. The accumulator tank is externally mounted, often on a nearby wall or column.

Pneumatic actuators are large in size and require frequent maintenance because of air leakage over time (particularly piston types) that also makes response time longer. There is a limitation on maximum valve differential pressure.

Hydraulic Actuators. These devices produce torque by using an electric pump to push fluid to a piston. They are capable of providing fast actuation and are suitable for modulating service. They allow operation on large valves with high pressure differentials and are appropriate for frequent cycling. They have no fail-safe mode unless emergency electrical power is available. The stroke is easily adjustable in service.

Typically, these actuators operate slowly. Their cost is between the electric and pneumatic systems.

OPERATING AND TORQUE CONSIDERATIONS

The following factors require consideration in the selection of an actuator:

1. *Valve type and size.* The valve-operating torque results from the inherent size and characteristics of the valve itself and the type of seat. The amount of torque necessary to overcome static imbalance must be obtained from the manufacturer.

2. *Pressure drop.* The operating torque increases with an increase in pressure drop across the valve. A valve operating at full-rated pressure will require significantly more operating torque than one operating at a low-pressure drop. Depending on the source of pressure, it is probable that the pressure differential will vary throughout the valve's entire stroke. This condition is important if the actuator torque output must be carefully matched with that of the valve.

3. *Service-operating conditions.* Will the valve be required to be only opened or closed or will it also be required for throttling flow? Actuators for ON/OFF service will be selected only on breakaway torque. For quarter-turn valves requiring throttling, calculating the torque is more complicated because additional torque is required to counterbalance the momentum of the flowing fluid. Unbalanced forces generate "hydrodynamic torque." The actuator torque output must be well above the operating torque to achieve smooth operation.

4. *Seat material.* Most valves have a metal closure member sealing on a soft seat made of elastomers. Metal-seated valves may require as much as 50 percent more seat material as needed for soft seat valves.

5. *Fluid being transported.* Since air and gas do not provide any lubrication, their operating torque requirements add to the frictional forces. Water and other media may provide excellent lubrication. Liquids carrying solids clog clearances between stem and bearings. The fluid may also corrode internal parts, so that in time the torque valve may rise considerably, up to twice that when new. An adequate safety factor should be considered to assure reliable and continued operation.

6. *Bidirectional seating.* If operating conditions require the reversal of flow, additional torque may be required for seating.

7. *Fire safety.* The valve may require secondary metal-to-metal seating if the primary seat is destroyed by fire. This will require more operating torque.

8. *Fail-safe operation.* With the automatic fail-safe operation, the energy necessary to close or open the valve requires a larger size actuator than one without a failsafe requirement.

9. *Temperature of fluid.* Torque requirements are lowest at room temperature. High temperature and cryogenic bearings require higher operating torque. Fluid temperatures above 300°F may require a special operating and mounting assembly, often a stem extension. Ambient temperatures must also be considered, for example, actuators located outdoors require special consideration.

10. *Cycling rate.* Pneumatic and hydraulic actuators cycling in excess of 30 cycles per h are considered to have high operating rates. The same is true for electric actuators cycling in excess of 10 percent of their duty cycle (operating for 1 cycle and resting for a time equivalent equal to 9 cycles). An extended duty motor should be obtained for this condition.

11. *Cycle speed.* Fast cycle speeds of less than one-half standard cycle times require special consideration. The sudden physical shock associated with fast operating speed combined with fast cycling rates can damage valve and actuator parts. Pneumatic actuators may need quick exhaust valves, special solenoids, and larger actuators. Higher speeds are accomplished using different gearing devices, which may increase torque output, or an electronic speed control, which will not affect torque output.

12. *Stem orientation.* Orientation of the valve stem in a position other than vertical will require mounting in a manner that may cause stem seal leakage or galling due to side thrusts induced by an overhung load on the actuator. The use of heavy-duty couplings and mounting brackets will minimize these problems.

FIRESAFE VALVES

By nature of their service, some valves require a firesafe designation. There is no single generally recognized definition of firesafe or a code that can be used to determine suitability or acceptance. A simplified definition is that a valve must not melt in a fire or leak after a fire and that the seat must close adequately.

The standard used most often for the CPI is the API 607 rating. For water fire-service lines, FM is the most conservative, although a listing with UL may be acceptable depending on the specific insurance carrier used. Specific companies often have ratings that must be used when projects are designed for them.

Firesafe valves require testing to meet minimum recommended performance standards when operating in a firesafe environment. These recommendations are:

1. *Minimum internal leakage.* A valve must offer acceptable seating prior to and after exposure to high temperatures without depending on supplementary pressure from spring-loaded or other devices and without depending on a critical seal.

2. *Minimal external leakage.* The valve body design should minimize external leakage by using fire-resistant stem seals and avoiding large gasketed body joints.

3. *Continued operability.* A valve must be operable despite fire damage. The body and actuator must resist warpage and damage from high temperatures.

VALVE RATINGS

There are a number of designations used to indicate the pressure ratings of valves. Valves are pressure rated by their ability to withstand pressure within a range of temperatures. Standard pressure ratings have been established to match ANSI ratings of flanges and fittings and are designated by class, conforming to ANSI B 16.34 ratings. Two types of designation are WSP and WOG. WSP, or working steam pressure, rates the ability to handle steam at the specified working pressure. WOG, or water, oil, and gas, rates the ability to handle cold water, oil, and gases at the assigned working pressure. When the two ratings are given, WSP is called the primary rating. When only one rating is given, the valve is not generally used for the service not mentioned. The rating 150 lb refers to the working pressure in psig for which the valve is rated. If a valve is primarily used for water service, a common designation is WWP, or water working pressure. This designation rates the ability to handle cold water. The valve class designates the working pressure of a valve. A class 300 rating indicates a valve with a working pressure of 300 psig.

Cold temperatures mean ambient temperatures from 32 to 90°F. For high temperatures, the valve pressure shall be derated. For high pressures, the temperature rating shall be derated. The temperature limitation on most metallic valves is generally based on the capabilities of the seat and interior trim materials.

PRESSURE LOSS THROUGH VALVES

In general, valves used for utility piping are rarely selected based on pressure drop through the valve but rather for their suitability in service. Calculations are not needed since established equivalent lengths of pipe for each type of valve are sufficiently accurate for determination of the approximate pressure drop through the valve. Refer to Fig. 9.1 to determine the equivalent length of pipe for common valves.

There may be occasions where precise determination of the pressure drop through any valve would be desired, such as in cases where pressure drop must be kept to a minimum or the exact determination of the pressure drop is necessary. This is done by using the standard measure of valve flow, the coefficient C_v . This coefficient is the flow in gallons per minute that will pass through a valve in the wide-open position with a pressure drop of 1 psi (6.9 kPa). This coefficient is determined by the valve manufacturer using actual flow tests. With the C_v known, the pressure differential can be found using the following formula:

$$\Delta P = \frac{S F^2}{C_v^2} \quad (2.1)$$

where ΔP = pressure difference, psig

S = specific gravity of fluid (the value for water is 1)

F = flow rate in gpm

C_v = valve flow coefficient (obtained from valve manufacturer)

The C_v is calculated by dividing the flow in GPM by the square root of the pressure difference across the valve.

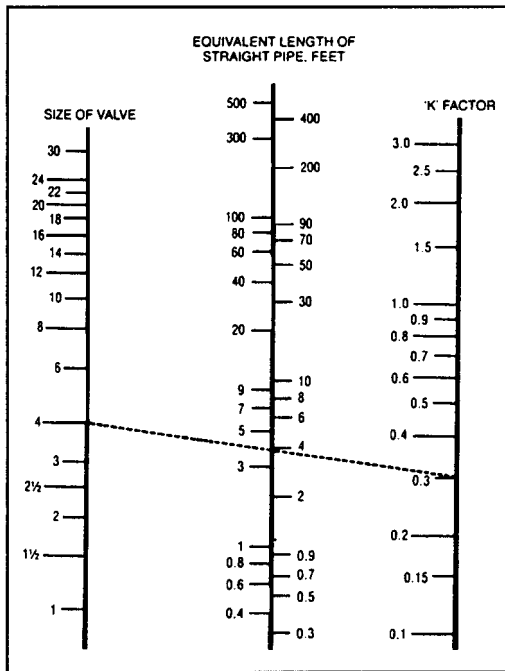


FIGURE 2.22 Equivalent run determination from K factor. (Courtesy Stockham.)

Another designation used by some manufacturers is the K factor, which will allow determination of the pressure drop through a valve in equivalent length of a straight run of pipe. The K factor is obtained from the valve manufacturer and is determined by actual tests. Figure 2.22 is a chart to determine the equivalent length from the K factor of a valve. For example, the dashed line shows the resistance of a 4-in valve to be equivalent to approximately 3.8 ft of 4-in standard steel pipe.

VALVE SELECTION CONSIDERATIONS

The following general items must be considered in selecting valves.

- 1. Temperature.** The valve bodies, trim, and operating parts must be capable of withstanding the highest temperature expected during sustained normal and transient operating conditions.
- 2. Pressure.** The valve must be rated for the highest transient pressure that might be expected.
- 3. Shutoff.** The degree of allowable shutoff must be known. For utility piping, some minor leakage should be allowed and would prove extremely costly to eliminate. Bubbletight valves are those that exhibit no visible leakage through the elastomeric seat of the valve for the duration of a test as defined by MSS SP 82.

4. *Valve operation.* It must be determined whether the valve be used only for ON/OFF use or for throttling.
5. *Pressure drop.* Allowable pressure drop must be established and the size (equal to or less than that figure) selected.
6. *Corrosion resistance.* This is affected by the nature, concentration, and temperature of the fluid.
7. *Velocity.* The velocity of the fluid through the valve must be considered.
8. *Firesafe.* It must be known if this is a requirement. (Refer to previous discussion.)
9. *Hazardous material.* When the fluid being transported is considered hazardous or lethal, valves must be specifically designed to handle these materials. Redundant stem packing and leak detection ports are typical design features. ANSI B 31.3, category M, defines this category of fluids.

GATE VALVES

Gate valves, illustrated in Fig. 2.23, use a wedge-shaped disk or gate as the closure member operating perpendicular to the flow; it is raised to open and lowered to close the valve. As the disk closes, it fits tightly against the seat surfaces in the valve body. A gate valve is used fully opened or closed only. It should not be used for throttling service (partly open), as the gate will vibrate and quickly become damaged and subject to wire drawing caused by the velocity of the liquid flowing past the disk.

Primary Gate Valve Components

There are four main features that dictate gate valve design: the disk, stem, bonnet/body connection, and body. The body materials and end connections have been previously discussed.

Often, iron body valves use a combination of materials to provide corrosion-resistant bearings for stems and other wear points such as seating surfaces. These valves are called iron body bronze mounted (IBBM).

Disk Design. There are three types of disk constructions: solid wedge, split wedge, and flexible wedge (illustrated in Fig. 2.24).

Solid Wedge. Solid wedge disks are most prevalent because of their simple and usually less expensive design.

Split Wedge. Split wedge disks, also called double disks, have somewhat better sealing characteristics than solid disks because the two disk halves are forced outward against the body seats by a spreader after the disk has been fully lowered into its seating position. When the valve is opened, pressure on the disk is relieved before it is raised, eliminating the friction and scoring of body seats and disk.

Flexible Wedge. Flexible wedge disks are solid only at the center and are flexible at the outer edge and seating surface. This design enables the disk face to overcome the tendency to stick in high-temperature service where wide swings in temperature occur. This type of disk is generally found only in steel valves.

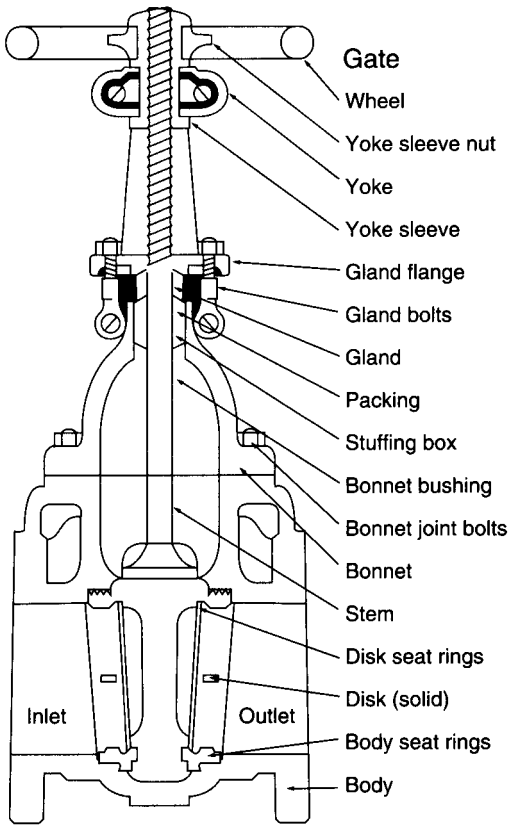


FIGURE 2.23 Gate valve. (Courtesy Stockham.)

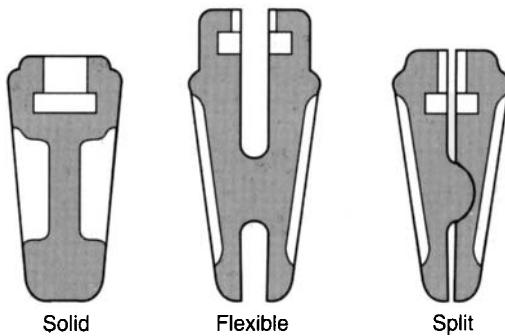


FIGURE 2.24 Gate valve disk construction.

Stem Construction. There are also five basic types of stem construction, shown in Fig. 2.25.

Rising Stem/Outside Screw and Rising Stem/Outside Screw and Yoke. These two types of stem construction keep stem threads outside the valve and are recommended where high temperatures, corrosives, and solids in the line might damage stem threads inside the valve. When the hand wheel (nonrising) is turned, the stem rises as the yoke bushing engages the stem threads. The external threads enable easy lubrication; however, care must be taken to protect the exposed stem threads from damage.

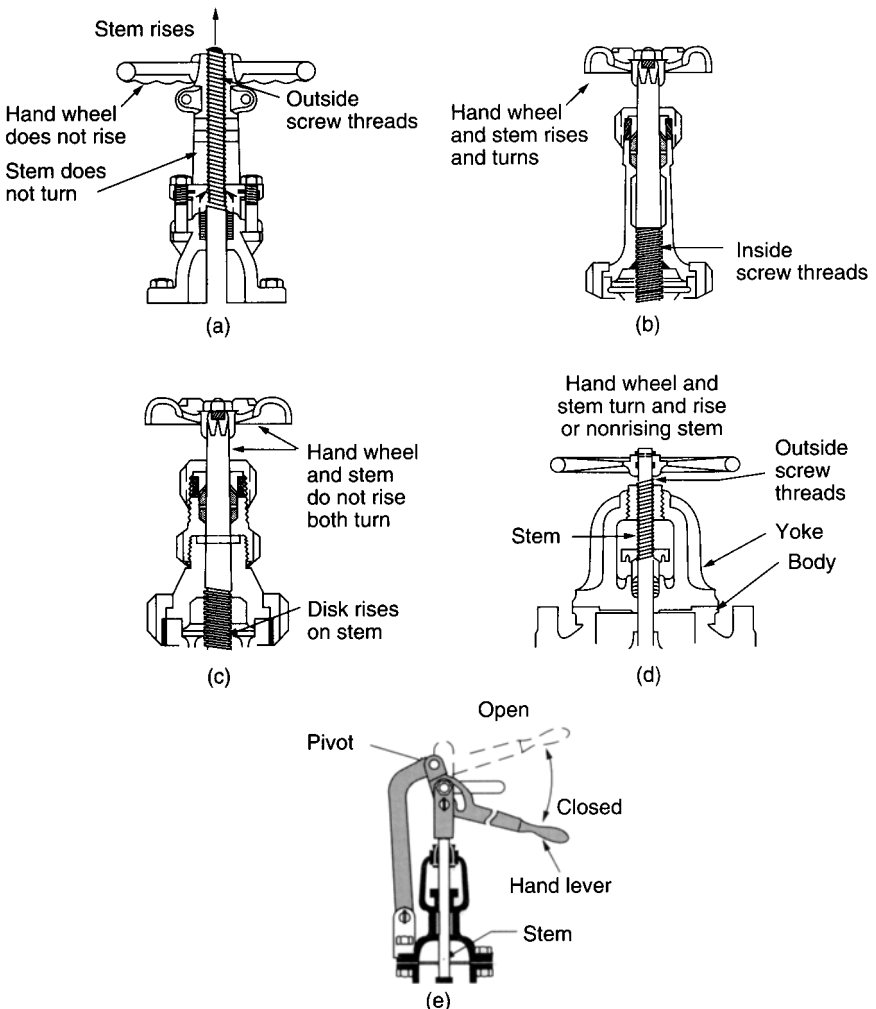


FIGURE 2.25 Basic stem construction. (a) Rising stem, outside screw; (b) rising stem, inside screw; (c) nonrising stem, inside screw; (d) rising stem, outside screw and yoke; (e) sliding stem.

Rising Stem/Inside Screw. Rising stem/inside screw is the most common stem design in bronze gate valves. Because the hand wheel and stem both rise, adequate clearance must be provided for operation. The stem and hand wheel positions indicate the position of the disk inside the valve. In the open position, the backseat helps protect the stem threads, but care must be taken to protect the stem externally.

Nonrising Stem/Inside Screw. Nonrising stem/inside screw design has the chief advantage of requiring minimum head room for operation. Since the stem does not travel vertically, packing wear is reduced. Heat, corrosion, erosion, and solids may damage the stem threads inside the valve and cause excessive wear. Also, it is impossible to determine the disk position since the hand wheel and stem do not rise.

Sliding Stem. The operation of the stem is linear, straight up and down. A lever takes the place of a hand wheel and there are no threads on the stem. Available on gate and globe valves, this type of stem is useful where quick closing or opening of a valve is desired.

Bonnet Construction. The basic types of bonnet construction include union, screwed, and welded designs (shown in Fig. 2.26). Union bonnets are preferred for rugged service. Screwed bonnets are the least expensive design and should be used for lower pressures only. Welded bonnet construction provides the most leak-free body-to-bonnet joint. The disadvantage of the welded bonnet is that it provides no access to the trim parts if repairs are needed.

GLOBE VALVES

Globe valves are so named due to the globular shape of the valve body. Globe valves are used where throttling and/or frequent operation is desired. Each uses the same method of closure—a round disk or tapered plug-type disk that seats against a round opening (port). This design deliberately restricts flow, so globes should not be used where full, unobstructed flow is required. There are three basic types of globe valve: the standard globe valve (Fig. 2.27), the angle globe valve (Fig. 2.28), and the needle valve (Fig. 2.29).

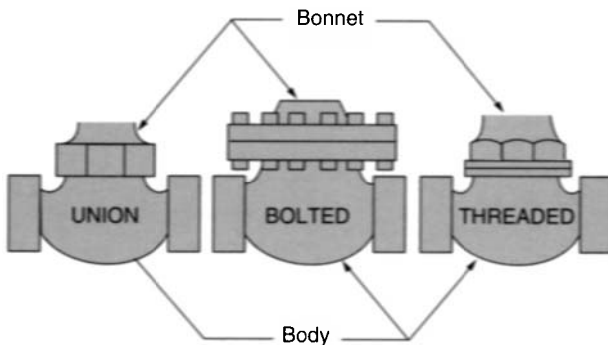


FIGURE 2.26 Typical bonnet construction.

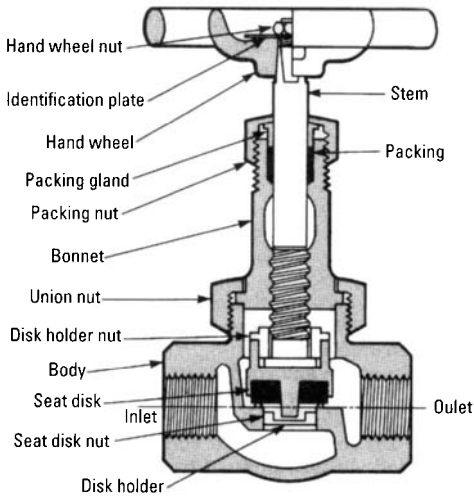


FIGURE 2.27 Standard globe valve.

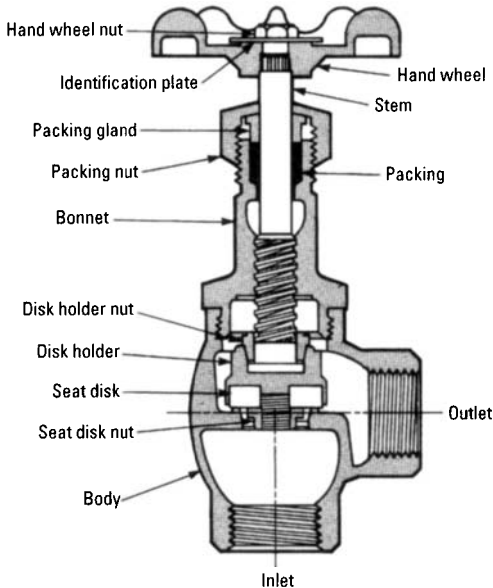


FIGURE 2.28 Typical angle globe valve.

Angle valves are identical to standard globe valves in seat design and operation. The basic difference is that the body of the angle valve acts as a 90° elbow, eliminating the need for a fitting at that point in the system. Angle valves also have less resistance to flow than the combination of globe valves and the fittings they replace. Needle valves are generally small in size and are intended to provide

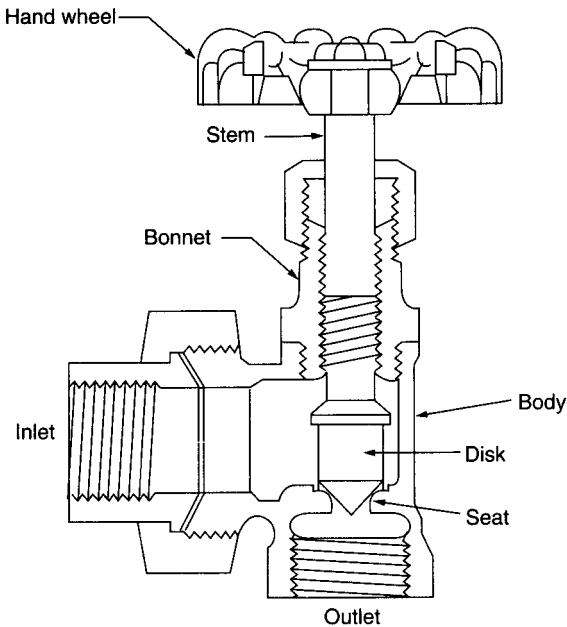


FIGURE 2.29 Typical needle valve.

precise flow control. Many turns of the handle are required to adjust flow in order to achieve precise control.

A globe valve should be installed with the flow entering under the disk. The end of the valve through which you can see the disk seat when the valve is closed is the end where the flow should enter. This is necessary for good throttling control of flow and best shutoff conditions. Globe valves should also be installed with the disk closed to prevent seat damage during installation.

Most globe valve leakage is due to foreign matter settling on the area between the disk and seat. When this occurs, it can often be corrected by opening the valve slightly and then closing it.

PLUG VALVES

A plug valve, shown in Fig. 2.30, is a quarter-turn valve that uses a tapered cylindrical plug that fits a body seat of corresponding shape. When the port in the plug is aligned with the body opening, flow is permitted in a way similar to a ball valve. A one-quarter (90°) turn operates the valve from opened to closed and vice versa.

Plug valves fall into two basic categories, lubricated and nonlubricated. A lubricated plug valve is designed with grooves in the surface of the plug. The grooves are connected to a lubricant channel in the stem. When the grooves are filled with lubricant (also called sealant), a tight seal develops between the plug and valve body. Lubricant is usually applied with a hand pump, providing a hydraulic jacking force and lifting the plug slightly for easier turning. When properly lubricated, this valve gives tight shutoff and is easily operated. Proper lubrication requires addi-

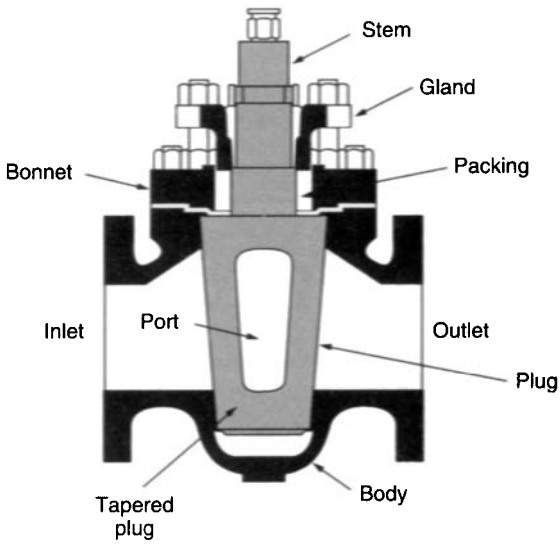


FIGURE 2.30 Typical plug valve.

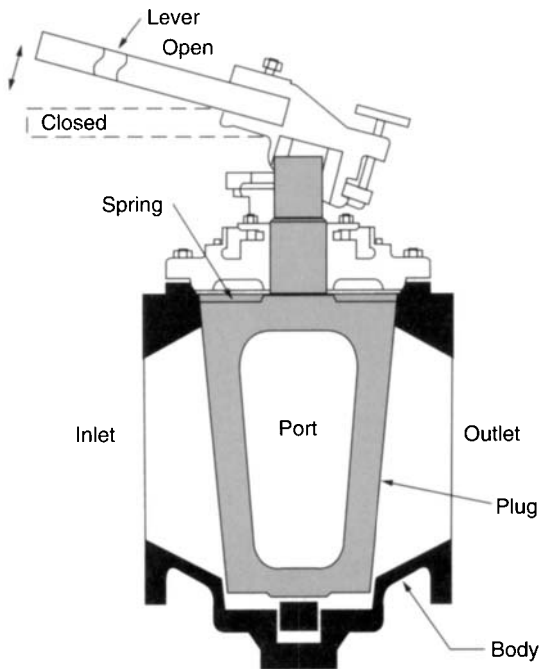


FIGURE 2.31 Typical lift-type plug valve.

tional maintenance. This valve is often used in natural gas service. A disadvantage is that the lubrication may enter the product stream and is not recommended where purity is a primary concern.

Nonlubricating plug valves have two basic designs, lift type and sleeved. In the lift type (Fig. 2.31), the plug is mechanically lifted while being turned to disengage it from the seating surface, thereby reducing seating force. The sleeve type generally has a fluorocarbon sleeve (retained in the body) that surrounds the plug, giving a continuous seal.

There are three port sizes: 100, 70, and 40 percent of inlet pipe size opening, as shown in Fig. 2.32. The size of the port determines the physical size of the valve, with the larger port having the largest valve size. The 70 percent port is normally supplied.

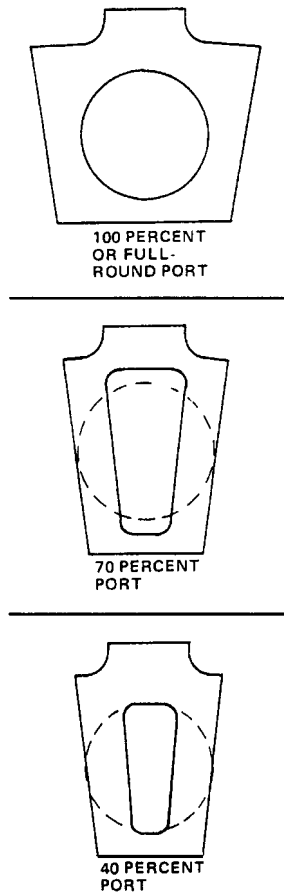


FIGURE 2.32 Plug valve port sizes.

BALL VALVES

A ball valve utilizes a ball with a hole drilled through it as the opening/closing device. It is a quarter-turn valve. The ball seals by fitting tightly against resilient seat rings on either side. Flow is straight through, and pressure loss depends on the size of the opening in the ball (port).

Ball valves are available in one-, two-, or three-piece body types (Fig. 2.33). The one-piece body, also called “end entry,” is machined from solid bar stock material or is a one-piece casting. The ball is inserted into one end for assembly, and a body insert that acts as a seat ring is threaded in against the ball. The two-piece body, also an end-entry design, is the same as a one-piece valve except 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. The entire assembly is held together by two or more body bolts. This design allows the valve to be repaired without disassembling surrounding piping. This type is recommended for utility services.

There are three port sizes, standard, reduced, and full port. Standard port is generally one pipe size smaller than the valve size, reduced port is up to two sizes smaller, and full port has the same opening as the connecting pipe.

Ball valves are generally selected for ON/OFF service. They are easily adapted to power actuation and are generally less expensive than equivalent sizes of gate and globe valves. With the development of high temperature and superior grade elastomeric seating material, tight seating problems have been overcome.

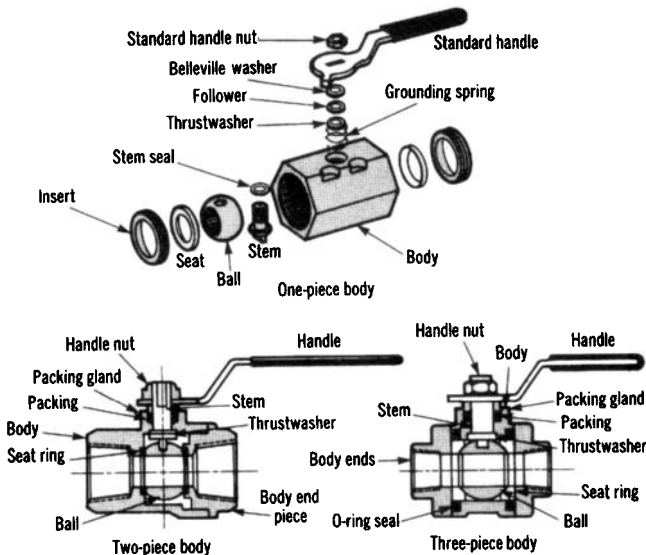


FIGURE 2.33 Typical ball valves.

BUTTERFLY VALVES

A butterfly valve has a wafer-shaped body with a thin rotating disk as the closing device. Like the ball valve, the butterfly operates with a one-quarter turn from fully opened to fully closed. The disk is always in the flow path, but since it is relatively thin, it offers little restriction to the flow. When the valve is closed, the disk edge fits tightly against a ring-shaped liner (seat).

These valves generally have one-piece bodies that fit sandwich-style between two pipe flanges. The two most common body types are wafer body and lug body, illustrated in Fig. 2.34. The wafer body is placed between pipe flanges, and the flange bolts surround the valve body. The lug body has protruding lugs that provide bolt holes matching those in the flanges.

Another design has an extended body for connections to grooved end piping. In this valve, the sealing member is the disk itself, which is fully encapsulated with a resilient material selected for the service conditions at hand.

Butterfly valves have continued to grow in popularity, generally at the expense of gate valves, because they are lightweight, easy to install, low in cost, easy to actuate, and easy to insulate and also because they feature one-quarter turn operation, tight shutoff (due to resilient seal), and a variety of construction materials.

DIAPHRAGM VALVES

A diaphragm valve uses a rubber, plastic or elastomer diaphragm to seal the stem. The diaphragm not only seals the stem but forms the closure element.

There are two styles of diaphragm valves, one having a body with a weir and the other having a straight-through body. On the weir type, shown in Fig. 2.35, the stem is connected to a finger arrangement, which in turn presses the diaphragm down onto a weir. This creates an extremely tight seal that will seal even on some solids. This valve has been used extensively in radwaste services and maintenance

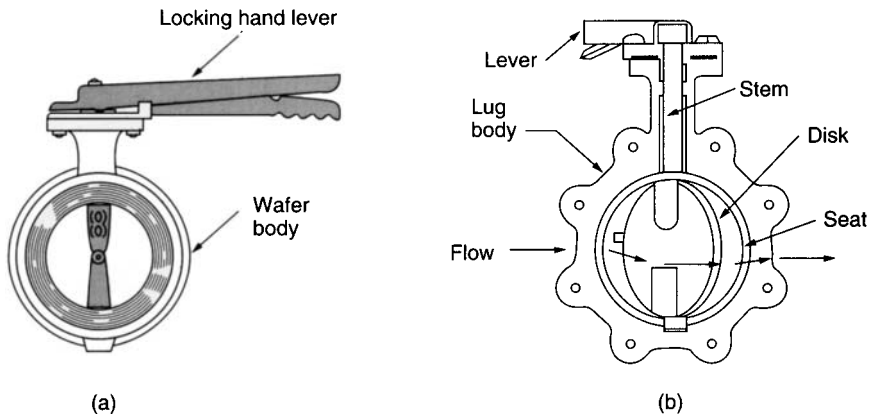


FIGURE 2.34 Butterfly valves. (a) Wafer body; (b) lug body.

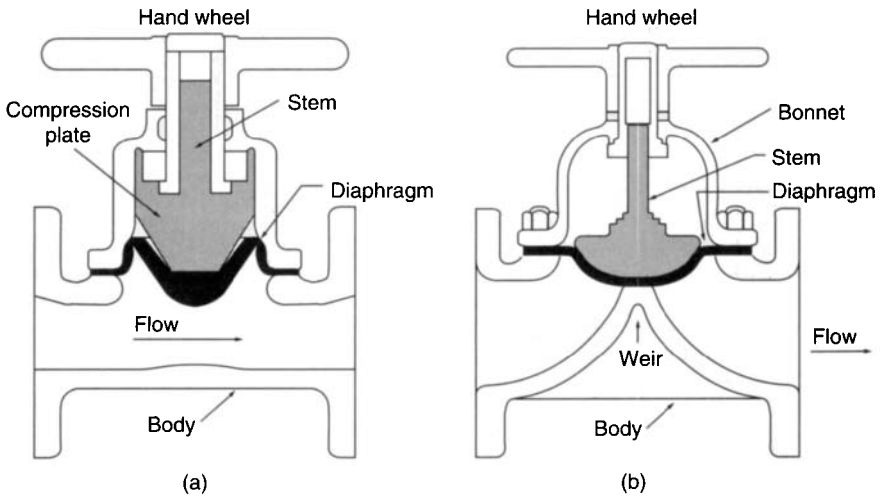


FIGURE 2.35 Diaphragm valves. (a) Straight-through valve in open position; (b) weir-type valve in closed position.

is extremely simple. On the straight-through type (Fig. 2.34), the diaphragm presses onto the bottom of the valve body for seating.

Since the diaphragm is not metallic and forms the closure, the valve is severely limited in pressure and temperature. A wide variety of diaphragm materials are available for use with different fluids. To enable draining of horizontal pipelines, the weir valve must be mounted 15° from the horizontal plane (because of the weir). This complicates installation, especially with air actuators.

PINCH VALVES

A pinch valve (Fig. 2.36) uses a round elastomeric sleeve connected to the valve body from inlet to outlet that completely isolates the liquid passing through the valve from all internal valve components. Closure is made by a movable closure element outside the sleeve that pinches the sleeve between the element and the valve body.

This type of valve is used for slurry and other liquids with highly corrosive properties.

CHECK VALVES

Check valves (Fig. 2.37) automatically check or prevent the reversal of flow. Basic types are the swing check, lift check, ball check, and wafer check designs. Another designation used for sanitary waste systems is a backwater valve. The swing check has a hinged disk, sometimes called a flapper, that swings on a hinge pin. When flow reverses, the pressure pushes the disk against a seat. The flapper may have a

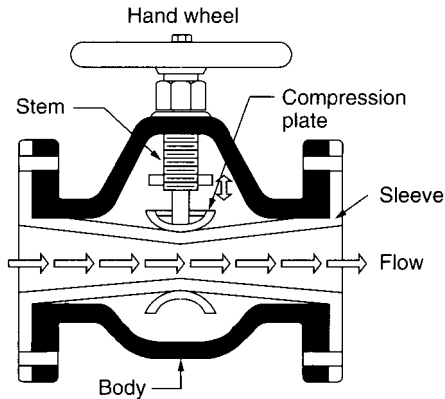


FIGURE 2.36 Pinch valve.

composition disk, rubber or Teflon, rather than metal when tight closure is required. Swing checks offer little resistance to flow.

The lift check has a guided disk that is raised from the seat by upward flow pressure. Reversal of flow pushes the disks down against the seat, stopping back flow. Lift checks have considerable resistance to flow, similar to that of a globe valve. They are well suited for high-pressure service.

Another common check is a wafer design which fits between flanges in the same fashion as a butterfly valve. Wafer checks come in two types: a dual flapper that is hinged on a center post and a single flapper that is similar to the standard swing check. They are generally used in larger size piping (4 in and larger) because they are much lighter and less expensive than traditional flanged end swing check valves.

A demand check valve is of two-piece construction, with one piece having a spring-loaded closure similar to the air valves found on automobile tires. The second piece, when inserted into the first, opens the valve, allowing free passage of air. The demand check valve is used for connecting gauges, allowing removal without permitting air to escape from the pipe.

MISCELLANEOUS VALVE TYPES

Various other types of valves are often used in utility systems. They can be either independently installed to operate as self-contained units or controlled electronically from a panel, system signal, or other remote source.

Pump Control Valve

This type of valve is used on pumped systems to control or eliminate surges caused by pump start and stop. It operates by using a spring-loaded closure member that opens or closes slowly to restrict the initial flow of water when a pump starts and stops.

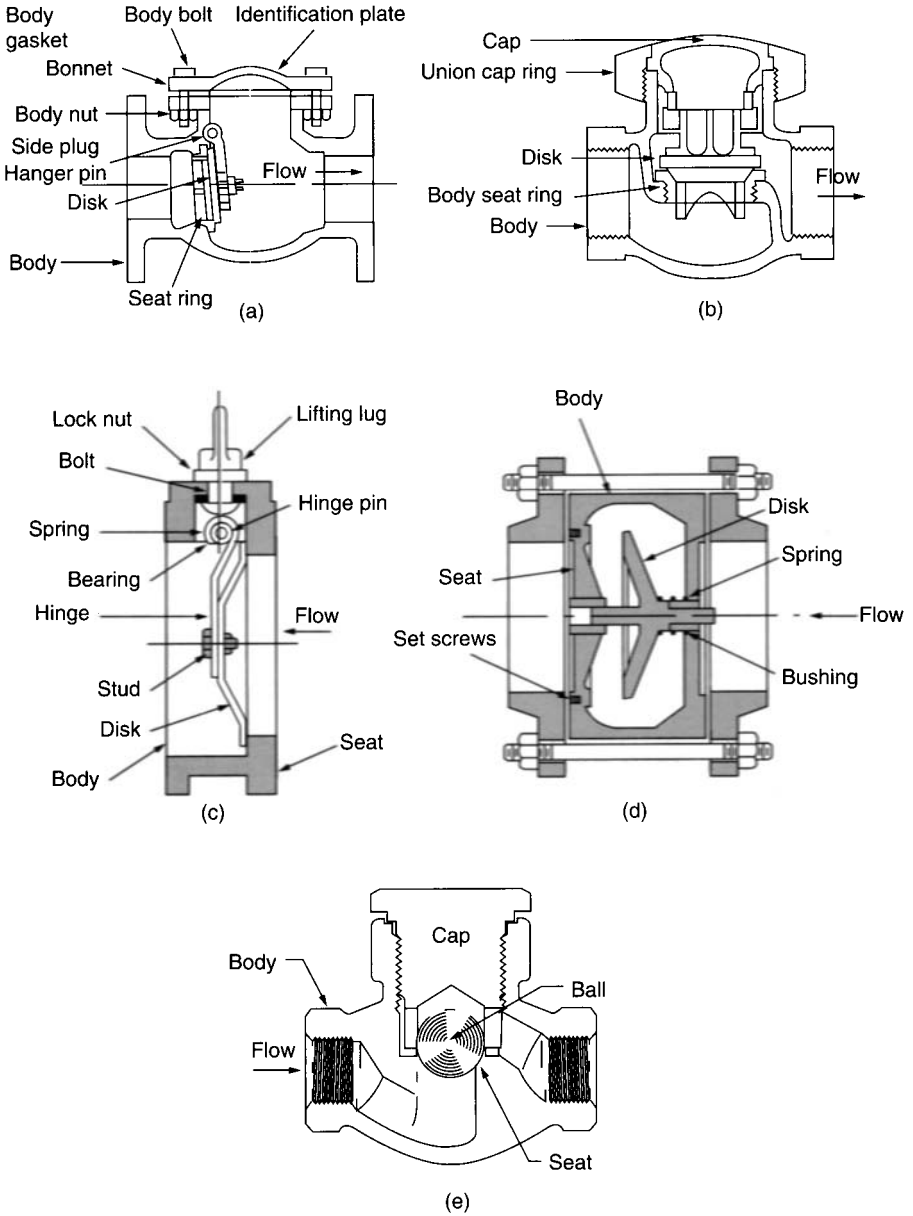


FIGURE 2.37 Check valves. (a) Swing check; (b) lift check; (c) single flapper wafer check; (d) double flapper wafer check; (e) hall check.

Flow Control Valve

This valve operates by using a calibrated orifice or venturi tube to control the flow of liquid to a predetermined set point regardless of fluctuating line pressure.

Pressure Control Valve

Similar to the flow control valve, this valve limits the pressure of a flowing liquid to a predetermined set point regardless of fluctuating flow rate.

Level Control Valve

This valve accurately controls the level of liquid in a tank or vessel. An altitude valve uses a controlling device to maintain the level, and a float valve uses a movable float on an arm (similar to that in a water closet) to stop the flow at a predetermined level.

Conduit Valve

A conduit valve (Fig. 2.38) is used where an unobstructed opening through the valve is required, such as when pigs are used to clean the pipeline.

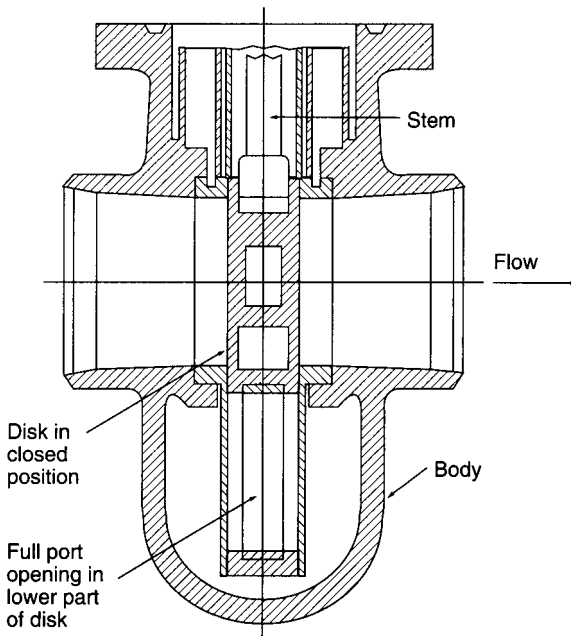


FIGURE 2.38 Lower portion of conduit valve.

METALLIC ALLOY DESIGNATIONS

The Unified Numbering System (UNS) is intended to correlate the many metal alloy numbering systems currently administered by North American technical societies, trade associations, individual users, and ASTM. Prior to the introduction of the UNS by the ASTM, a confusing array of names and numbers for metal and alloy designations had been developed independently over a 60-year period. Proprietary alloys were designated by trade names and some were registered trademarks. Often, different companies manufactured the same alloy under different trade names. Another factor is that the old numbering system does not allow the use of computer databases requiring uniform designations. Although it originated in the United States, the UNS is gaining national and worldwide acceptance. The book, *Metals and Alloys in the Unified Numbering System*, ASTM DS56B, published by ASTM, is now in its fifth edition.

The UNS is a simple alphanumeric system consisting of a letter prefix followed by five digits. This requires only six spaces to identify any metal or alloy. The letter prefix is usually suggestive of the family of metals identified. The system establishes 17 categories or families of metals. The categories are given in Table 2.8.

As an example, stainless steel ASTM type 304 is now S30400 and type 316 is S31600. If 304L is required, it is called S30403.

TABLE 2.8 UNS Metal Family Designations

The first letter (followed by five digits)	Alloy category (assigned to date)
Axxxxx	Aluminum and its alloys
Cxxxxx	Copper and its alloys
Exxxxx	Rare-earth metals, and similar metals and alloys
Fxxxxx	Cast irons
Gxxxxx	AISI and SAE carbon and alloy steels
Hxxxxx	AISI and SAE H-steels
Jxxxxx	Cast steels (except tool steels)
Kxxxxx	Miscellaneous steels and ferrous alloys
Lxxxxx	Low-melting metals and their alloys
Mxxxxx	Miscellaneous nonferrous metals and their alloys
Nxxxxx	Nickel and its alloys
Pxxxxx	Precious metals and their alloys
Rxxxxx	Reactive and refractory metals and their alloys
Sxxxxx	Heat- and corrosion-resistant steels (including stainless), valve steels and iron-based "superalloys"
Txxxxx	Tool steels (wrought and cast)
Wxxxxx	Welding filler metals
Zxxxxx	Zinc and its alloys

The UNS designation is not a specification and it does not establish a requirement for form, condition, properties, or quality. These are all established by individual specification literature such as ASTM alloy standards and those obtained from manufacturers.

There is no UNS for plastic pipe or related materials.

METRIC PIPE SIZES

The United States is the only major industrial country where inch sizes are commonly used. This is commonly referred to as the inch/pound, or IP system. All U.S. government projects are required to be in metric sizes, and many individual states are also requiring project documents to use metric units. Metric units are referred to as SI units, or International System of Units. Table 2.9 is compiled from several sources and presents the different conversions of pipe IP size to SI metric units. DN refers to nominal dimension, which is a soft, rounded standard obtained by multiplying the nominal pipe size by 25. Refer to Appendix D for additional conversion factors.

TABLE 2.9 Equivalent Metric (SI) Pipe Sizes

Nominal pipe size (NPS), in IP	ASHRAE std. wt. size, mm	AWWA pipe size, mm	NFPA pipe size, mm	ASTM copper tube size, mm	Nominal pipe size DN
1/8	—	—	—	6	6
3/16	—	—	—	8	8
1/4	8	—	—	10	10
3/8	10	—	—	12	12
1/2	15	12.7 & 13	12	15	15
5/8	—	—	—	18	18
3/4	20	—	—	22	20
1	25	25	25 & 25.4	28	25
1 1/4	32	—	33	35	32
1 1/2	40	45	38 & 38.1	42	40
2	50	50 & 50.8	51	54	50
2 1/2	65	63 & 63.5	63.5 & 64	67	65
3	80	75	76 & 80	79	80
3 1/2	—	—	89	—	90
4	100	100	102	105	100
4 1/2	—	114.3	—	—	115
5	—	—	127	130	125
6	150	150	152	156	150
8	200	200	203	206	200
10	250	250	—	257	250
12	300	300	305	308	300
14	—	350	—	—	350
16	—	400	—	—	400
18	—	—	—	—	450
20	—	500	—	—	500
24	—	600	—	—	600
28	—	—	—	—	700
30	—	—	—	—	750
32	—	—	—	—	800
36	—	—	—	—	900
40	—	—	—	—	1000
44	—	—	—	—	1100
48	—	—	—	—	1200
52	—	—	—	—	1300
56	—	—	—	—	1400
60	—	—	—	—	1500

HANGERS AND SUPPORTS

This section will provide a general overview of basic methods and devices required to properly support the piping network within a facility. The utility systems that are the subject of this handbook generally are low-pressure and low-temperature networks, whose support requirements are not considered complex.

GENERAL

The entire piping network must be attached to the building structure in a manner that will ensure adequate support under all static and dynamic operating conditions. These conditions include:

1. Adequate connection to both the structure and the pipe
2. An allowance for weight of the filled pipe
3. Slope
4. Expansion of the pipe run
5. Seismic forces
6. Pipeline temperature

CODES AND STANDARDS

The following standards are often referred to regarding the selection and design of pipe supports:

1. ANSI B 31: series.
2. MSS SP-58: material and design of pipe supports.
3. MSS SP-69: selection and application of pipe supports.
4. MSS SP-89: fabrication and installation of pipe supports.
5. NFPA-13: sprinkler systems. This standard has wide application to pipe supports other than those for sprinkler systems.

SYSTEM COMPONENTS

The pipe support is an assembly of components including a device or method used as a direct attachment to the structure, a means of securing the pipe, and a connecting member extending from the structure attachment to the device used to secure the pipe. Other devices include pipe restraints or anchors and pipe guides.

Attachment to Structure

Various methods and devices are used to attach the support to the structure. Typical attachments include:

1. An insert (Fig. 2.39a) is installed at the time the slab is poured. An anchor or expansion bolt is installed after the slab is poured.
2. A beam clamp (Fig. 2.39b) provides attachment to exposed structural members. Beam clamps can also be welded to the beam.
3. Brackets (Fig. 2.39c) attach to walls.

The manufacturer of each type of attachment will have specifications for the maximum loading permitted for each type of attachment.

Hanger Rods

The hanger rod is usually threaded and connects the attachment to the hanger that is threaded to receive the rod. The diameter of the rod is selected by the amount of weight it will support, which is determined by the area of the rod at the root of the thread. The safe weight capable of being supported by different rod diameters is shown in Table 2.10. Table 2.11 conforms to UL and FM requirements for minimum acceptable rod diameters for various sizes supporting individual pipes. A rod diameter less than $\frac{3}{8}$ in (12 mm) is not recommended to be used as support for any pipe inside a facility.

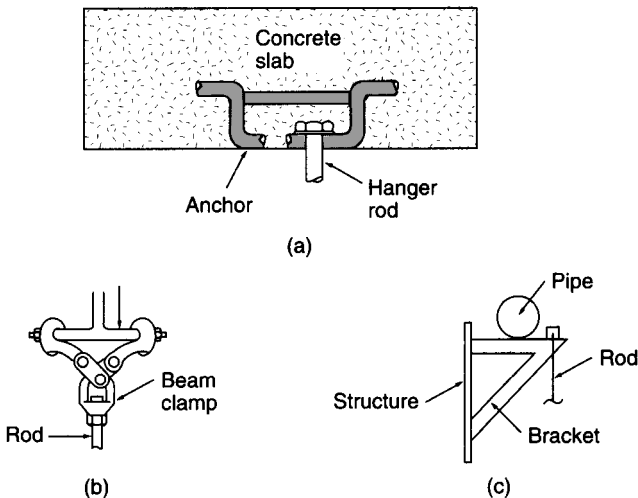


FIGURE 2.39 Typical structure attachments. (a) Insert; (b) beam clamp; (c) bracket.

TABLE 2.10 Load Rating of Threaded Rods

Nominal rod diameter, in	Root area of thread, in ²	Maximum safe load at rod temperature of 650°F, lb
1/4	0.027	240
5/16	0.046	410
3/8	0.068	610
1/2	0.126	1,130
5/8	0.202	1,810
3/4	0.302	2,710
7/8	0.419	3,770
1	0.552	4,960
1 1/8	0.693	6,230
1 1/4	0.889	8,000
1 3/8	1.053	9,470
1 1/2	1.293	11,630
1 5/8	1.515	13,630
1 3/4	1.744	15,690
1 7/8	2.048	18,430
2	2.292	20,690
2 1/4	3.021	27,200
2 1/2	3.716	33,500
2 3/4	4.619	41,600
3	5.621	50,600
3 1/4	6.720	60,500
3 1/2	7.918	71,260

TABLE 2.11 Recommended Rod Size for Individual Pipes

Pipe size, in	Rod size, in
2 and smaller	3/8
2 1/2 to 3 1/2	1/2
4 and 5	5/8
6	3/4
8 to 12	7/8
14 and 16	1
18	1 1/8
20	1 1/4
24	1 1/2

Hangers

A hanger is the device used to secure the pipe to the hanger rod. It must not distort, cut, or abrade any pipe while allowing free movement. There is a wide variety to choose from, including:

1. Pipe clamps (Fig. 2.40a) support pipes passing through openings in floors.
2. Saddles (Fig. 2.40b) support pipe from floors.

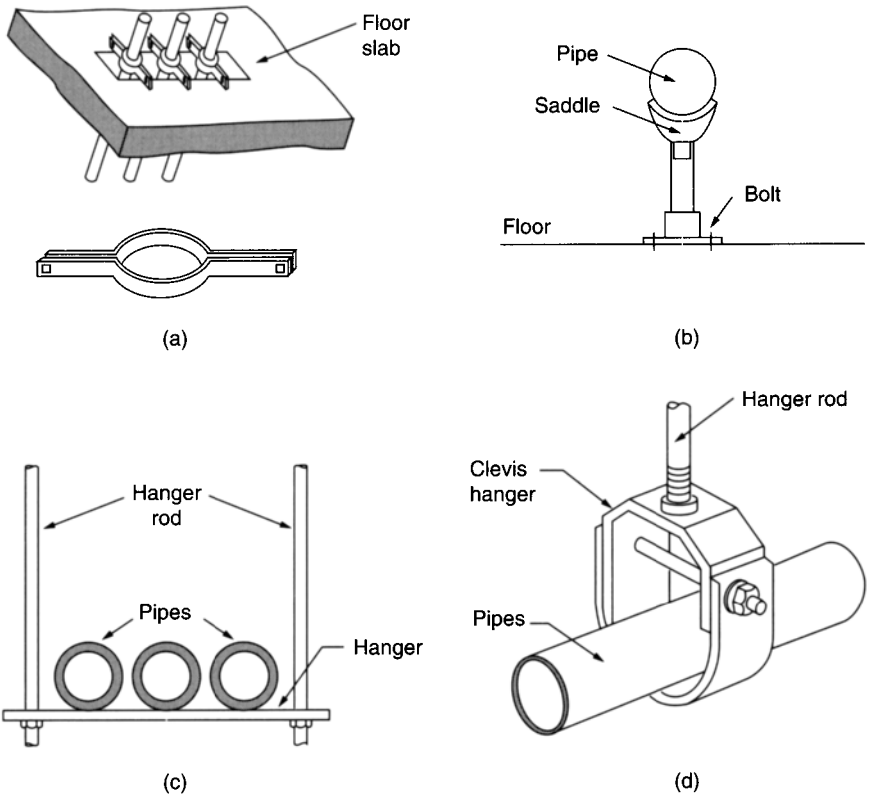


FIGURE 2.40 Typical pipe hanger types. (a) Pipe clamp; (b) adjustable saddle; (c) trapeze hanger; (d) adjustable clevis hanger.

3. Trapeze hangers (Fig. 2.40c) support multiple pipes.
4. A clevis hanger (Fig. 2.40d) is an adjustable hanger for a single pipe.

When pipes are insulated, precautions must be taken in order not to distort softer fiberglass insulation or create a break in the vapor barrier, if one is provided. Refer to Fig. 2.41 for an illustration of insulation over a split ring hanger and Fig. 2.42 for an illustration of protective inserts used with a clevis hanger.

The manufacturer of each type of hanger will have specifications for the maximum loading permitted for each type.

Hanger Spacing

The horizontal spacing of hangers depends on the size of the pipe and the requirement to prevent sagging based on the weight of the pipe filled with water, weight

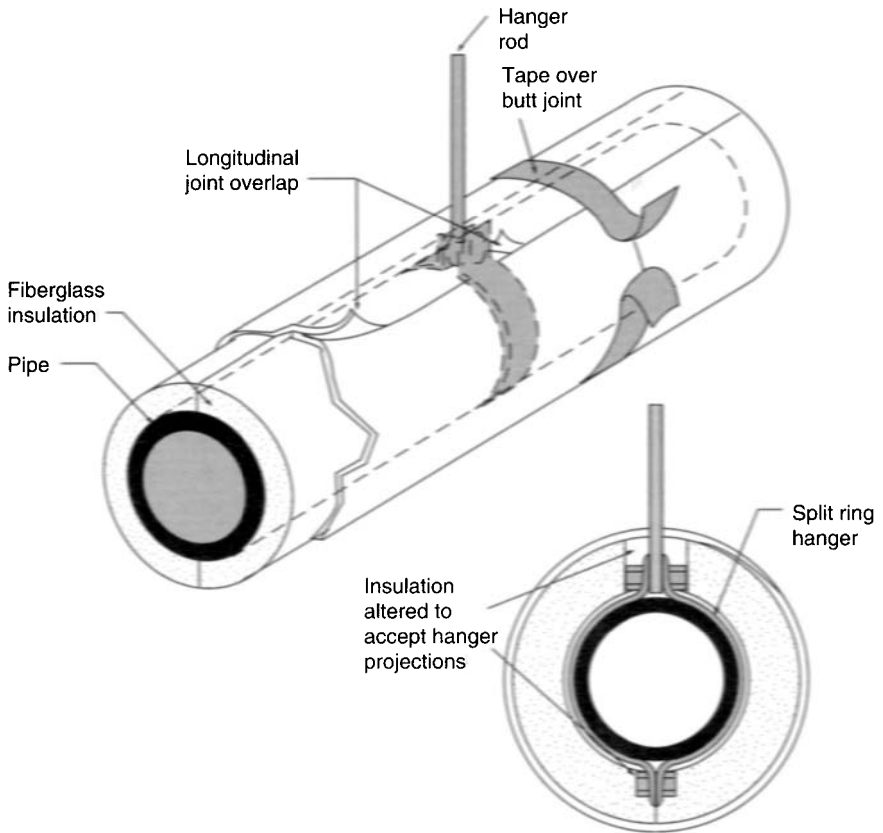


FIGURE 2.41 Insulation over a split ring hanger. (Courtesy Mica.)

of insulation, and other heavy valves and fittings on the pipe run. For pipe where no other requirements exist, the recommended maximum spacing is as follows:

1. For steel piping 1 in and smaller, 8 ft O.C.
2. Steel pipe 1¼ in and larger, 12 ft OC.
3. Copper tubing 1¼ in and smaller, 6 ft O.C.
4. Copper tubing 1½ in and larger, 10 ft O.C.
5. SS tubing, same as copper pipe
6. Cast iron pipe, every 5 ft and at each fitting. For pipe length of 10 ft, hangers shall be equal to pipe length.
7. Glass pipe, 10 ft O.C. and extra hangers at places where three joints exist in a 10-ft section.
8. Plastic pipe—all sizes and types, continuously supported to prevent sagging by means of an angle iron or 18-gauge angle, supported every 10 ft

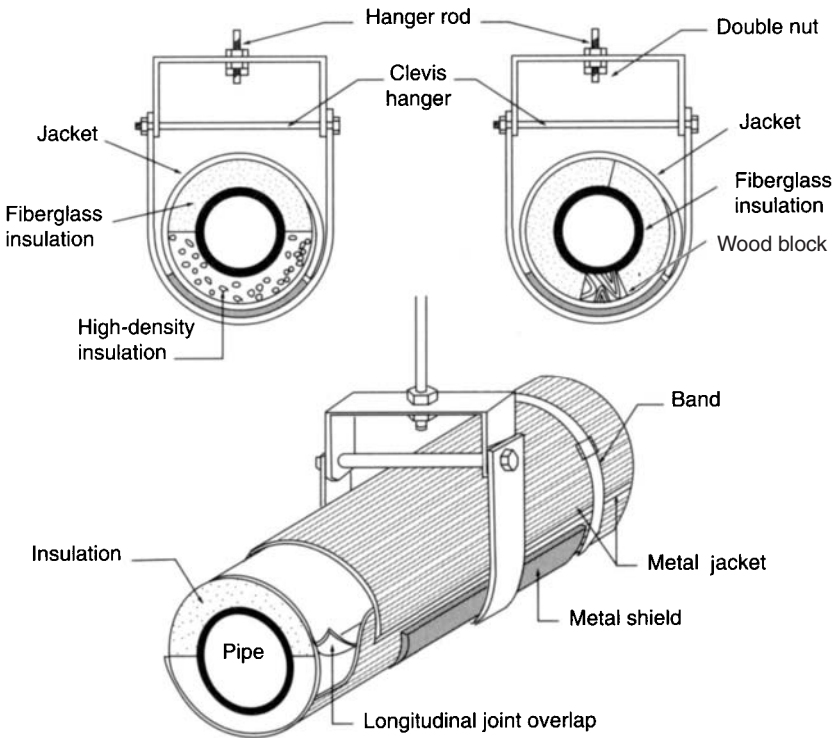


FIGURE 2.42 Clevis hanger with protective inserts. (Courtesy Mica.)

Vertical piping shall be supported as follows:

1. Cast iron pipe with caulked joints, each floor or 20 ft O.C.
2. Cast iron pipe with no-hub joints, each floor or 10 ft O.C.
3. Copper and SS tubing, 10 ft O.C.
4. Glass pipe 2 in and smaller, alternate floors or 20 ft O.C.
5. Glass pipe 2½ in and larger, each floor or 10 ft O.C.
6. All other piping, alternate floors or 25 ft O.C.
7. A base support or hanger support at the offset of all piping from vertical to horizontal.

Calculating Weight of Pipe and Contents

For systems with limited complexity that comply with conventional spacing, the hanger assembly shall be selected to support the total weight of the piping. The procedure used to calculate the total weight is as follows:

1. Calculate the weight of the pipe using the following formula:

$$W = F \times 10.68 \times T \times (\text{O.D.} - T) \tag{2.2}$$

where W = weight of pipe, lb/ft

F = relative weight factor, see Table 2.12

T = wall thickness of pipe

O.D. = outside diameter of pipe, inches

Note: Add a safety factor of 5 percent for tolerance in pipe manufacturing.

2. Determine the weight of the water contained in the pipe. Refer to Table 2.13 for the water weight based on the size of the pipe. The quantity and weight of

TABLE 2.12 Relative Weight Factor for Metal Pipe

Pipe	Weight factor*
Aluminum	0.35
Brass	1.12
Cast iron	0.91
Copper	1.14
Stainless steel	1.0
Carbon steel	1.0
Wrought iron	0.98

*Average plastic pipe weighs one-fifth as much as carbon steel pipe.

TABLE 2.13 Weight of Steel Pipe and Contained Water

IPS, in	Weight per foot, lb	Length in feet containing 1 ft ³ of water	Gallons in 1 linear ft
1/4	0.42		0.005
3/8	0.57	754	0.0099
1/2	0.85	473	0.016
3/4	1.13	270	0.027
1	1.67	166	0.05
1 1/4	2.27	96	0.07
1 1/2	2.71	70	0.1
2	3.65	42	0.17
2 1/2	5.8	30	0.24
3	7.5	20	0.38
4	10.8	11	0.66
5	14.6	7	1.03
6	19.0	5	1.5
8	25.5	3	2.6
10	40.5	1.8	4.1
12	53.5	1.2	5.9

TABLE 2.14 Relative Weight Factor for Insulation

Nominal pipe size*	Nominal insulation thickness*											
	1"	1½"	2"	2½"	3"	3½"	4"	4½"	5"	5½"	6"	
1	0.055	0.10	0.16	0.23	0.31	0.40						
1¼	0.048	0.12	0.15	0.22	0.30	0.39						
1½	0.063	0.11	0.21	0.29	0.38	0.48						
2	0.080	0.14	0.21	0.29	0.37	0.47	0.59					
2½	0.091	0.19	0.27	0.36	0.46	0.58	0.70	0.83				
3	0.10	0.17	0.25	0.34	0.44	0.56	0.68	0.81				
3½	0.14	0.23	0.31	0.41	0.54	0.66	0.78	—	0.97			
4	0.13	0.21	0.30	0.39	0.51	0.63	0.77	0.96	1.10			
5	0.15	0.24	0.34	0.45	0.58	0.71	0.88	1.04	1.20			
6	0.17	0.27	0.38	0.51	0.64	0.83	0.97	1.13	1.34			
8	—	0.34	0.47	0.66	0.80	0.97	1.17	1.36	1.56	1.75		
10	—	0.43	0.59	0.75	0.93	1.12	1.32	1.54	1.76	1.99		
12	—	0.50	0.68	0.88	1.07	1.28	1.52	1.74	1.99	2.24	2.50	
14	—	0.51	0.70	0.90	1.11	1.34	1.57	1.81	2.07	2.34	2.62	
16	—	0.57	0.78	1.01	1.24	1.49	1.74	2.01	2.29	2.58	2.88	
18	—	0.64	0.87	1.12	1.37	1.64	1.92	2.21	2.51	2.82	3.14	
20	—	0.70	0.96	1.23	1.50	1.79	2.09	2.40	2.73	3.06	3.40	
24	—	0.83	1.13	1.44	1.77	2.10	2.44	2.80	3.16	3.54	3.92	

*For pipe sizes and insulation thicknesses not shown in above chart, use Eq. (2.4).

water shown for steel pipe should be used for all pipe. They are well within the accuracy and safety factors expected for selection of hangers.

3. Calculate the weight of insulation on the pipe. For standard insulation and thickness, use the following formula:

$$W = F \times D \tag{2.3}$$

where W = weight of insulation, lb/ft³

F = relative weight factor for insulation, see Table 2.14

D = density of insulation, lb/ft³

TABLE 2.15 Thermal Expansion of Piping Materials

Piping Material	Coefficient of Thermal Expansion in/in/°F per ASTM 0696
Aluminum	0.000098
Brass-red	0.000009
Brass-yellow	0.000001
Copper	0.00001
Cast iron	0.0000056
Carbon steel	0.000005
Ductile iron	0.0000067
Stainless steel	0.0000115
Borosilicate (glass)	0.0000018
ABS	0.00005
CAB	0.00008
CPVC	0.000035
FRP-epoxy	0.000012
FRP-polyester	0.000017
FRP-vinyl ester	0.00001
FEP	0.000005
HDPE	0.00011
PAEK	0.000023
PB	0.00015
PE	0.00008
PEEK	0.000026
PEX	0.00093
PFA	0.000066
PP	0.000065
PPS	0.00003
PVC	0.00004
PS	0.000031
PTFE	0.000038
PVDF	0.000096
Saran	0.000038
Styrene	0.00006

When insulation thickness is not standard or the pipe size is outside the values in Table 2.11, use the following formula:

$$W = D \times 0.0218 \times T \times (\text{O.D.} \times T) \quad (2.4)$$

where W = weight of insulation, lb/ft³

D = density of insulation, in lb/ft³

T = wall thickness of insulation, inches

O.D. = outside diameter, inches

Add all three of the above figures together to find the total weight for any run of pipe that must be supported. Then, determine the number of hangers required so that the weight on any single hanger is less than the smallest weight allowed for any component of the specific hanger assembly chosen.

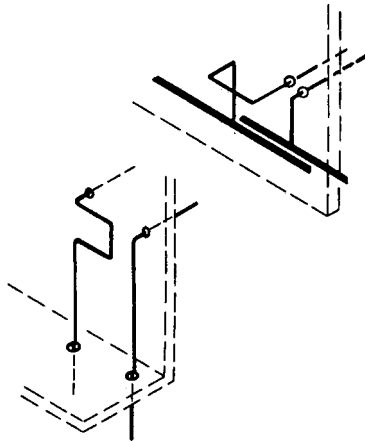


FIGURE 2.43 Methods of providing pipeline flexibility.

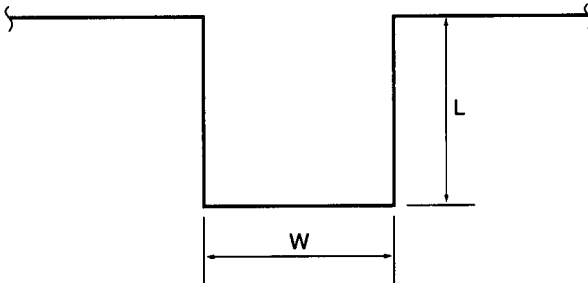


FIGURE 2.44 Expansion loop.

Pipe Expansion

All piping materials will change dimensions as they expand and contract due to temperature changes above and below the temperature at which they were installed. These dimensional changes result in a change in the length of run of the pipe. If the piping network does not have the necessary flexibility to compensate for the expansion and contraction, the resultant stress could cause damage to connected equipment or cause the pipe to leak or fail completely. Thermal expansion of piping materials is given in Table 2.15.

The thermal expansion for plastic pipe is not linear, but increases with increasing temperature. In the range of temperature encountered in general utility piping, this is not a consideration.

Expansion Loops

The stress and forces resulting from thermal expansion must be compensated for by providing flexibility in the piping network. Flexibility is generally provided by changes in direction of the pipe and with offsets. These are generally enough to allow adequate compensation for normal expansion. Branch piping connections to provide flexibility are illustrated in Fig. 2.43. Where their installation is not possible, a mechanical expansion joint must be provided.

For long runs of straight pipe or when there is doubt as to adequate flexibility, the method used most often to provide required flexibility is the expansion loop (Fig. 2.44). In the figure, there is no specific dimension for W ; however, this dimension is generally the same as L , but could be as little as $\frac{1}{2}L$ when necessary for installation space requirements. To calculate the length required to absorb movement without damage, the following formula is used:

$$L = 1.44 \sqrt{D \times \Delta C} \quad (2.5)$$

where L = pipe leg length, ft

D = nominal outside diameter of pipe, in

ΔC = change of dimension of pipe run, in (This figure is calculated by multiplying the pipe run by the rate of thermal expansion found in Table 2.12.)

Seismic Considerations

All utility piping must be installed in conformance with code requirements for the earthquake zone where the facility is located. A map of the United States showing the earthquake zones is shown in Fig. 2.45.

The model and local codes provide guidance and criteria for the design of piping supports. In general, sway bracing is provided to prevent excessive pipe movement. The design of pipe supports to resist earthquake loads is outside the scope of this handbook.

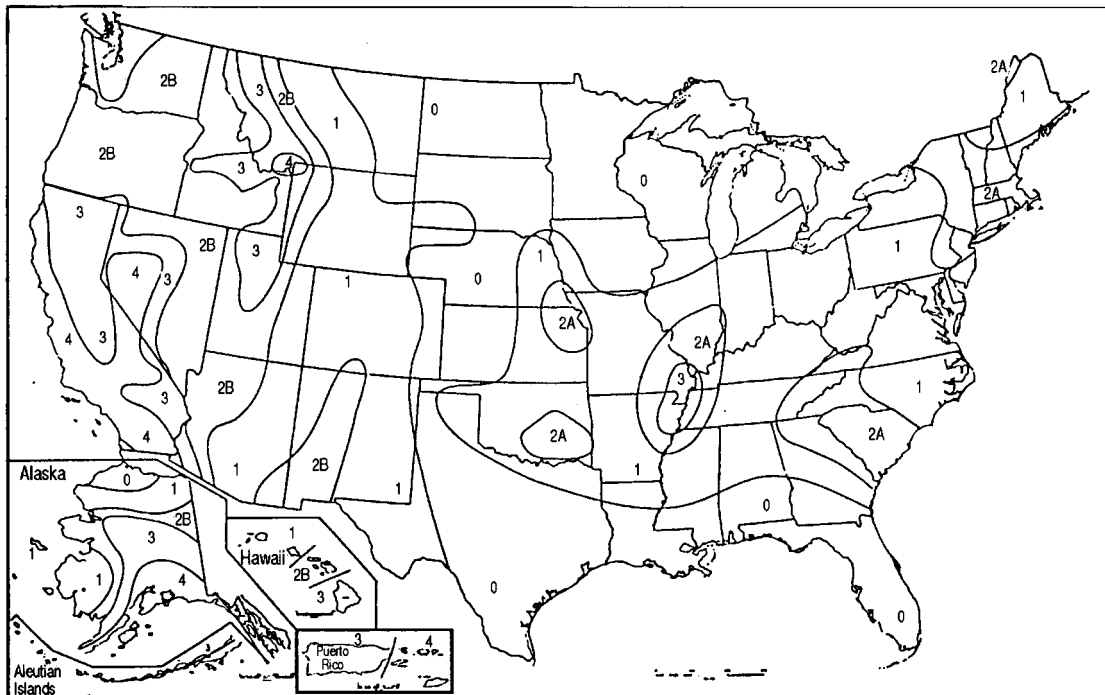


FIGURE 2.45 Earthquake zone for the United States. Zone 0: no earthquake damage areas. Zone 1: minor damage areas. Zone 2A: minor to moderate damage areas. Zone 2B: moderate to major damage areas. Zone 3: major damage areas. Zone 4: areas near earthquake faults.

REFERENCES

- Air Conditioning, Heating and Ventilating Magazine* data sheet, "Formulas for Sizing Control Valves," April 1959.
- Bhasin, V. C., "Actuator Selection," *Chemical Engineering Magazine*, pp.140–145, November 1990.
- Coleman, D. C., and R. W. Evans, "Fundamentals of Passivation and Passivity in the Pharmaceutical Industry," *Pharmaceutical Engineering Magazine*, March/April 1993.
- Delstar Electropolish, "Electropolishing."
- Dillon, C. P., et al, "Stainless Steels for Bioprocessing," *BioPharm Magazine*, April–July 1992.
- Fagan, D., "Piping Materials and Jointing Methods for Plumbing Systems," *Heating, Piping and Air Conditioning Magazine*, October 1993.
- Frankel, M. "Selecting Plastic Pipe," *Plumbing Engineer Magazine*, pp.26–31, April 1993.
- Harris, C. M. (ed.), *Handbook of Utilities and Services for Buildings*, McGraw-Hill, New York, 1990.
- International Copper Association, "Water Tube from Copper and Other Materials," April 1990.
- Henon, B., "Welding of WDI and WFI Piping Systems for a Bioprocess Application," *Pharmaceutical Engineering Magazine*, pp.18–24, December 1993.
- Issacs, M., and R. B. Setterlund, "A Guide to Pipe Jointing Methods."
- Nayar, M. (ed.), *Piping Handbook*, 6th ed., McGraw-Hill, New York, 1992.
- Pollock, W. I., "Baffled by How Alloys are Labeled?," *Chemical Engineering Magazine*, pp. 169–174, October 1992.
- Reid, R. N., "Double-Walled Pipe and Plumbing Systems," *Heating, Piping and Air Conditioning Magazine*, pp. 53–56, April 1993.
- Reschenberg, A., "Taking the Mystery Out of Specifying Sanitary Stainless Steel Finishes," *Powder and Bulk Engineering Magazine*, pp. 21–32, April 1993.
- Robinson, T., "Compare Nonmetal and Metal Valves," *Chemical Process Magazine*, pp. 25–30, December 1993.
- Sinha, D., "Choose the Right Thermoplastic for High Purity Water," *Chemical Process Magazine*, pp. 84–87, October 1991.
- Ulanski, W., *Valve and Actuator Technology*, McGraw-Hill, New York, 1991.