PIPING AND VALVES

FUNDAMENTALS *for the* WATER & WASTEWATER MAINTENANCE OPERATOR SERIES

PIPING AND VALVES

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Series Preface

Currently several books address broad areas of wastewater and waterworks operation. Persons seeking information for professional development in water and wastewater can locate study guides and also find materials on technical processes such as activated sludge, screening and coagulation. What have not been available until now are accessible treatments of each of the numerous specialty areas that operators must master to perform plant maintenance activities and at the same time to upgrade their knowledge and skills for higher levels of certification.

The *Fundamentals for the Water and Wastewater Maintenance Operator Series* is designed to meet the needs of operators who require essential background knowledge of subjects often overlooked or covered superficially in other sources. Written specifically for maintenance operators, the series comprises focused books designed to enhance knowledge and understanding.

Fundamentals for the Water and Wastewater Maintenance Operator Series covers over a dozen subjects in volumes that form stand-alone information guides or elements of a library of key topics. Areas to be presented in series volumes include: electricity, electronics, water hydraulics, water pumps, handtools, blueprint reading, piping systems, lubrication, and data collection.

Each volume in the series is written in a straightforward style without jargon or complex calculations. All are heavily illustrated and include extensive, clearly outlined sample problems. Self-check tests are found within every chapter, and a comprehensive examination concludes each book.

The series provides operators with the information required for improved job performance. Equally important, using key points, worked problems, and sample test questions, the series is designed to help operators answer questions and solve problems on certification and licensure examinations.

Preface

Anyone who has worked in a water or wastewater facility knows that piping and valves are the major conduits (piping) and critical controls (valves) that enable proper treatment and distribution of water and/or proper treatment and outfall of wastewater. Indeed, a water/wastewater operator would find it extremely difficult (if not impossible) to find any location on a plant site or at remote locations (pumping stations, distribution networks, etc., for example) where there were no pipes or valves.

Because water cannot be properly treated and distributed, and wastewater cannot be outfalled without the use of piping and valves, as water/wastewater maintenance operators, we must be familiar with piping, piping systems, valves, fittings, strainers, filters, traps and accessories that make piping systems function. We are also directly concerned with various forms of piping, tubing, hose, and the fittings that connect these components into workable systems.

In water/wastewater operations, we must not forget that the "workable systems" not only include the conveyance of raw water through treatment to delivery or the conveyance of the wastewater influent through treatment to effluent outfall, but also much more. For example, piping and valves are used to feed various chemicals used in both water and wastewater treatment unit processes. Plant auxiliary systems (including low- and high-pressure air systems, hydraulic systems, and conveyance of off-gases such as methane and hydrogen sulfide) all depend, in one way or another, on piping and valves. We also work with various types of piping systems. For example, in water distribution, a typical piping system consists of transmission lines, in-plant piping systems, distribution mains, and services (service lines). In wastewater treatment, piping systems include chemical feed lines, conventional sludge piping, and gravity sludge withdrawal lines, to name only a few. A key point to keep in mind is that any piped system can vary from simple to extremely complicated —a complex maze of pipes, connections, valves, and other accoutrements—but with a basic understanding of piping and valves, working your way through the maze becomes much easier.

Piping and Valves is the fifth volume of Technomic Publishing Company, Inc.'s Water and Wastewater *Maintenance Operator Series*. As such, and as with the first four volumes of the series, *Piping and Valves* is designed to bridge the gap that exists between the available training materials and the information water and wastewater maintenance operators need to know.

Each lesson presents important, practical knowledge about piping systems that are a vital part of plant operations and are essential to the success of its total activity, every step of the way. Completion of the lessons in this text will increase your maintenance skills and enhance your ability to score on licensure/certification examinations. The information provided in this book and this series will help you build your skills—and water/wastewater facilities need skilled maintenance operators to perform the important functions of preventive maintenance, to avoid major plant and/or system trouble, and to depend on to handle the needed repairs when breakdowns occur.

To assure correlation to modern practice and design, illustrative problems are presented in terms of commonly used piping and valve parameters and cover typical piping systems found in today's water/wastewater treatment systems.

Each chapter ends with a Self-Test to help you evaluate your mastery of the concepts presented. Before going on to the next chapter, take the Self-Test, compare your answers to the key, and review the pertinent information for any problems you missed. If you miss many items, review the whole chapter. A comprehensive final examination can be found at the end of this text.

IMPORTANT ***Note:*** *This symbol (to the left), displayed in various locations throughout this manual, indicates a point is especially important and should be studied carefully.*

This text is accessible to those who have no experience with piping and valves; however, an understanding of basic mechanics and water hydraulics will help. If you work through the text systematically, you will be surprised at how easily you acquire an understanding and skill in piping and valves, adding another critical component to your professional knowledge.

Acknowledgements

To water and wastewater operators everywhere.

Acknowlegements

Piping System Basics

The human circulatory system depends on the heart to provide the motive force for the circulation of blood. No one can doubt the vital importance of the heart in its steady, life-sustaining function. The heart provides only a power supply for the entire circulatory system, however. We must also credit the circulatory system's conduits (the arteries, veins, and capillaries) and control mechanisms (the valves) that ensure the ultimate delivery of the life-sustaining substance to the rest of the system (the body) in maintaining life. Similarly, in a fluid mechanical system, an electric motor and pump unit typically provide the all important motive force to push various fluid substances (any substance or material that flows) from a source to its delivery point. No one can doubt the importance of the prime mover (motor/pump), especially the maintenance operator, in the operation. Again, though, we must also credit the system's delivery (piping) and control system (valves) for ultimate delivery of the fluid substance.

TOPICS

1.1 DELIVERING THE LIFEBLOOD OF CIVILIZATION

Piping systems resemble veins, arteries, and capillaries. According to Nayyar (2000, p. A-3), "they carry the lifeblood of modern civilization. In a modern city they transport water from the sources of water supply to

Key Terms Used in This Chapter

EXPANSION JOINT	Absorbs thermal expansion/contraction in piping systems.
FLUIDS	Any substance that flows.
DOUBLE-LINE DIAGRAM	Pictorial view of the pipes, joints, valves, and other major components similar to an electrical wiring diagram.
PIPING SYSTEM	A complete network of pipes, valves, and other components.
SINGLE-LINE DIAGRAM	Uses symbols for all the diagram components.

the points of distribution; convey waste from residential and commercial buildings and other civic facilities to the treatment facility or the point of discharge."

Water/wastewater maintenance operators must be familiar with piping, piping systems, and the many components that make piping systems function. Maintenance operators are directly concerned with various forms of piping, tubing, hose, and the fittings that connect these components to create workable systems.

This chapter covers important, practical knowledge about the piping systems that are a vital part of plant operation, essential to the success of the total activity. To prevent major system trouble, skilled maintenance operators are called upon to perform the important function of preventive maintenance to avoid major breakdowns and must be able to make the needed repairs when breakdowns do occur. A comprehensive knowledge of piping systems and accoutrements is essential to maintaining plant operations.

As with the other volumes in the series, this volume presents detailed technical information based on real-life experience-the kind of information that you will find beneficial for enhancing your personal knowledge on piping and valves and for improving the professional performance of your technical responsibilities.

1.2 PIPING SYSTEMS

In water/wastewater operations, the term *piping system* refers to a complete network of pipes, valves, and other components. For water/wastewater operations in particular, the piping system is all-inclusive; it includes the network of pipes, valves, and other components that bring the flow (water or wastewater) to the treatment facility, as well as piping, valves, and other components that distribute treated water to the end-user and/or treated wastewater to outfall. In short, all piping systems are designed to perform a specific function.

Probably the best way to illustrate the importance of a "piping system" is to describe many of its applications used in water/wastewater operations. In the modern water/wastewater treatment plant, for example, piping systems are critical to successful operation. In water/wastewater operations, fluids and gases are used extensively in processing operations; they are usually conveyed through pipes. Piping carries water/wastewater into the plant for treatment, fuel oil to heating units, steam to steam services, lubricants to machinery, compressed air to pneumatic service outlets for air-powered tools, etc., and chemicals to unit processes.

Besides raw water, treated water, wastewater influent, and treated wastewater effluent, the materials moved through piping systems include oils, chemicals, liquefied gases, acids, paints, sludge, and many others.

IMPORTANT

Important Point: *Because of the wide variety of materials that piping systems can convey, the components of piping systems are themselves made of different materials and are furnished in many sizes to accommodate the requirements of numerous applications. For example, pipes and fittings can be made of stainless steel, many different types of plastic, brass, lead, glass, steel, and cast iron.*

Any waterworks or wastewater treatment plant has many piping systems, not just the systems that convey water and/or wastewater. Plant piping systems include those that provide hot and cold water for plant personnel use. Another system heats the plant, while still another may be used for air conditioning.

Water/wastewater maintenance operators have many responsibilities and basic skills. The typical plant maintenance operator is skilled in HVAC systems, chemical feed systems, mechanical equipment operation and repair, and piping system maintenance activities. However, only the fluid transfer systems themselves are important to us in this text. The units that the piping system serves or supplies (such as pumping, unit processes, and machines) are discussed in other volumes of the series.

For water/wastewater maintenance operators, a familiar example of a piping system is the network of sodium hypochlorite pipes in treatment plants that use this chemical for disinfection and other purposes. The whole group of components—pipes, fittings, and valves—working together for one purpose makes up a *system*. This particular system has a definite purpose, which is to carry sodium hypochlorite and distribute it, conveying it to the point of application.

This text is concerned only with the piping system used to circulate the chemical, not with the hypochlorination equipment itself. Our concern begins where the chemical outlet is connected to the storage tank and continues to the point where the pipe is connected to the point of application. The piping, fittings, and valves of the hypochlorination pipeline (and others) are important to us. Gate, needle, pressure-relief, air-and-vacuum relief, diaphragm, pinch butterfly, check, rotary and globe valves, traps, expansion joints, plugs, elbows, tee fittings, couplings, reducers, laterals, caps, and other fittings help ensure the effective flow of fluids through the lines. As you trace a piping system through your plant site, you will find many of them (see Figure 1.1). They are important because they are directly related to the operation of the system. Piping system maintenance is concerned with keeping the system functioning properly, and to function properly, piping systems must be kept closed and leakproof.

IMPORTANT

Important Point: *Figure 1.1 shows a single-line diagram that is similar to an electrical schematic. It uses symbols for all the diagram components. A double-line diagram (not shown here) is a pictorial view of the pipe, joints, valves, and other major components similar to an electrical wiring diagram, instead of an electrical schematic.*

1.3 FLUIDS VS. LIQUIDS

We use the term "fluids" throughout this text to describe the substance(s) being conveyed through various piping systems from one part of

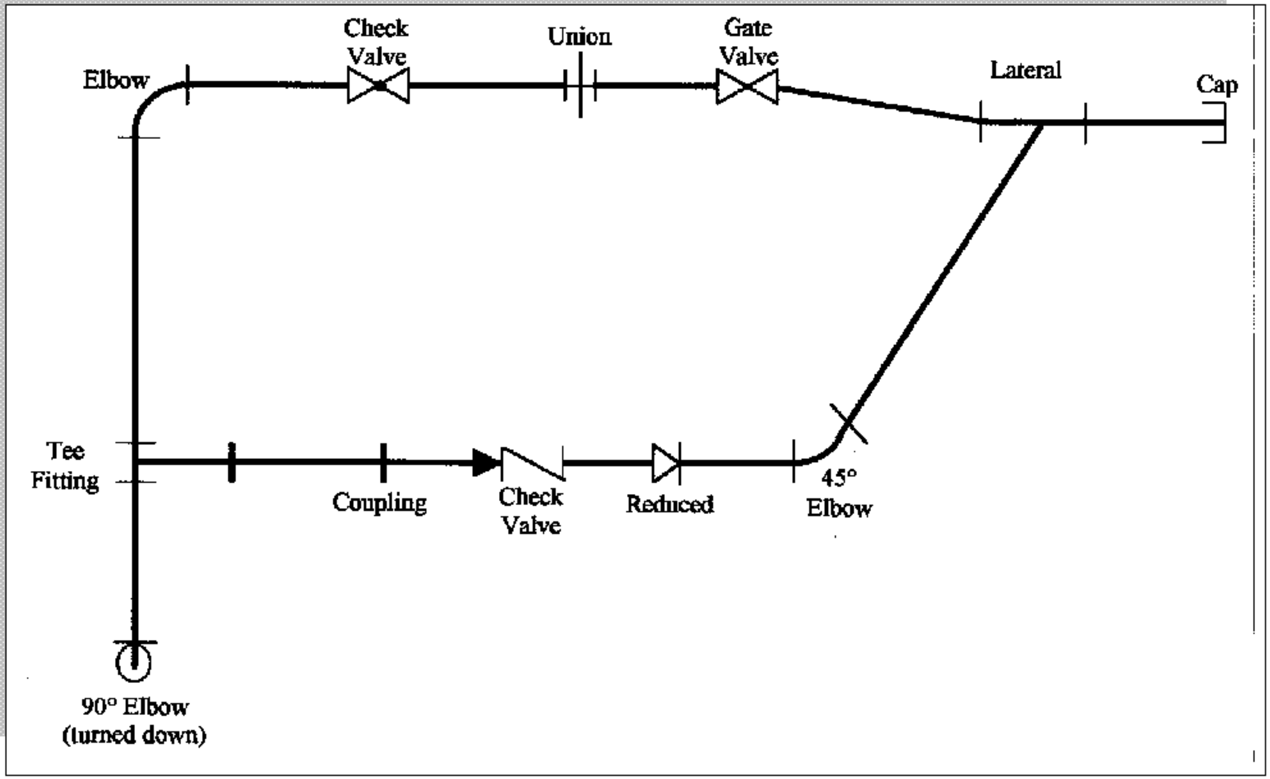


Figure 1.1
Shows various components in a single-line piping diagram.

the plant to another. We normally think of pipes conveying some type of liquid substance, which most of us take to have the same meaning as fluid, however, there is a subtle difference between the two terms. The dictionary's definition of *fluid* is "any" substance that flows, which can mean a liquid or gas (air, oxygen, nitrogen, etc.). Some fluids carried by piping systems include thick viscous mixtures such as sludge in a semi-fluid state. Although sludge and other such materials might seem more solid (at times) than liquid, they do flow, and are considered fluids.

In addition to carrying liquids such as oil, hydraulic fluids, and chemicals, piping systems carry compressed air and steam, which are also considered fluids because they flow.

IMPORTANT

Important Point: *Fluids travel through a piping system at various pressures, temperatures, and speeds.*

1.4 MAINTAINING FLUID FLOW IN PIPING SYSTEMS

The primary purpose of any piping system is to maintain free and smooth flow of fluids through the system. Another purpose is to ensure that the fluids being conveyed are kept in good condition (i.e., free of contamination).

Piping systems are purposely designed to ensure free and smooth flow of fluids throughout the system, but additional system components are often included to ensure that fluid quality is maintained. Piping system filters are one example, and strainers and traps are two others.

It is extremely important to maintain free and smooth flow and fluid quality in piping systems, especially those that feed vital pieces of equipment/machinery. Consider the internal combustion engine, for example. Impurities such as pieces of dirt and metal can damage internal components and cause excessive wear and eventual breakdown. To help prevent such wear, the oil is run continuously through a filter designed to trap and filter out the impurities.

Other piping systems need the same type of protection that the internal combustion engine does, which is why most piping systems include filters, strainers, and traps. These filtering components may prevent damage to valves, fittings, the pipe itself, and to downstream equipment/machinery. Chemicals, various types of waste products, paint, and pressurized steam are good examples of potentially damaging fluids. Filters and strainers play an important role in piping systems, protecting both the piping system and the equipment that the piping system serves.

Figure 1.2 shows what can happen [*scaling* (see Section 1.3.1)] in a PVC piping system used to feed sodium hypochlorite (a chemical disinfectant commonly used in water/wastewater treatment) if adequate protection (and preventive maintenance) is not provided. Figure 1.2 emphasizes the necessity for providing maximum protection and preventive maintenance in a piping system.

Figure 1.2
Shows the effect of scaling buildup in a PVC-type pipe used in a sodium hypochlorite system.

1.4.1 SCALING[1]

Because sodium and calcium hypochlorite are widely used in water/wastewater treatment operations, problems common in piping systems feeding these chemicals are of special concern. In this section, we discuss *scaling* problems that can occur in piping systems that convey hypochlorite solution.

To maintain the chlorine in solution (used primarily as a disinfectant), sodium hydroxide (caustic) is used to raise the pH of the hypochlorite; the excess caustic raises the shelf life. A high pH caustic solution raises the pH of the dilution water to over pH 9.0 after it is diluted. The calcium in the dilution water reacts with dissolved CO_2 and forms calcium carbonate. Experience has shown that two-inch pipes have turned into 3/4-inch pipes due to scale buildup (and even worse in some cases; see Figure 1.2). The scale deposition is greatest in areas of turbulence such as pumps, valves, rotameters, backpressure devices, etc.

If lime (calcium oxide) is added (for alkalinity), plant water used as dilution water will have higher calcium levels and generate more scale. For example, assume that there is approximately 48 mg/L of calcium in the effluent. A diluted hypochlorite (1:50) generates 82 mg of scale per liter in lab experiments. While it is true that softened water will not generate scale, it is also true that it is expensive in large quantities. Many facilities use softened water on hypochlorite mist odor scrubbers only.

Scaling also often occurs in solution rotameters, making flow readings impossible and freezing the flow indicator in place. Various valves can freeze, and pressure-sustaining valves freeze and become plugged. Various small diffuser holes fill with scale. To slow the rate of scaling, many facilities purchase water from local suppliers to dilute hypochlorite for the RAS and miscellaneous uses.

Some facilities have experimented with the system by not adding lime to it. When they did this, manganese dioxide (black deposits) developed on the rotameter glass, making viewing the float impossible. In many instances, moving the point of hypochlorite addition downstream of the rotameter seemed to solve the problem.

[1] Adapted from Baur. 1998. p. 6.

Various facilities have also had three large (3-inch) 1400-foot long delivery lines scale up. (**Note:** Detention time in the lines was significant at 30 hours.) To avoid additional scaling, some facilities deliver only neat (undiluted) hypochlorite in them. This appears to have rendered positive results.

If remedial steps are not taken, scaling from hypochlorite solutions can cause the type of problem shown in Figure 1.2. Consider what happened in this particular instance. The scale buildup reduced the inside diameter of the pipe so much that the actual supply of hypochlorite solution required to properly disinfect water or wastewater was reduced. As a result, the water sent to the customer or outfalled to the receiving body was not properly disinfected. Because of the scale buildup, the system itself did not function as designed and could have resulted in a hazardous situation in which the reduced pipe size increased the pressure level to the point of catastrophic failure. The above situation clearly demonstrates that scaling, corrosion, or other clogging problems in certain piping systems are far from an ideal situation.

EXAMPLE 1.1

For explanation purposes, this problem will be taken a step further by use of example. Assume that we have a piping system designed to provide chemical feed to a critical plant unit process. If the motive force for the chemical being conveyed is provided by a positive-displacement pump (for more information on the positive-displacement pump see the fourth volume of the series: *Pumping*) at a given volume of solution at 70 psi through clean pipe. After clogging takes place, the pump continues trying to force the same volume of chemical through the system at 70 psi, but the pressure drops to 25 psi. Friction caused the pressure to drop. The reduction of the inside diameter of the pipe increased the friction between the chemical solution and the inside wall of the pipe.

IMPORTANT ***Important Point:*** *A basic principle in fluid mechanics states that fluid flowing through a pipe is affected by friction—the greater the friction, the greater the loss of pressure.*

IMPORTANT ***Important Point:*** *Another principle or rule states that the amount of friction increases as the square of the velocity. (**Note:** speed and velocity are not the same, but common practice refers to the "velocity" of a fluid.) In short, if the velocity of the fluid doubles, the friction increases four times more than what it was before. If the velocity is multiplied by five, the friction is multiplied by 25, and so on.*

In Example 1.1, the pressure dropped from 70 psi to 25 psi because the water had to run faster to move through the pipe. Because the velocity of the water pushed by the pump had to increase to levels above what it was when the pipe was clean, the friction increased at a higher rate than before. The fiction loss was the reason that a pressure of 25 psi reached the far end of the piping system. The equipment designed to operate at a pressure of 70 psi could not work on the 25 psi of pressure being supplied.

IMPORTANT ***Important Point:*** *After reviewing the previous example, you might ask: Why couldn't the pump be slowed so that the chemical solution could pass more slowly through the system, thus avoiding the effect of increased friction? Lower pressure results as pump speed is reduced. This causes other problems as well. Pumps that run at a speed other than that for which they are designed do so with a reduction in efficiency.*

What is the solution to our pressure loss problem in Example 1.1? Actually, we can solve this problem two possible ways, either replace the piping or clean it.

"Replace the piping or clean it," sounds simple and straightforward, but it can be complicated. If referring to a pipe that is relatively short, no more than 20 to a few hundred feet in length, then we may decide to replace the pipe. If discussing a pipe that is three to five miles or more in length, cleaning it probably makes more sense than replacing its entire length. Each situation is different, requiring remedial choices based on practicality and expense.

1.5 PIPING SYSTEM MAINTENANCE

Maintaining a piping system can be an involved process. However, good maintenance practices can extend the life of piping system components, and rehabilitation can further prolong their life.

The performance of a piping system depends on the ability of the pipe to resist unfavorable conditions and to operate at or near the capacity and efficiency that it was designed for. This performance can be checked in several ways: flow measurement, fire flow tests, loss-of-head tests, pressure tests, simultaneous flow and pressure tests, tests for leakage, and chemical and bacteriological water tests. These tests are an important part of system maintenance. They should be scheduled as part of the regular operation of the system (AWWA, 1996, p. 211).

Most piping systems are designed with various protective features included to minimize wear and catastrophic failure and, therefore, the amount of maintenance required. Such protective features include pressure relief valves, blow-off valves, and clean-out plugs.

- *Pressure relief valve*—a valve that opens automatically when the fluid pressure reaches a preset limit to relieve the stress on a piping system.
- *Blow-off valve*—a valve that can be opened to blow out any foreign material in a pipe.
- *Clean-out plug*—a threaded plug that can be removed to allow access to the inside of the pipe for cleaning.

IMPORTANT

Important Point: *Use caution when removing a clean-out plug from a piping system. Before removing the plug, pressure must be cut off, and the system must be bled of residual pressure.*

Many piping systems (including water distribution networks and wastewater lines and interceptors) can be cleaned either by running chemical solvents through the lines or by using mechanical clean-out devices.

1.6 VALVES

Depending on the complexity of the piping system, the number of valves included in a system can range from no more than one in a small, simple system to a large number in very complex systems such as water distribution systems. *Valves* are necessary for the operation of a piping system and for control of the system and system components. In water/wastewater treatment, this control function is used to control various unit processes, pumps, and other equipment.

Valves also function as protective devices. For example, valves used to protect a piping system may be designed to open automatically to vent fluid out of the pipe when the pressure in the lines gets too high. In lines that carry liquids, relief valves preset to open at a given pressure are commonly used.

IMPORTANT ***Important Point:*** *Not all valves function as safety valves. For example, hand-operated gate and globe valves function primarily as control valves.*

The correct size and type of valve are selected for each use. Most valves require periodic inspection to ensure they are operating properly.

1.7 PIPING SYSTEM ACCESSORIES

Along with valves, piping systems typically include accessories such as pressure and temperature gauges, filters, strainers, and pipe hangers and supports.

- *Pressure gauges*—show what the pressure in the piping system is.
- *Temperature gauges*—show what the temperature in the piping system is.
- *Filters and Strainers*—are installed in piping systems to help keep fluids clean and free from impurities.

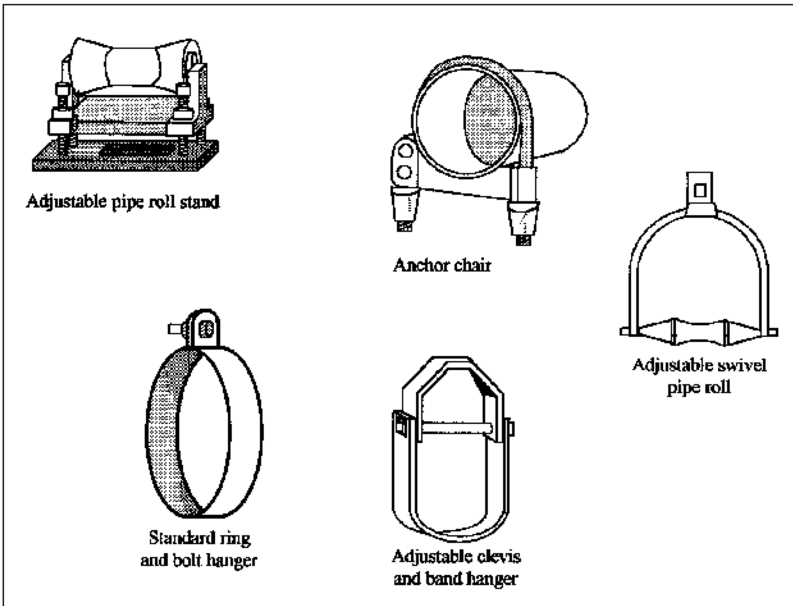


Figure 1.3
Pipe hangers and supports.

- *Pipe hangers and supports*—support piping to keep the lines straight and prevent sagging, especially in long runs. Various types of pipe hangers and supports are shown in Figure 1.3.

1.8 PIPING SYSTEMS: TEMPERATURE EFFECTS

Most materials, especially metals, expand as the temperature increases and contract as the temperature decreases. This can be a significant problem in piping systems. To combat this problem, and to allow for expansion and contraction in piping systems, expansion joints must be installed in the line between sections of rigid pipe. An *expansion joint* absorbs thermal expansion and/or terminal movement; as the pipe sections expand or contract with the temperature, the expansion joint expands or compresses accordingly, eliminating stress on the pipes.

1.9 PIPING SYSTEMS: INSULATION

You do not need to wander too far in most plant sites to find pipes covered with layers of piping insulation. Piping insulation amounts to wrapping the pipe in an envelope of insulating material. The thickness of the insulation depends on the application. Under normal circumstances, heat passes from a hot or warm surface to a cold or cooler one. Insulation helps prevent hot fluid from cooling as it passes through the system. For systems conveying cold fluid, insulation helps keep the fluid cold.

Materials used for insulation vary, and they are selected according to the requirements of the application. Various types of insulating materials are also used to protect underground piping against rusting and corrosion caused by exposure to water and chemicals in the soil.

Self-Test

1.1 Define expansion joint:

1.2 A __________ is defined as any substance or material that flows.

1.3 Compressed air is considered to be a __________.

1.4 Sections or lengths of pipe are __________ with fittings.

1.5 The __________ of fluids through a pipe is controlled by valves.

1.6 Friction causes __________ __________ in a piping system.

1.7 As friction __________ in a piping system, the output pressure decreases.

1.8 Relief valves are designed to open __________.

1.9 __________ is used to help keep the fluids carried in piping systems hot or cold.

1.10 The major problems in piping systems are caused by __________ and corrosion.

1.11 If the speed of fluid in a pipe doubled, the friction is __________.

1.12 The most important factor in keeping a piping system operating efficiently is __________.

Metallic Piping

Pipe materials that are used to transport water may also be used to collect wastewater. It is more usual, however, to employ less expensive materials since wastewater lines rarely are required to withstand any internal pressure. Iron and steel pipe are used to convey wastewater only under unusual loading conditions or for force mains (interceptor lines) in which the wastewater flow is pressurized.[2]

TOPICS

2.1 PIPING MATERIALS

Materials selected for piping applications must be chosen with the physical characteristics needed for the intended service in mind. For example, the piping material selected must be suitable for the flow medium and the given operating conditions of temperature and pressure during the intended design life of the product. For long-term service capability, the material's mechanical strength must be appropriate; the piping material must be able to resist operational variables such as thermal or mechanical cycling. Extremes in application temperature must also be considered in respect to material capabilities.

Environmental factors must also be considered. The operating environment surrounding the pipe or piping components affects pipe durability and life span. Corrosion, erosion, or a combination of the two can result in degradation of material properties or loss of effective load-carrying cross section. The nature of the substance contained by the piping is an important factor as well.

[2] Adapted from McGhee, 1991, p. 297.

Key Terms Used in This Chapter

ALLOY	A substance composed of two or more metals.
METALLURGY	The science and study of metals.
FERROUS	A term applied to a metal that contains iron.
NONFERROUS	A term applied to a material that does not contain iron.
DUCTILE	A term applied to a metal that can be fashioned into a new form without breaking.
ANNEAL	To heat and then cool a metal in order to make it softer and less brittle.
WATER HAMMER	The concussion of moving water against the sides of pipe, caused by a sudden change in the rate of flow or stoppage of flow in the line.
VISCOSITY	The thickness or resistance to flow of a liquid.
SCHEDULE	Approximate value of the expression 1000 P/S, where P is the service pressure and S is the allowable stress, both expressed in pounds per square inch.
NOMINAL PIPE SIZE	The thickness given in the product material specifications or standard to which manufacturing tolerances are applied.
CAST IRON	A generic term for the family of high carbon-silicon-iron casting alloys including gray, white, malleable, and ductile iron.
STAINLESS STEEL	An alloy steel having unusual corrosion-resisting properties, usually imparted by nickel and chromium.
JOINT	A connection between two lengths of pipe or between a length of pipe and a fitting.

Knowledge of the basic characteristics of the metals and nonmetals (nonmetallic piping is discussed in Chapter 3) used for piping provides clues to the uses of the piping materials in water/wastewater treatment operations. Such knowledge is especially helpful to maintenance operators, making their job much easier and more interesting. In this chapter, metallic piping is discussed. Piping joints, how to join or connect sections of metallic piping, and how to maintain metallic pipe are also described.

2.2 PIPING: THE BASICS

Earlier, we pointed out that "piping" includes pipe, flanges, fittings, bolting, gaskets, valves, and the pressure-containing portions of other piping components.

IMPORTANT ***Important Point:*** *According to Nayyar (2000, p. A-4), "a* pipe *is a tube with round cross section conforming to the dimensional requirements of ASME B36.10M (Welded and Seamless Wrought Steel Pipe) and ASME B36.19M (Stainless Steel Pipe)."*

Piping also includes pipe hangers and supports and other accessories necessary to prevent overpressurization and overstressing of the pressure-containing components. From a system viewpoint, a pipe is one element or a part of piping. Accordingly, when joined with fittings, valves, and other mechanical devices or equipment, pipe sections are called *piping*.

2.2.1 PIPE SIZES

With time and technological advancements (development of stronger and corrosion-resistant piping materials), pipe sizes have become standardized and are usually expressed in inches or fractions of inches. As a rule, the size of a pipe is given in terms of its outside or inside diameter. Figure 2.1 shows the terminology that applies to a section of pipe. Pipes are designated by diameter. The principal dimensions are as follows:

- wall thickness
- length
- outside diameter (O.D.)—used to designate pipe greater than 12 inches in diameter

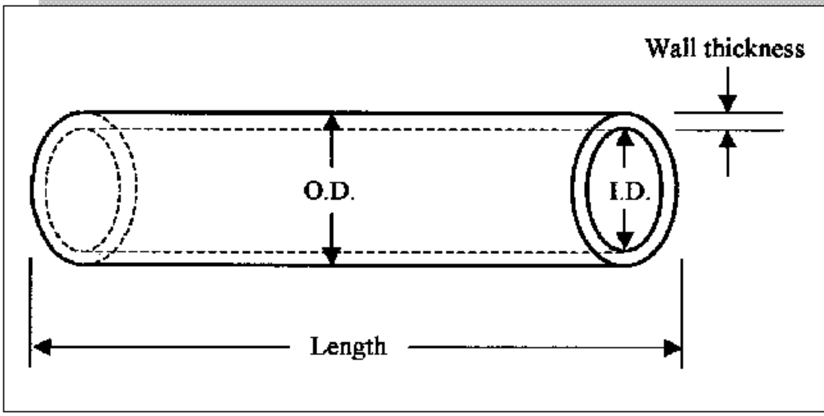


Figure 2.1
Pipe terminology.

- inside diameter (I.D.)—used to designate pipe less than 12 inches in diameter

IMPORTANT ***Important Point:*** *Another important pipe consideration not listed above or shown in Figure 2.1 is weight per foot, which varies according to the pipe material and pipe's wall thickness.*

In the continuing effort to standardize pipe size and wall thickness of pipe, the designation *nominal pipe size (NPS)* replaced the iron pipe size designation, and the term *schedule (SCH)* was developed to specify the nominal wall thickness of pipe.

The *nominal pipe size diameter* (approximate dimensionless designator of pipe size) is generally somewhat different from its actual diameter. For example, the pipe we refer to as a "3-inch diameter pipe" has an actual O.D. of 3.5 inches, while the actual O.D. of a "12-inch pipe" may be .075 inch greater (i.e., 12.750 inches) than the nominal diameter. On the other hand, a pipe 14 inches or greater in diameter has an actual O.D. equal to the nominal size. The inside diameter will depend upon the pipe wall thickness specified by the schedule number.

IMPORTANT ***Important Point:*** *Keep in mind that whether the O.D. is small or large, the dimensions must be within certain tolerances in order to accommodate various fittings.*

2.2.2 PIPE WALL THICKNESS

Original pipe wall thickness designations of STD (standard), XS (extra-strong), and XXS (double extra-strong) are still in use today; however, because this system allowed no variation in wall thickness, and because pipe requirements became more numerous, greater variation was needed. As a result, pipe wall thickness, or *schedule*, today is expressed in numbers (5, 5S, 10, 10S, 20, 20S, 30, 40, 40S, 60, 80, 80S, 100, 120, 140, 160). (**Note:** You will often hear piping referred to either in terms of its diameter or schedule number.) The most common schedule numbers are 40, 80, 120, and 160. The outside diameter of each pipe size is standardized. Therefore, a particular nominal pipe size will have a different inside diameter depending upon the schedule number specified. For example, a Schedule 40 pipe with a 3-inch nominal diameter (actual O.D. of 3.500 inches) has a wall thickness of 0.216 inch The same pipe in a Schedule 80 (XS) would have a wall thickness of 0.300 inch.

IMPORTANT ***Important Point:*** *A schedule number indicates the approximate value of the expression 1000 P/S, where P is the service pressure and S is the allowable stress, both expressed in pounds per square inch (psi). The higher the schedule number, the thicker the pipe.*

IMPORTANT ***Important Point:*** *The schedule numbers followed by the letter S are per ASME B36.19M, and they are primarily intended for use with stainless steel pipe.*[3]

2.2.3 PIPING CLASSIFICATION

The usual practice is to classify pipe in accordance with the pressure-temperature rating system used for classifying flanges. However, because

[3]ASME. 1996. p. B 111; ASME, 1985. B 113.

of the increasing variety and complexity of requirements for piping, a number of engineering societies and standards groups have devised codes, standards, and specifications that meet most applications. By consulting such codes (e.g., ASTM, Manufacturer's Specifications, NFPA, AWWA, and others), a designer can determine exactly what piping specification should be used for any application.

IMPORTANT ***Important Point:*** *Because pipelines often carry hazardous materials and fluids under high pressures, following a code helps ensure the safety of personnel, equipment, and the piping system itself.*

2.2.3.1 ASTM RATINGS

The American Society for Testing and Materials (ASTM) publishes standards (codes) and specifications that are used to determine the minimum pipe size and wall thickness to be used in any given application.

2.2.3.2 MANUFACTURER'S RATING

Pipe manufacturers, because of propriety design of pipe, fitting, or joint, often assign a pressure-temperature rating that may form the design basis or the piping system. (**Note:** In addition, the manufacturer may impose limitations that must be adhered to.)

IMPORTANT ***Important Point:*** *Under no circumstances shall the manufacturer's rating be exceeded.*

2.2.3.3 NFPA RATINGS

Certain piping systems fall within the jurisdiction of the National Fire Protection Association (NFPA). These pipes are required to be designed and tested to certain required pressures (usually rated for 175 psi, 200 psi, or as specified).

2.2.3.4 AWWA RATINGS

The American Water Works Association (AWWA) publishes standards and specifications that are used to design and install water pipelines and distribution system piping. The ratings used may be in accordance with the flange ratings of AWWA; or the rating could be based upon the rating of the joints used in the piping.

2.2.3.5 OTHER RATINGS

Sometimes a piping system may not fall within the above related rating systems. In this case, the designer may assign a specific rating to the piping system. This is a common practice in classifying or rating piping for main steam or hot reheat piping systems of power plants that have design pressure and design temperature that may exceed the pressure-temperature rating of ASME B16.5. In assigning a specific rating to such piping, the rating must be equal to or higher than the design conditions.

IMPORTANT ***Important Point:*** *The rating of all pressure-containing components in the piping system must meet or exceed the specific rating assigned by the designer (Nayyar, 2000, p. A-7).*

When piping systems are subjected to full-vacuum conditions or are submerged in water, they experience the internal pressure of the flow medium and the external pressure. In such instances, piping must be rated for both internal and external pressures at the given temperature. Moreover, if a piping system is designed to handle more than one flow medium during its different modes of operation, it must be assigned a dual rating for two different flow media.

2.2.4 TYPES OF PIPING SYSTEMS

Piping systems consist of two main categories: process lines and service lines.

Process lines convey the flow medium used in a manufacturing process or a treatment process (such as fluid flow in water and/or wastewater treatment). For example, one of the major unit process operations in wastewater treatment is sludge digestion. The sludge is converted from bulky, odorous, raw sludge to a relatively inert material that can be rapidly dewatered with the absence of obnoxious odors. Because sludge digestion is a unit process operation, the pipes used in the system are called process lines.

Service lines (or utility lines) carry water, steam, compressed air, air-conditioning fluids, and gas. Normally, all are part of the plant's general service system composed of service lines. Service lines cool and heat the plant, provide water where it is needed, and carry the air that drives air equipment and tools.

2.2.4.1 CODE FOR IDENTIFICATION OF PIPELINES

Under guidelines provided by the American National Standards Institute (ANSI-A 13.1-current date), a code has been established for the identification of pipelines. This code involves the use of nameplates (tags), legends, and colors. The code states that the contents of a piping system shall be identified by lettered legend giving the name of the contents. In addition, the code requires that information relating to temperature and pressure should be included. Stencils, tape, or markers can be used to accomplish the marking. To identify the characteristic hazards of the contents, color should be used, but its use must be in combination with legends.

IMPORTANT

Important Point: *Not all plants follow the same code recommendations, which can be confusing if you are not familiar with the system used. Standard piping color codes are often used in water and wastewater treatment operations. Plant maintenance operators need to be familiar with the pipe codes used in their plants.*

2.3 METALLIC PIPING MATERIALS

In the not too distant past, it was not (relatively speaking) that difficult to design certain pipe delivery systems. For example, several hundred years ago (and even more recently in some cases), when it was desirable to convey water from a source to point of use, the designer was faced with only two issues. First, a source of fresh water had to be found. Next, if the source was found and it was determined suitable for whatever need required, a means of conveying the water to point of use was needed.

In designing an early water conveyance system, gravity was the key player. This point is clear when you consider that before the advent of the pump, a motive force to power the pump, and the energy required to provide power to the motive force were developed, gravity was the means by which water was conveyed (with the exception of burdened humans/animals that physically carried the water) from one location to another.

Early gravity conveyance systems employed the use of clay pipe, wood pipe, natural gullies or troughs, aqueducts fashioned from stone, and any other means suitable/available to convey the water. Some of these earlier pipe or conveyance materials are still in use today.

With the advent of modern technology (electricity, the electric motor, the pump, and various machines/processes) and the need to convey fluids other than water, also came the need to develop piping materials that could carry a wide variety of fluids.

The modern waterworks has a number of piping systems made up of different materials. One of the principal materials used in piping systems is metal. Metal pipes may be made of cast iron, stainless steel, brass, copper, and various alloys. Waterworks/wastewater maintenance operators who work with metal piping must be knowledgeable about the characteristics of individual metals as well as the kinds of considerations common to all piping systems. These considerations include the effect of temperature changes, impurities in the line, shifting of pipe supports, corrosion, and water hammer.

In this section, information about pipes made of cast iron, steel, copper, and other metals is presented. The behavior of fluids in a piping system and the methods of connecting sections of pipe are also discussed.

2.3.1 CHARACTERISTICS OF METALLIC MATERIALS

Different metals have different characteristics, making them usable in a wide variety of applications. Metals are divided into two types: ferrous, which includes iron and iron-base alloys (a metal made up of two or more metals that dissolve into each other when melted together); and nonferrous, covering other metals and alloys.

IMPORTANT ***Important Point:*** *An alloy can also be formed by mixing a metal and a nonmetal [e.g., steel, which is a mixture of iron (a metal) and carbon (a nonmetal)].*

Metallurgy (the science and study of metals) deals with the extraction of metals from ores and with the combining, treating, and processing of metals into useful materials.

2.3.1.1 FERROUS, NONFERROUS METALS AND SPECIAL PIPE MATERIALS

A *ferrous* metal is one that contains iron (elemental symbol—Fe). Iron is one of the most common of metals but is rarely found in nature in its pure form. Comprising about 6% of the earth's crust, iron ore is actually in the form of iron oxides (Fe_2O_3 or Fe_3O_4). Coke and limestone are used in reduction of iron ore in a blast furnace, where oxygen is removed from the ore, leaving a mixture of iron and carbon and small amounts of other impurities. The end product removed from the furnace is called *pig iron*, an impure form of iron. Sometimes, the liquid pig iron is cast from the blast furnace and used directly for metal castings. However, the iron is more often remelted in a furnace to further refine it and adjust its composition (Babcock & Wilcox, 1972).

IMPORTANT **Important Note:** *Piping is commonly made of wrought iron, cast iron, or steel. The difference among them is largely the amount of carbon each contains.*

Remelted pig iron is known as *cast iron* (meaning the iron possesses carbon in excess of 2% weight). Cast iron is inferior to steel in malleability, strength, toughness, and ductility (i.e., it is hard and brittle). Cast iron has, however, better fluidity in the molten state and can be cast satisfactorily into complicated shapes.

Steel is an alloy of iron with not more than 2.0% by weight carbon. The most common method of producing steel is to refine pig iron by oxidation or impurities and excess carbon, both of which have a higher affinity for oxygen than iron. *Stainless steel* is an alloy of steel and chromium.

IMPORTANT **Important Note:** *When piping is made of stainless steel, it is identified by an "S" after the schedule number.*

Various heat treatments can be used to manipulate specific properties of steel, such as hardness and ductility (meaning it can be fashioned into a new form without breaking).

One of the most common heat treatments employed in steel processing is annealing. *Annealing* (sometimes referred to as stress-relieving) consists of heating the metal and permitting it to cool gradually to make it softer and less brittle.

IMPORTANT **Important Point:** *Steel is one of the most important basic production materials of modern industry.*

Nonferrous metals, unlike ferrous metals, do not contain iron. A common example of a nonferrous metal used in piping is brass. Other examples of nonferrous materials used in piping include polyethylene, polybutylene, polyurethane, and polyvinyl chloride (PCV). Pipes of these materials are commonly used in low-pressure applications for transporting coarse solids (Snoek and Carney, 1981).

In addition to the more commonly used ferrous and nonferrous metals, special pipe materials for special applications are also gaining wider use in industry, even though they are more expensive. Probably one of the most commonly used materials that falls into this category is aluminum pipe. Aluminum pipe has the advantage of being lightweight and corrosion-resistant with relatively good strength characteristics.

IMPORTANT ***Important Note:*** *Although aluminum is relatively strong, it is important to note that its strength decreases as temperature increases.*

Lead is another special pipe material used for certain applications, especially where a high degree of resistance to corrosive materials is desired. Tantalum, titanium, and zirconium piping materials are also highly resistant to corrosives.

2.3.2 METALLIC PIPE USED IN WATER/WASTEWATER TREATMENT OPERATIONS

In the preceding sections, the types of metallic piping currently available for industrial use were described. In this section, the types of metallic piping materials used in water and/or wastewater treatment are described, and the advantages and disadvantages of each type are highlighted.

2.3.2.1 METALLIC PIPING USED IN WATER TREATMENT/DISTRIBUTION

Piping systems convey many types of water, including service water, city water, treated or processed water, and distilled water. Service water, used for flushing and cooling purposes, is untreated water that is usually strained but is otherwise raw water taken directly from a source (e.g., lake, river, or deep well). City water is treated potable water. Treated water has been processed to remove various minerals that could cause deterioration or sludge in piping. Distilled water is specially purified.

Important Point: *Piping materials selection for use in water treatment/distribution operations should be based on commonly accepted piping standards such as those provided by the American Society for Testing and Materials (ASTM), American Water Works Association (AWWA), American National Standards Institute (ANSI), the American Society of Mechanical Engineers (ASME), and the American Petroleum Industry (API).*

2.3.2.1.1 CAST-IRON PIPE

According to the AWWA (1996, p. 27), "There are more miles of [cast iron pipe] in use today than of any other type. There are many water systems having cast-iron mains that are over 100 years old and still function well in daily use." Cast-iron pipe has the advantages of strength, long service life, and is reasonably maintenance-free. Its disadvantages include being subject to electrolysis and attack from acid and alkali soil, and being heavy to handle (Gagliardi and Liberatore, 2000, p. C-26).

2.3.2.1.2 DUCTILE-IRON PIPE

Ductile-iron pipe resembles cast-iron pipe in appearance and has many of the same characteristics. It differs from cast-iron pipe in that the graphite in the metal is spheroidal or nodular in form, that is, in ball-shape form rather than in flake form. Ductile-iron pipe is strong, durable, has high flexural strength, good corrosion resistance, lighter weight than cast iron, greater carrying capacity for the same external diameter, and is easily tapped. However, ductile-iron pipe is subject to general corrosion if installed unprotected in a corrosive environment (Gagliardi and Liberatore, 2000, p. C-28).

2.3.2.1.3 STEEL PIPE

Steel pipe is sometimes used for large feeder mains in water-distribution systems. It is frequently used where there is particularly high pressure or where very large-diameter pipe is required. Steel pipe is relatively easy to install, has high tensile strength, has lower cost, is good hydraulically when lined, and can be adapted to locations where some movement may occur. However, it is subject to electrolysis external corrosion in acid or alkali soil and has poor corrosion resistance unless properly lined, coated, and wrapped.

2.3.2.2 METALLIC PIPING USED IN WASTEWATER TREATMENT OPERATIONS

The materials of which street wastewater (sewer) pipes are most commonly constructed are vitrified clay pipe, plastic, concrete, and ductile-iron pipe. However, it is metallic ductile-iron pipe that is most commonly used in wastewater collection, primarily for force mains (interceptor lines, etc.) and for piping in and around buildings. Ductile-iron pipe is generally not used for gravity sewer applications, however.

2.4 MAINTENANCE CHARACTERISTICS OF METALLIC PIPING

Maintenance of metallic piping is determined in part by characteristics of the metal (i.e., expansion, flexibility, and support) and by the kind of maintenance common to nonmetallic piping systems. The major considerations are as follows:

- expansion and flexibility
- pipe support systems
- valve selection
- isolation
- preventing backflow
- water hammer
- air binding
- corrosion effects

2.4.1 EXPANSION AND FLEXIBILITY

Because of thermal expansion, water/wastewater systems (which are rigid and laid out in specified lengths) must have adequate flexibility. In water/wastewater systems without adequate flexibility, thermal expansion may lead to failure of piping or anchors. Moreover, it may also lead to joint leakage and excessive loads on appurtences. The thermal expansion of piping can be controlled by use of proper locations of anchors, guides, and snubbers. Where expansion cannot be controlled, flexibility is provided by use of bends, loops, or expansion joints (Gagliardi and Liberatore, 2000, p. C-32).

IMPORTANT

Important Point: *Metals expand or contract according to temperature variations. Over a long run (length of pipe), the effects can cause considerable strain on the lines, and damage or failure may result.*

2.4.2 PIPE SUPPORT SYSTEMS

Pipe supports are normally used to carry dead weight and thermal expansion loads. These pipe supports may loosen in time, and, therefore, they require periodic inspection. Along with normal expansion and contraction, vibration (water hammer and/or fluids traveling at high speeds and pressures) can cause the supports to loosen.

2.4.3 VALVE SELECTION

Proper valve selection and routine preventive maintenance are critical in the proper operation and maintenance of any piping system. In water/wastewater piping systems, valves are generally used for isolating a section of a water main/wastewater collection line, draining the water/wastewater line, throttling liquid flow, regulating water/wastewater storage levels, controlling water hammer, controlling bleed off of air, or preventing backflow.

2.4.4 ISOLATION

Various valves are used in piping systems to provide for isolation. For instance, gate valves are used to isolate specific areas (valve closed) of the system during repair work or to reroute water/wastewater flow (valve open) throughout the distribution or collection system. Service stop valves are commonly used to shut off service lines to individual homes or industries. Butterfly valves are also used for isolation purposes.

2.4.5 PREVENTING BACKFLOW

Backflow, or reversed flow, could result in contaminated or polluted water entering the potable water system. There are numerous places in a water distribution system where unsafe water may be drawn into the potable water mains if a temporary vacuum should occur in the system. In addition, contaminated water from a higher-pressure source can be forced through a water system connection that is not properly controlled. A typical backflow condition from a recirculated system is illustrated in Figure 2.2.

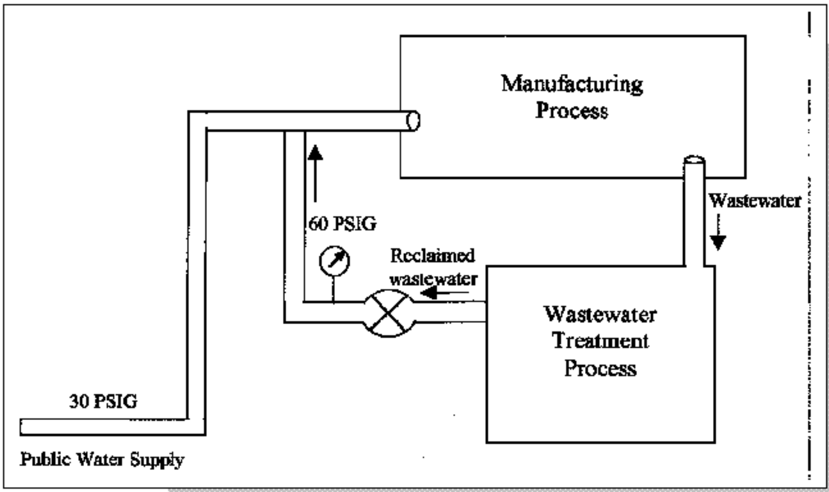


Figure 2.2
Backflow from a recirculated system.

IMPORTANT ***Important Point:*** *Valves, air gaps, reduced-pressure-zone backflow preventers, vacuum breakers, and barometric loops are often used as backflow-prevention devices, depending on the situation.*

2.4.6 WATER HAMMER

In water/wastewater operations specifically involving flow through piping, we often hear the term water hammer used. The term water hammer (often called surging) is actually a misnomer in that it implies only water and the connotation of a "hammering" noise. However, it has become a generic term for pressure wave effects in liquids.

By definition, *water hammer* is a pressure (acoustic) wave phenomenon created by relatively sudden changes in the liquid velocity. In pipelines, sudden changes in the flow (velocity) can occur as a result of pump and valve operation in pipelines, vapor pocket collapse, or even the impact of water following the rapid expulsion of air from a vent or a partially open valve (Marine, 1999, p. 6.1). Water hammer can damage or destroy piping, valves, fittings, and equipment.

IMPORTANT ***Important Point:*** *When water hammer occurs, there is little the maintenance operator can do except to repair any damage that results.*

2.4.7 AIR BINDING

Air enters a piping system from several sources, such as the release of air from the water, air carried in through vortices into the pump suction, air leaking in through joints that may be under negative pressure, and air present in the piping system before it is filled. The problem with air entry or air binding, because of air accumulation in piping, is that the effective cross-sectional area for water/wastewater flow in piping is reduced. This flow reduction can, in turn, lead to an increase in pumping costs through the resulting extra head loss.

2.4.8 CORROSION EFFECTS

All metallic pipes are subject to corrosion. Many materials react chemically with metal piping to produce rust, scale, and other oxides. In water treatment processes, when raw water is taken from wells, rivers, or lakes, the water solution is an extremely dilute liquid of mineral salts and gases. The dissolved mineral salts are a result of water flowing over and through the earth layers. The dissolved gases are atmospheric oxygen and carbon dioxide, picked up by water-atmosphere contact. Wastewater picks up corrosive materials mainly from industrial processes and/or from chemicals added to the wastewater during treatment.

IMPORTANT

Important Point: *Materials such as acids, caustic solutions, and similar solutions are typical causes of pipe corrosion.*

There are several types of corrosion to be considered in water and/or wastewater distribution/collection piping systems (AWWA, 1996, pp. 239–241):

- internal corrosion—caused by aggressive water flowing through the pipes
- external corrosion—caused by the soil's chemical and electrical conditions
- bimetallic corrosion—caused when components made of dissimilar metals are connected
- stray-current corrosion—caused by uncontrolled DC electrical currents flowing in the soil

2.5 JOINING METALLIC PIPE

According to Crocker, pipe joint design and selection can have a major impact on the initial cost, long-range operating cost, and the performance of the piping system. When determining the type of joint to be used in connecting pipe, certain considerations must be made. For example, initial considerations include material cost, installation labor cost, and degree of leakage integrity required. The maintenance operator is also concerned with periodic maintenance requirements and specific performance requirements (Crocker, 2000, p. B.28).

Metallic piping can be joined or connected in a number of ways. The method used depends on the nature of the metal sections (ferrous, nonferrous) being joined, the kind of liquid or gas to be carried by the system, pressure and temperature in the line, and access requirements.

A *joint* is defined simply as the connection between elements in a piping system. At present, there are five major types of joints, each used for a special purpose, used for joining metal pipe (see Figure 2.3):

1. Bell-and-spigot joints
2. Screwed or threaded joints
3. Flanged joints
4. Welded joints
5. Soldered joints

2.5.1 BELL-AND-SPIGOT JOINTS

The *bell-and-spigot joint* has been around since its development in the late 1780s. The joint is used for connecting lengths of cast-iron water and wastewater pipe (gravity flow only). The *bell* is the enlarged section at one end of the pipe; the plain end is the *spigot* (see Figure 2.3). The spigot end is placed into the bell, and the joint is sealed. The joint-sealing compound is typically made up of lead and oakum. Lead and oakum constitute the prevailing joint sealer for sanitary systems. Bell-and-spigot joints are usually reserved for sanitary sewer systems; they are no longer used in water systems.

IMPORTANT

Important Point: *Bell-and-spigot joints are not used in ductile-iron pipe.*

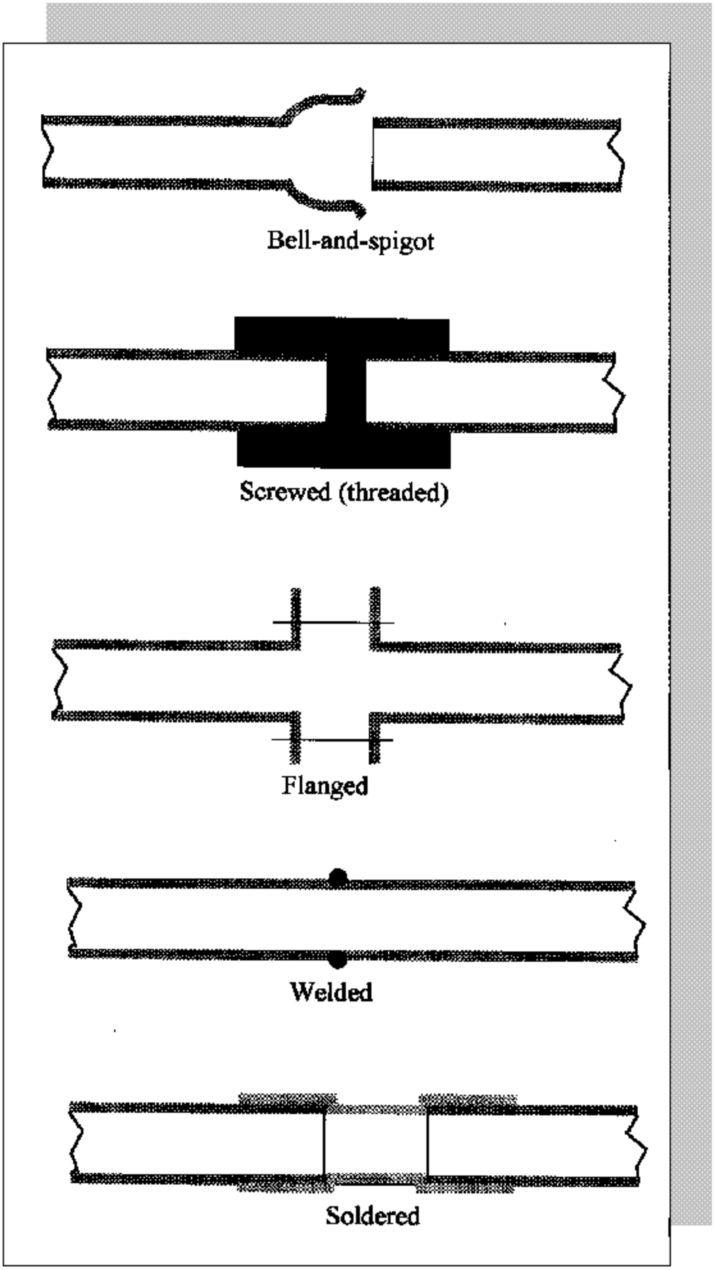


Figure 2.3
Common pipe joints.

2.5.2 SCREWED OR THREADED JOINTS

Screwed or threaded joints (see Figure 2.3) are commonly used to join sections of smaller-diameter low-pressure pipe; they are used in low-cost, noncritical applications such as domestic water, industrial cooling, and fire protection systems. Diameters of ferrous or nonferrous pipe joined by threading range from 1/8 inch up to 8 inches. Most couplings have threads on the inside surface. The advantages of this type of connection are its relative simplicity, ease of installation (where disassembly and reassembly are necessary to accommodate maintenance needs or process changes), and high leakage integrity at low pressure and temperature where vibration is not encountered. Screwed construction is commonly used with galvanized pipe and fittings for domestic water and drainage applications.

IMPORTANT ***Important Point:*** *maintenance supervisors must ensure that screwed or threaded joints are used within the limitations imposed by the rules and requirements of the applicable code.*

2.5.3 FLANGED JOINTS

As shown in Figure 2.4, flanged joints consist of two machined surfaces that are tightly bolted together with a gasket between them. The

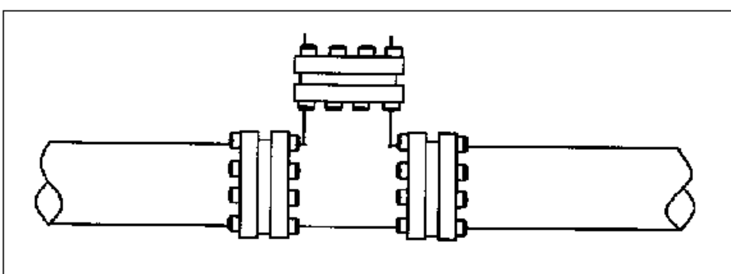


Figure 2.4
Flanged assembly.

flange is a rim or ring at the end of the fitting, which mates with another section. Flanges are joined either by being bolted together or welded together. Some flanges have raised faces and others have plain faces, as shown in Figure 2.5. Steel flanges generally have raised faces, and iron flanges usually have plain or flat faces.

IMPORTANT

Important Point: *A flange with a raised face should never be joined to one with a plain face.*

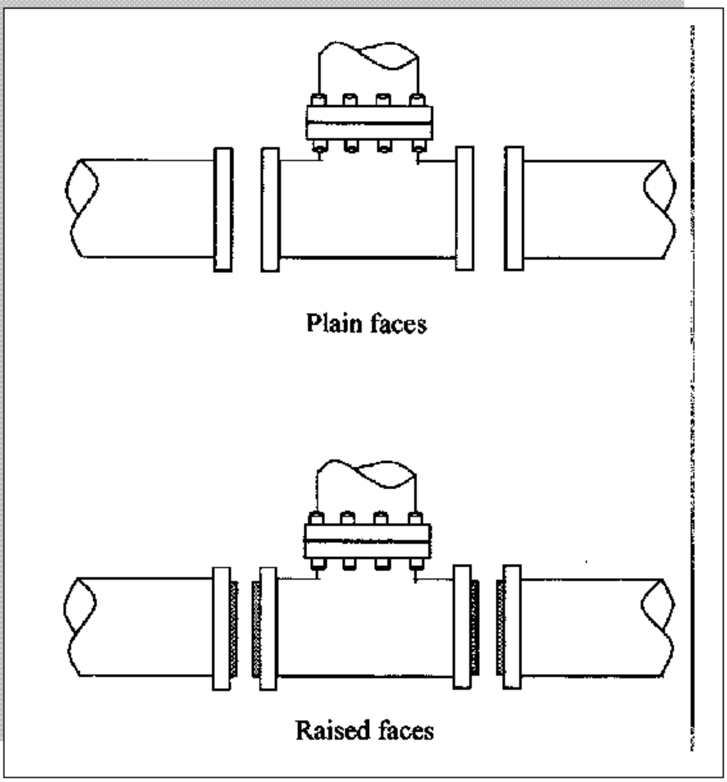


Figure 2.5
Flange faces.

Flanged joints are used extensively in water/wastewater piping systems because of their ease of assembly and disassembly; however, they are expensive. Contributing to the higher cost are the material costs of the flanges themselves and the labor costs for attaching the flanges to the pipe and then bolting the flanges to each other (Crocker, 2000, p. B.30). Flanged joints are not normally used for buried pipe because of their lack of flexibility to compensate for ground movement. Instead, flanged joints are primarily used in exposed locations where rigidity, self-restraint, and tightness are required (e.g., inside treatment plants and pumping stations).

2.5.4 WELDED JOINTS

For applications involving high pressures and temperatures, *welded joints* are preferred. Welding of joints is the process whereby metal sections to be joined are heated to such a high temperature that they melt and blend together. The advantage of welded joints is obvious: the pieces joined become one continuous piece. When a joint is properly welded, the joint is as strong as the piping itself.

The two basic welded joints are as follows (see Figure 2.6):

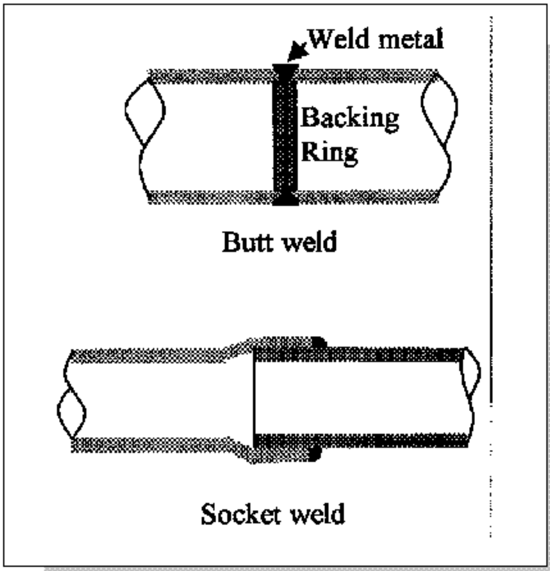


Figure 2.6
Two kinds of welding pipe joints.

1. Butt-welded joints, in which the sections to be welded are placed end-to-end, are the most common method of joining pipe used in large industrial piping systems.

2. Socket-welded joints, in which one pipe fits inside the other, the weld being made on the outside of the lap, are used in applications where leakage integrity and structural strength are important.

2.5.5 SOLDERED AND BRAZED JOINTS

Soldered and brazed joints are most often used to join copper and copper-alloy (nonferrous metals) piping systems, although brazing of steel and aluminum pipe and tubing is possible. The main difference between *brazing* and welding is temperatures employed with each process. Brazing is accomplished at far lower temperatures. Brazing, in turn, requires higher temperatures than *soldering*. In both brazing and soldering, the joint is cleaned (using emery cloth) and then coated with flux that prevents oxides from forming. The clean, hot joint draws solder or brazing rod (via capillary action) into the joint to form the connection. The parent metal does not melt in brazed or soldered construction.

Self-Test

2.1 Pipe sizes above __________ inches are usually designated by outside diameter.

2.2 The difference in __________ numbers represents the difference in the wall __________ of pipes.

2.3 When pipe wall thickness __________, the I.D. decreases.

2.4 A __________ metal contains iron.

2.5 As temperature __________, the viscosity of a liquid decreases.

2.6 Another name for rust is:

2.7 Sections of __________ water pipe are usually connected with a bell-and-spigot joint.

2.8 Under what conditions would a welded joint most likely be preferred?

2.9 How are nonferrous metals usually connected?

2.10 What class of pipeline is used to carry compressed air?

2.11 When does water hammer in a piping system occur?

2.12 A ferrous metal always contains __________.

Nonmetallic Piping

Although metal piping is in wide use today, nonmetallic piping (especially clay and cement) is of equal importance. These older materials have been modified by new processes to make them more useful in meeting today's requirements.

TOPICS

Nonmetallic Piping Materials

3.1 INTRODUCTION

Relatively speaking, using metallic piping is a new practice. Originally, all piping was made from clay or wood, and stone soon followed. Open stone channels or aqueducts were used to transport water over long distances. After nearly 2000 years of service, some of these open channels are still in use today.

Common practice today is to use metal piping, though nonmetallic piping is of equal importance and has many applications in water/wastewater operations. Many of the same materials that have been used for centuries (clay, for example) are still used today, but now many new piping materials are available, and choice depends on the requirements of the planned application. The development of new technological processes has enabled the modification of older materials for new applications in modern facilities and has brought about the use of new materials for old applications as well.

In this chapter, we study nonmetallic piping materials, what they are, and where they are most commonly used. We also describe how to join sections of nonmetallic piping and how to maintain them.

3.2 NONMETALLIC PIPING MATERIALS

Nonmetallic piping materials used in water/wastewater applications include clay (wastewater), concrete (water/wastewater), asbestos-cement pipe (water/wastewater), and plastic (water/wastewater). Other nonmetal-

Key Terms Used in This Chapter

VITRIFIED CLAY	Clay that has been treated in a kiln to produce a glazed, watertight surface.
PRESTRESSED CONCRETE	Concrete that has been compressed with wires or rods in order to reduce or eliminate cracking and tensile forces.
ASBESTOS	Fibrous mineral form of magnesium silicate.
FRIABLE	Readily crumbled by hand.
PVC	Polyvinyl chloride plastic pipe.

lic piping materials include glass (chemical porcelain pipe) and wood (continuous-strip wooden pipes for carrying water and waste chemicals are used in some areas, especially in the western part of the United States); however, these materials are not discussed in this text, because of their limited application in water/wastewater operations.

IMPORTANT

Important Point: *As with the use of metallic piping, nonmetallic piping must be used in accordance with specifications established and codified by a number of engineering societies and standards organizations. These codes were devised to help ensure personnel safety and protection of equipment.*

3.2.1 CLAY PIPE

Clay pipes are used to carry and/or collect industrial wastes, wastewater, and storm water (they are not typically used to carry potable water). Clay pipes typically range in size from 4 to 36 inches in diameter and are available in more than one grade and strength.

Clay pipe is used in nonpressurized systems. For example, when used in drainpipe applications, liquid flow is solely dependent on gravity; that is, it is used as an open-channel pipe, whether partially or completely filled. Clay pipe is manufactured in two forms: vitrified (glass-like) and unglazed (not glassy).

IMPORTANT ***Important Point:*** Vitrified clay pipe *is extremely corrosion proof. It is ideal for many industrial waste and wastewater applications.*

IMPORTANT ***Important Point:*** *McGhee recommends that wyes and tees (see Figure 3.1) should be used for joining various sections of wastewater piping. Failure to provide wyes and tees in common wastewater lines invites builders to break the pipe to make new connections. Obviously, this practice should be avoided, because such breaks are seldom properly sealed and can be a major source of infiltration (McGhee, 1991, pp. 297–298).*

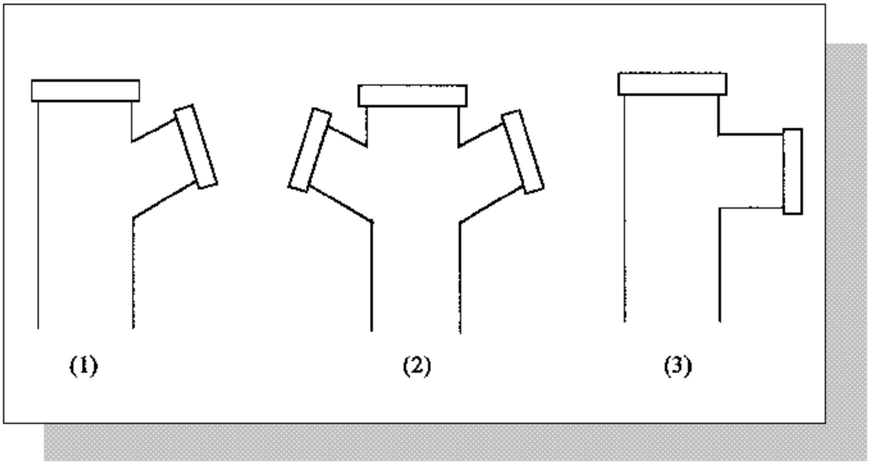


Figure 3.1
Section of bell-and-spigot fillings for clay pipe. (1) wye, (2) double wye, (3) tee.

Vitrified and unglazed clay pipe are made and joined with the same type of bell-and-spigot joint described in Chapter 2. The bell-and-spigot shape is shown in Figure 3.2. In joining sections of clay pipe, both ends of the pipe must first be thoroughly cleaned. The small (spigot) end of the pipe must be centered properly and then seated securely in the large (bell) end. The bell is then packed with fibrous material (usually jute) for solid joints, which is tamped down until about 30% of the space is filled. The joint is then filled with sealing compound. In flexible joint applications, the sealing elements are made from natural or synthetic rubber or from a plastic-type material.

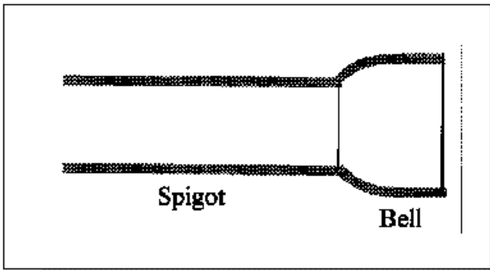


Figure 3.2
Bell-and-spigot ends of clay pipe sections.

Drainage and wastewater collection lines designed for gravity flow are laid downgrade at an angle, with the bell ends of the pipe pointing upgrade. The pipe is normally placed in a trench with strong support members (along its small dimension and not on the bell end). Vitrified clay pipe can be placed directly into a trench and covered with soil. However, unglazed clay pipe must be protected against the effects of soil contaminants and ground moisture.

3.2.2 CONCRETE PIPE

Concrete is another common pipe material and is sometimes used for sanitary sewers in locations where grades, temperatures, and wastewater characteristics prevent corrosion (American Concrete Pipe Association, 1987, p. 44). The pipe provides high tensile and compressive strength and corrosion resistance.

Concrete pipe is generally found in three basic forms: non-reinforced concrete pipe; reinforced concrete, cylinder and non-cylinder pipe; and reinforced and prestressed concrete pressure pipe.

With the exception of reinforced and prestressed pressure pipe, most concrete pipe is limited to low-pressure applications. Moreover, almost all concrete piping is used for conveying industrial wastes, wastewater, and storm water; similarly, some is used for water service connections.

Rubber gaskets are used to join sections of many non-reinforced concrete pipes. However, for circular concrete sewer and culvert pipe, flexible, watertight, rubber joints are used to join pipe sections.

The general advantages of concrete pipe include the following:

- relatively inexpensive to manufacture
- can withstand relatively high internal pressure or external load
- high resistance to corrosion (internal and external)
- generally, when installed properly, cement pipe has a very long, trouble-free life
- minimal bedding requirements during installation

Disadvantages of concrete pipe include the following:

- very heavy, and thus expensive when shipped long distances
- its weight makes special handling equipment necessary
- exact pipes and fittings must be laid out in advance for installation (AWWA, 1996, pp. 51–52).

3.2.2.1 NON-REINFORCED CONCRETE PIPE

Non-reinforced concrete pipe, or ordinary concrete pipe, is manufactured in 4- to 24-inch diameters. As in vitrified clay pipe, non-reinforced concrete pipe is made with bell-and-spigot ends. Non-reinforced concrete pipe is normally used for small wastewater (sewer) lines and culverts.

3.2.2.2 REINFORCED CONCRETE PIPE

All concrete pipe made in sizes larger than 24 inches is reinforced; however, reinforced pipe can also be obtained in sizes as small as 12 inches. Reinforced concrete pipe is used for water conveyance (cylinder pipe), carrying wastewater, storm water, and industrial wastes. It is also used in culverts. It is manufactured by wrapping high-tensile-strength wire or rods about a steel cylinder that has been lined with cement mortar. Joints are either bell-and-spigot or tongue-and-groove in sizes up to 30 inches and tongue-and-groove exclusively above that size.

3.2.2.3 REINFORCED AND PRESTRESSED CONCRETE PIPE

When concrete piping is to be used for heavy-load high-pressure applications (up to 600 psi), it is strengthened by reinforcement and prestressing. Prestressed concrete pipe is reinforced by steel wire, steel rods, or bars embedded lengthwise in the pipe wall. If wire is used, it is wound tightly to prestress the core and is covered with an outer coating of concrete. Prestressing is accomplished by manufacturing the pipe with a permanent built-in compression force.

3.2.3 ASBESTOS-CEMENT (A-C) PIPE

Before beginning a brief discussion of asbestos-cement (A-C) pipe, it is necessary to discuss safety and health implications involved with performing maintenance activities on A-C pipe.

3.2.3.1 A-C PIPE: SAFETY AND HEALTH CONSIDERATIONS

Prior to 1971, *asbestos* was known as the "material of a thousand uses" (Coastal Video Comm. Corp., 1994, p. 2). It was used for fireproofing (primarily), insulation (secondarily, on furnaces, ducts, boilers, and hot water pipes, for example), soundproofing, as well as a host of other applications, including its use in conveyance of water and wastewater. However, while still used in some industrial applications and in many water/wastewater piping applications, asbestos-containing materials (ACM), including asbestos-cement (A-C) pipe, are not as widely used as they were before 1971.

Asbestos-containing materials lost favor with regulators and users primarily because of the health risks involved. Asbestos has been found to cause chronic and often-fatal lung diseases, including asbestosis and certain forms of lung cancer. Although debatable, there is some evidence that asbestos fibers in water may cause intestinal cancers as well. While it is true that asbestos fibers are found in some natural waters (Bales et al., 1984) and can be leached from asbestos-cement pipe by very aggressive waters [i.e., those that dissolve the cement itself (Webber et al., 1989)] it is also true that the danger from asbestos exposure is not so much due to the danger of specific products (A-C pipe, for example) as it is to the overall exposure of people involved in the mining, production, installation, and ultimate removal and disposal of asbestos products (AWWA, 1996, p. 44).

A-C pipe is composed of a mixture of portland cement and asbestos fiber that is built up on a rotating steel mandrel and then compacted with steel pressure rollers. This pipe has been used for over 70 years in the United States. Because it has a very smooth inner surface, it has excellent hydraulic characteristics (McGhee, 1991, p. 121).

In water/wastewater operations, it is the installation, and ultimate removal and disposal of asbestos-cement pipe that poses the problem for operators. For example, consider an underground wastewater line-break that must be repaired. After locating exactly where the line break is (this is sometimes difficult to accomplish, because A-C pipe is not as easily located as conventional pipe), the work crew must first excavate the soil covering the line break, being careful not to cause further damage (A-C pipe is relatively fragile). Once the soil has been removed, exposing the line break, the damaged pipe section must be removed. In some instances, it may be more economical or practical to remove the damaged portion of the pipe only and to install a replacement portion and then girdle it with a clamping mechanism (sometimes referred to as a *saddle-clamp*).

To this point in the described repair operation, there is little chance for exposure to personnel from asbestos. This is the case, of course, because in order to be harmful, ACM must release fibers that can be inhaled. The asbestos in undamaged A-C pipe is not friable (non-friable asbestos); that is, it cannot be readily reduced to powder form by hand pressure when it is dry. Thus, it poses little or no hazard in this condition. However, if the maintenance crew making the pipe repair must cut, grind, or sand the A-C pipe section under repair, the non-friable asbestos is separated from its bond. This type of repair activity is capable of releasing friable airborne fibers—and herein lies the hazard of working with A-C pipe.

To guard against the hazard of exposure to asbestos fibers, A-C pipe repairs must be accomplished in a safe manner. Maintenance operators must avoid any contact with ACM that disturbs its position or arrangement, disturbs its matrix or renders it friable, and generates any visible debris from it.

IMPORTANT ***Important Point:*** *Visibly damaged, degraded, or friable ACM in the vicinity are always indicators that surface debris or dust could be contaminated with asbestos. OSHA standards require that it be assumed that such dust or debris contains asbestos fibers (Coastal Video Comm. Corp., 1994, p. 9).*

In the A-C pipe repair operation described above, repairs to the A-C pipe require that prescribed USEPA, OSHA, state, and local guidelines be followed. General EPA/OSHA guidelines, at a minimum, require that repairs made to the A-C pipe be performed by trained personnel only. The following safe work practice is provided for those who must work on/with ACM (i.e., A-C pipe).

SAFE WORK PRACTICE—A-C PIPE[1]

1. When repairs/modifications are conducted that require cutting, sanding, or grinding on cement pipe containing asbestos, USEPA-trained asbestos workers/supervisors are to be called to the work site *immediately*.
2. Excavation personnel will unearth buried pipe to the point necessary to make repairs/modifications. The immediate work area will then be cleared of personnel as directed by the asbestos-trained supervisor.
3. The on-scene supervisor will direct the asbestos-trained workers as required to accomplish the work task.
4. The work area will be barricaded 20 feet in all directions to prevent unauthorized personnel from entering.
5. Asbestos-trained personnel will wear *all* required Personal Protective Equipment (PPE). Required PPE shall include Tyvek totally enclosed suits, 1/2 face respirator equipped with HEPA filters, rubber boots, goggles, gloves, and hardhat.

[1]Spellman, 1996, pp. 201–202.

6. Supervisor will perform the required air sampling prior to entry.
7. Air sampling shall be conducted using NIOSH 7400 Protocol.
8. A portable decontamination station will be set up as directed by the supervisor.
9. Workers will enter the restricted area *only* when directed by the supervisors and, using wet methods *only*, will either perform pipe cutting using a rotary cutter assembly or inspect the broken area to be covered with the repair saddle device.
10. After performing the required repair/modifications, workers will encapsulate bitter ends and/or fragmented sections.
11. After encapsulation, the supervisor can authorize entry into restricted area for other personnel.
12. Broken ACM pipe pieces must be properly disposed of following EPA/state/local guidelines.

IMPORTANT ***Important Point:*** *Although exposure to asbestos fibers is dangerous, it is important to note that studies by USEPA, AWWA, and other groups have concluded that the asbestos in water mains does not generally constitute a health threat to the public (AWWA, 1996, p. 45).*

3.2.3.2 A-C PIPE: WATER/WASTEWATER APPLICATIONS

Because asbestos-cement (A-C) pipe is strong and corrosion resistant, it is widely used for carrying water and wastewater. Standard sizes range from 3 to 36 inches. Though highly resistant to corrosion, A-C pipe should not be used for carrying highly acidic solutions or unusually soft water, unless its inner and outer surface walls are specially treated. A-C pipe is preferred for use in many outlying areas, because of its light weight, which results in greater ease of handling.

A-C pipe is joined by using an asbestos-cement sleeve. The sleeve's inner diameter (I.D.) is larger than the pipe's outer diameter (O.D.). The ends of the pipes fit snugly into the sleeve and are sealed with a natural or synthetic rubber seal or gasket, which acts as an expansion joint.

3.2.4 PLASTIC PIPE

Plastic pipe has been used in the United States for about 60 years; its use is becoming increasingly common. In fact, because of its particular advantages, plastic pipe is replacing both metallic and nonmetallic piping. The advantages of plastic piping include the following:

- internal and external high corrosion resistance
- rarely needs to be insulated or painted
- light weight
- ease of joining
- freedom from rot and rust
- will not burn (readily)
- lower cost
- long service life
- easy to maintain

There are several types of plastic pipe; still, where plastic pipe is commonly used in water and wastewater service, *polyvinyl chloride (PVC)* is the most common plastic pipe for municipal water distribution systems.

PVC is polymer extruded (shaped by forcing through a die) under heat and pressure into a thermoplastic that is nearly inert when exposed to most acids, fuels, and corrosives. PVC is commonly used to carry cold drinking water, because PVC is nontoxic and will not affect the water's taste or cause odor.

The limitations of PVC pipe include its limited temperature range (approximately 150° to 250° F) and low pressure capability (usually 75 to 100 psi).

Joining sections of plastic pipe is accomplished by welding (solvent, fusion, fillet), threading, and flanges.

IMPORTANT

Important Point: *The strength of plastic piping decreases as the temperature of the material it carries increases.*

Self-Test

3.1 Asbestos-cement pipe has the advantage of being highly resistant to __________.

3.2 Name six advantages of plastic piping.

3.3 Name two disadvantages of plastic piping.

3.4 As temperature increases, the strength of plastic pipe __________.

3.5 Name four basic nonmetallic piping materials.

3.6 Vitrified clay pipe is the most __________ pipe available for carrying industrial wastes.

3.7 Name three types of concrete pipe.

3.8 Cast-iron pipe can be lined with __________ to increase its resistance to corrosion.

3.9 What is the primary hazard of asbestos exposure?

3.10 Name three ways to join sections of plastic pipe.

Tubing

Piping by Another Name Might Be Tubing?

A logical question might be: When is a pipe a tube or a tube a pipe? However, does it really matter if we call piping or tubing by two distinct, separate, and different names? It depends, of course, on the difference(s) between the two.

When we normally think of pipe, we think in terms of either metallic or nonmetallic cylindrical products that are hollow and range in nominal size from about 0.5 inch (or less) to several feet in diameter, with possible applications from conveying raw petroleum from field to refinery, to conveying raw water from source to treatment facility, to wastewater discharge point, to treatment to outfall, and several others. On the other hand, when we think of tubing, we think of cylindrical, hollow products that are relatively smaller in diameter to that of many piping materials, with possible applications in the conveyance of compressed air, gases (including liquefied gas), steam, water, lubricating oil, fuel oil, chemicals, fluids in hydraulic systems, and waste products.

When attempting to classify or differentiate piping and tubing, the difference may come down to determination by end use. It is important to differentiate between piping and tubing, because they are different in physical characteristics and methods of installation, as well as in their advantages and disadvantages. In this chapter, these differences become clear.

TOPICS

Tubing vs. Piping: The Difference
Tubing
Advantages of Using Tubing
Connecting Tubing
Types of Tubing
Typical Tubing Applications

4.1 TUBING VS. PIPING: THE DIFFERENCE

Lohmeier and Avery point out that piping and tubing are considered separate products, even though they are geometrically quite similar.

Key Terms Used in This Chapter

SOLDERING	A form of brazing in which nonferrous filler metals having melting temperatures below 800°F (427°C) are used. The filler material is called *solder* and is distributed between surfaces by *capillary action.*
BRAZING	Soldering with a nonferrous alloy that melts at a lower temperature than that of the metals being joined; also known as hard soldering.
FLUX	Used in soldering to prevent the formation of oxides during the soldering operation and to increase the wetting action so solder can flow more freely.
TINNING	Covering metal to be soldered with a thin coat of solder to work properly. Overheating or failure to keep the metal clean causes the point to become covered with oxide. The process of replacing this coat of oxide is called tinning.
LAMINAR	Flow arranged in or consisting of thin layers.
FERRULE	A short bushing used for making a tight connection.
EXTRUDING	Process of shaping a metal or plastic by forcing it through a die.
ANNEALING	Process of heating and then cooling a metal, usually to make it softer and less brittle.

Moreover, the classification of "pipe" or "tube" is determined by end use (Lohmeier and Avery, 2000, p. A.257).

As mentioned, many of the differences between piping and tubing are related to physical characteristics, methods of installation, as well as the advantages and disadvantages.

4.2 TUBING

Simply, *tubing* refers to tubular materials (products) made to either an inside (I.D.) or outside diameter (O.D.; expressed in even inches or fractions). Tubing walls are generally much thinner than those of piping; thus, wall thickness in tubing is of particular importance.

IMPORTANT ***Important Point:*** *Wall thickness tolerance in tubing is held so closely that wall thickness is usually given in thousandths of an inch rather than as a fraction of an inch. Sometimes, a gauge number is used to indicate the thickness according to a given system.*

Tubing of different diameters has different wall thicknesses. An example from "Pipe Properties; Tube Properties" illustrates the difference between piping and tubing (Basavaraju, 2000, pp. E.13-E.36; Geiger, 2000, A.53). The wall thickness of a commercial type of 8-inch pipe is 0.406 inch. Light-wall 8-inch copper tubing, by contrast, has a wall thickness of 0.050 inch. When we compare these figures, it is clear that tubing has much thinner walls than piping of the same general diameter.

IMPORTANT ***Important Note:*** *It is important to note that the range between "thick" and "thin" is narrower for tubing than it is for piping.*

4.2.1 TUBING USES

The list of tubing applications is lengthy. Some tubing types can be used not only as conduits for electrical wire but also to convey waste products, compressed air, hydraulic fluids, gases, fuel oil, chemicals, lubricating oil, stream, waters, and other fluids (i.e., both gaseous and liquid).

4.2.2 TUBING MATERIALS

Tubing is made from metals and plastics. Metal tubing is designed to be somewhat flexible but also strong. Metallic materials such as copper, aluminum, steel, and stainless steel are used in applications where fluids are carried under high pressure (some types of tubing, e.g., stainless steel, can accommodate very high pressures, e.g., >5000 psi). As the diameter of the tubing increases, the wall thickness increases accordingly (slightly).

Ranging in size from 1/32 inch to 12 inches in diameter, it is the smaller sizes that are most commonly used. Standard copper tubing ranges from 1/32 inch to 10 inches in diameter, steel from 3/15 inch to 10 3/4 inches, aluminum from 1/8 inch to 12 inches, and special alloy tubing is available up to 8 inches in diameter.

One of the primary reasons tubing is employed for industrial applications is the fact that some tubing materials are extremely resistant to deterioration by corrosive chemicals.

Typically, in terms of initial cost, metal tubing materials are more expensive than iron piping. However, high initial cost vs. ability to do a particular application as designed (as desired), is a consideration that cannot be overlooked or underemphasized. Consider, for example, an air compressor. Typically, while in operation, air compressors are mechanical devices that not only produce a lot of noise but also vibrate. Installing a standard rigid metal piping system to such a device might not be practical. Installing tubing that is flexible to the same device, however, may have no detrimental impact on operation. An even more telling example is the internal combustion engine. For example, a lawnmower engine, like the air compressor, also vibrates and is used in less than static conditions (i.e., the lawnmower is typically exposed to all kinds of various dynamic stresses). Obviously, we would not want the fuel lines (tubing) in such a device to be "hard-wired" with rigid pipe; instead, we would want the fuel lines to be durable and somewhat flexible. Thus, flexible metal tubing is called for in this application, because it will hold up.

Simply put, initial cost can be important. However, considerations such as maintenance requirements, durability, length of life, and ease of installation, often favor the use of metallic tubing over the use of metallic pipe.

While it is true that most metallic tubing materials have relatively thin walls, it is also true that most are quite strong. Small tubing material with thin walls (i.e., soft materials up to approximately 1 inch O.D.) can be bent quite easily by hand. Tubing with larger diameters requires special bending tools. The big advantage of flexible tubing should be obvious: Tubing can be run from one point to another with fewer fittings than if piping were used.

Figures 4.1–4.3 show how malleable or ductile (i.e., how easy it is to bend) copper tubing is, and Figure 4.4 shows how the use of tubing can eliminate several pipefittings.

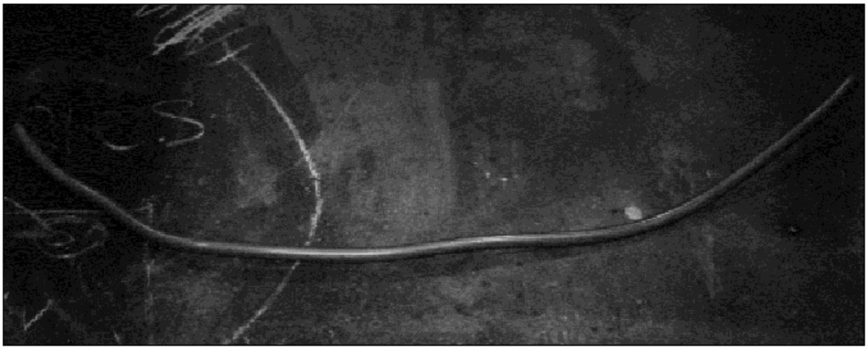


Figure 4.1
Copper tubing is easily bent—to a point.

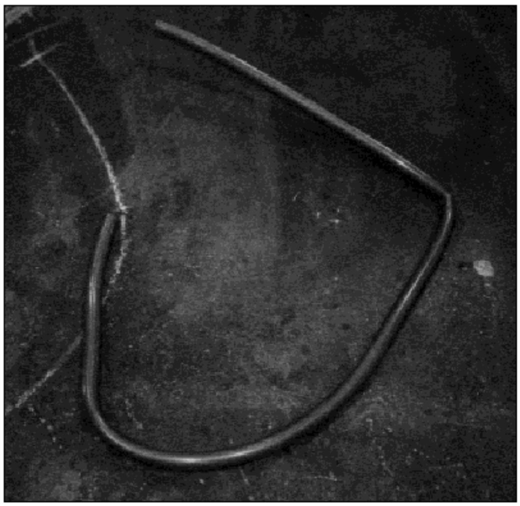


Figure 4.2
Copper tubing incorrectly bent (kinked).

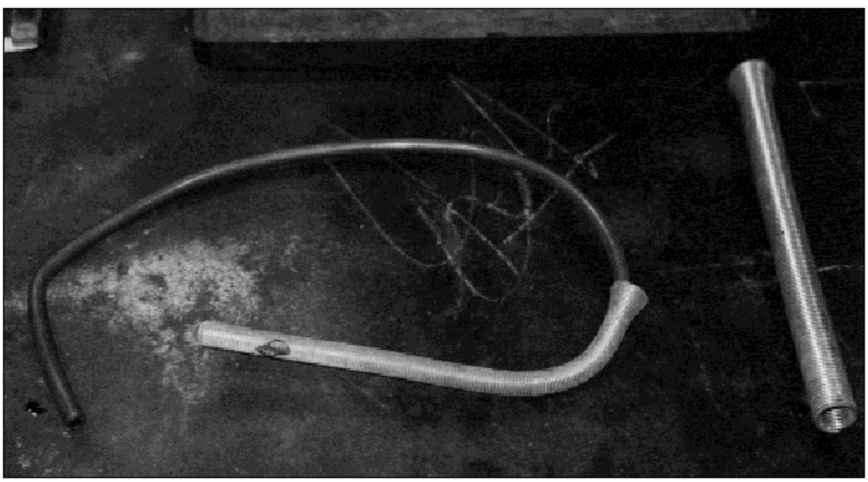


Figure 4.3
A type of copper tubing bending device (spring mechanism) used for properly bending copper tubing.

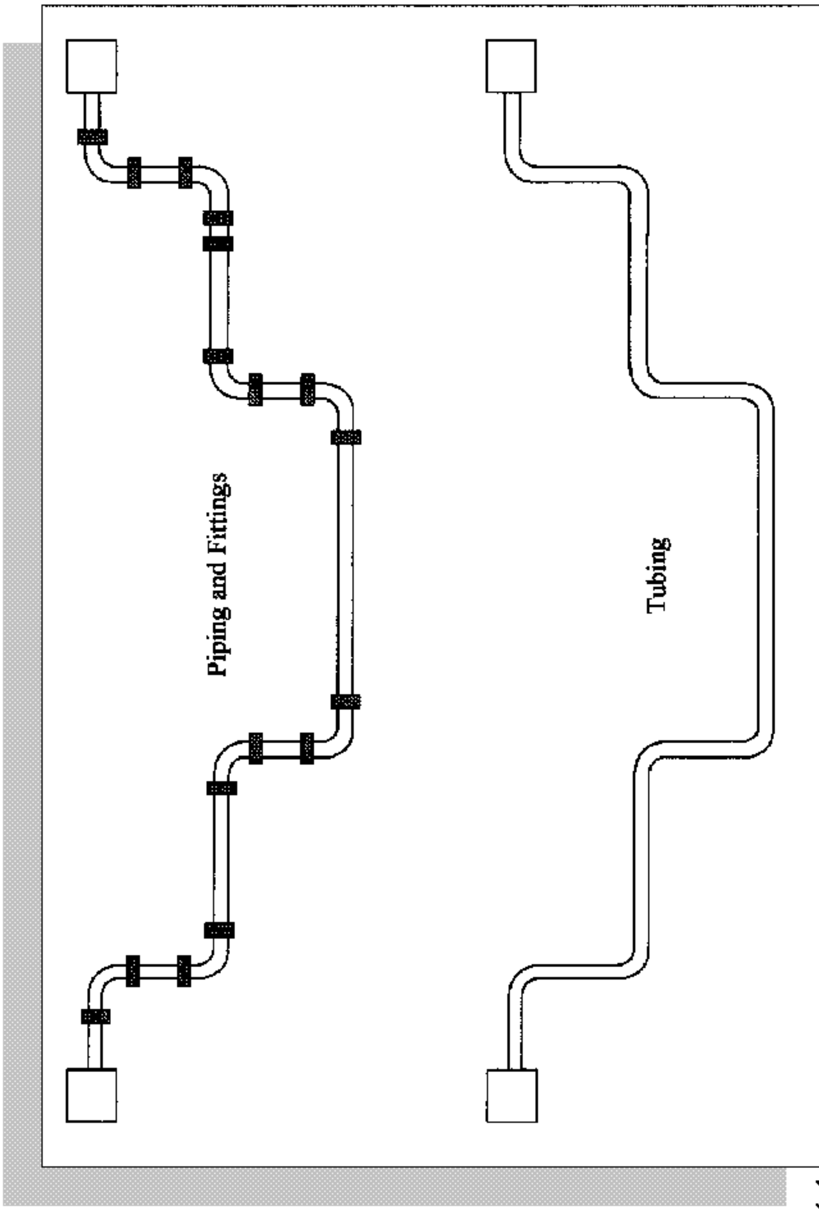


Figure 4.4
Tubing eliminates fittings.

The advantages of the tubing type of arrangement shown in Figure 4.4 include the following:

- It eliminates 18 potential sources of leaks.
- The cost of the 18 90° elbow fittings needed for the piping installation is eliminated.
- The time needed to cut, gasket, and flange the separate sections of pipe is conserved (obviously, it takes little time to bend tubing into the desired configuration).
- A tubing configuration is much lighter in weight than the separate lengths of pipe and the pipe flanges would have been.

As mentioned in the configuration shown in Figure 4.4, the amount of weight is considerably less for the copper tubing than the piping arrangement. Moreover, the single length of tubing bent to follow the same general conveyance route is much easier to install.

It may seem apparent to some readers that many of the weight and handling advantages of tubing compared to piping can be eliminated or at least matched simply by reducing the wall thickness of the piping. It is important to remember, however, that piping has a thick wall because it often needs to be threaded to make connection(s). If the wall thickness of iron pipe, for example, was made comparable to the thickness of copper tubing and then threaded at connection points, its mechanical integrity would be reduced. Piping must have sufficient wall thickness left after threading to not only provide a tight fit, but also to handle the fluid pressure. On the other hand, copper tubing is typically designed for brazed and soldered connections, rather than threaded ones. Thus, its wall thickness can be made uniformly thin. This advantage of tubing over iron piping is illustrated in Figure 4.5.

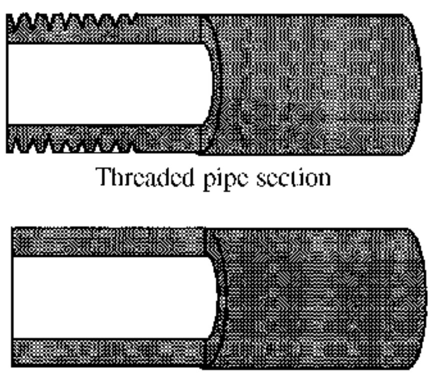


Figure 4.5
Pipe wall thickness is important when threading is required.

Important Point: *The lighter weight of tubing means greater ease of handling as well as lower shipping costs.*

IMPORTANT

4.3 ADVANTAGES OF USING TUBING

To this point, in regard to design requirements, reliability, and maintenance activities of using tubing instead of piping, several advantages of tubing have been pointed out. These advantages can be classified as *mechanical* and/or *chemical* advantages.

4.3.1 TUBING: MECHANICAL ADVANTAGES

Probably the major mechanical advantage of using tubing is its relatively small diameter and its flexibility, which makes it user-friendly in tight spaces where piping would be difficult to install and to maintain (i.e., for the tightening or repair/replacement of fittings).

Another mechanical advantage of tubing important to water/wastewater maintenance operators is the ability of tubing to absorb shock from *water hammer*. Water hammer can occur whenever fluid flow is started or stopped. In water/wastewater operations, certain fluid flow lines have a frequent on-off cycle. In a conventional piping system, this may produce vibration, which is transmitted along the rigid conduit, shaking joints, valves, and other fittings. The resulting damage usually results in leaks, which, of course, necessitates repairs. In addition, the piping supports can also be damaged. When tubing, with its built-in flexibility, is used in place of conventional iron piping, however, most of the vibration and shock is absorbed by the conduit. The result is far less wear and tear on the fittings and other appurtenances.

As mentioned, sections of tubing are typically connected by means of soldering, brazing, or welding, rather than by threaded joints, although steel tubing is sometimes joined by threading. In addition to the advantages in cost and time savings, avoidance of using threaded joints precludes other problems. For example, anytime piping is threaded, it is weakened. At the same time, threading is commonly used for most piping systems and usually presents no problem.

Another advantage of tubing over iron piping is the difference in inner-wall surfaces between the two. Specifically, tubing generally has a smoother inner-wall surface than does iron piping. This smoother inner-wall characteristic aids in reducing turbulent flow (wasted energy and decreased pressure) in tubing. Instead, flow in the smoother-walled tubing is more laminar; that is, it has less turbulence. Laminar flow is characterized as flow in layers, very thin layers. (Somewhat structurally analogous to this liquid laminar flow phenomenon is wood-type products such as kitchen cabinets, many of which are constructed of laminated materials.)

This might be a good time to address laminar flow inside a section of tubing. First, we need to discuss laminar and turbulent flow in order to point out the distinct difference between them. Simply, in *laminar* flow, streamlines remain parallel to one another and no mixing occurs between adjacent layers. In *turbulent* flow, mixing occurs across the pipe. The distinction between the two regimes lies in the fact that the shear stress in laminar flow results from viscosity, while that in turbulent flow results from momentum exchanges occurring as a result of motion of fluid particles from one layer to another (McGhee, 1991, p. 25).

Normally, flow is laminar inside tubing. However, if there are irregularities (dents, scratches, or bumps) on the tubing's inner wall, the fluid will be forced across the otherwise smooth surface at a different velocity. This causes turbulence.

In contrast to tubing, iron piping has more irregularities along its inner walls. This inner-wall surface roughness produces turbulence in the fluid flowing along the conduit. Ultimately, this turbulence can reduce the delivery rate of the piping system considerably.

4.3.2 TUBING: CHEMICAL ADVANTAGES

The major chemical advantage in tubing as compared to piping comes from the corrosion-resistant properties of the metals used to make the tubing. Against some corrosive fluids, most tubing materials do very well. Some metals perform better than others, however, depending upon the metal and the corrosive nature of the fluid.

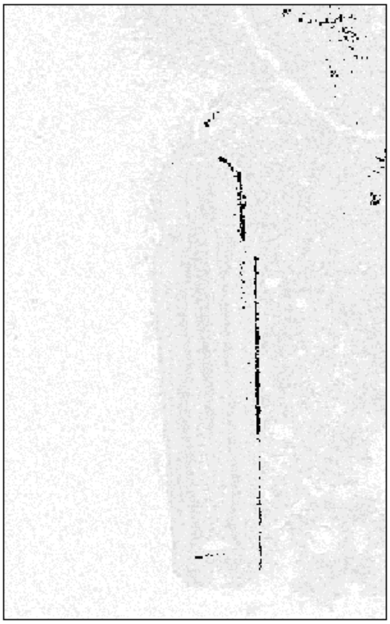
It is important to also point out that tubing used must be compatible with the fluid being conveyed. When conveying a liquid stream from one point to another, the last thing wanted is contamination from the tubing to be added to the fluid. Many tubing conveyance systems are designed for use in food-processing operations, for example. If we were conveying raw milk to or from a unit process, we certainly would not want to contaminate the milk. To avoid such contamination, where conditions of particular sanitation are necessary, stainless steel, aluminum, or appropriate plastic tubing must be used.

4.4 CONNECTING TUBING

The skill required to properly connect metal or nonmetallic tubing can be learned by just about anyone. However, a certain amount of practice and experience is required to ensure the tubing is properly connected. Moreover, certain tools are required for connecting sections of tubing. The tools used to make either a soldered connection or a compression connection (where joint sections are pressed together) include the following:

- hacksaw
- tube cutter (see Figure 4.6)

Figure 4.6
Cutting tool used to cut copper tubing.



- scraper
- flat file
- burring tool (see Figure 4.7)
- flaring tool (see Figure 4.8)
- presetting tool for flareless fittings
- assorted wrenches
- hammer
- tube bender (see Figure 4.3)

Figure 4.7
Burring tool.

4.4.1 CUTTING TUBING

No matter what type of connection you are making (soldered or compressed), it is important to cut the tubing cleanly and squarely. This can be accomplished using a tubing cutter (see Figure 4.3). Use of a tubing cutter is recommended, because it provides a much smoother cut than that made with a hacksaw. A typical tubing cutter has a pair of rollers on one

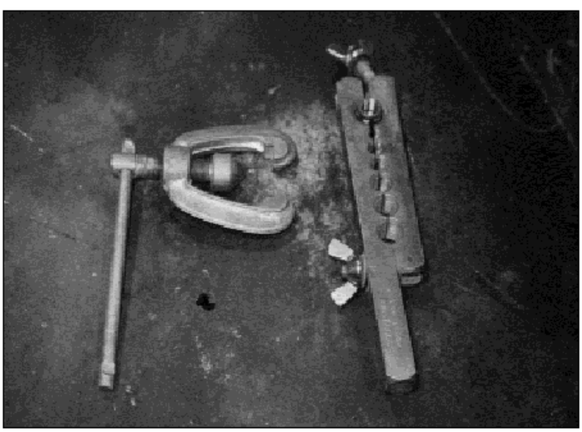


Figure 4.8
Flaring tool.

side and a cutting wheel on the other. Figure 4.9 shows such a tube cutter in use. The tube cutter is turned all the way around the tubing, making a clean cut.

IMPORTANT

Important Point: *When cutting stainless steel tubing, cut the tubing as rapidly and safely as you can, with as few strokes as possible. This is necessary, because as stainless steel is cut, it hardens, especially when cut with a hacksaw.*

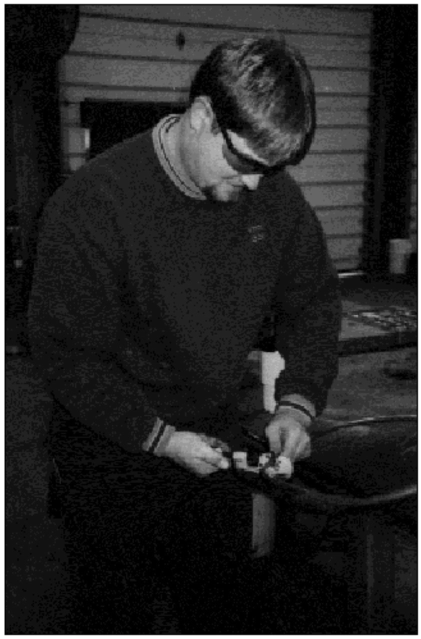


Figure 4.9
Using a tube cutter to cut copper tubing.

After making the tubing cut, the rough edge of the cut must be smoothed with a *burring tool* (see Figure 4.7) to remove the small metal chads, burrs, or whiskers. If a hacksaw is used to cut the tubing, ensure that the rough cut is filed until it is straight and square to the length of the tubing.

4.4.2 SOLDERING TUBING[5]

Soldering is a form of brazing in which nonferrous filler metals having melting temperatures below 800°F (427°C) are used. The filler metal is called solder (usually a tin-lead alloy, which has a low melting point) and is distributed between surfaces by capillary action.

Whether soldering two sections of tubing together or connecting tubing to a fitting, such as an elbow, the soldering operation is the same. Using emery cloth or a wire brush, the two pieces to be soldered must first be cleaned (turned to bright metal). Clean, oxide-free surfaces are absolutely necessary to make sound soldered joints. Uniform capillary

[5]Adapted from Giachino and Weeks, 1985, pp. 284–289.

action is possible only when surfaces are completely free of foreign substances such as dirt, oil, grease, and oxide.

IMPORTANT ***Important Point:*** *During the cleaning process, care must be taken to avoid getting the prepared adjoining surfaces too smooth. Surfaces that are too smooth will prevent the filler metal (solder) from effectively wetting the joining areas.*

The next step is to ensure that both the tubing outside and the fitting inside are covered with soldering flux and are fitted together. When joining two tubing ends, use a sleeve. The purpose of flux is to prevent or inhibit the formation of oxide during the soldering process. The two ends are fitted into the sleeve from opposite sides. Make sure the fit is snug.

Next, heat the joint. First, heat the tubing next to the fitting, then heat the fitting itself. When the flux begins to spread, solder should be added (this is known as *tinning*). The heat will suck the solder into the space between the tubing and the sleeve. Then, heat the fitting, on and off, and apply more solder until the joint is fully penetrated.

IMPORTANT ***Important Points:*** *During the soldering operation, it is important to ensure that the heat is applied evenly around the tubing. A continuous line of solder will appear where the fitting and tubing meet at each end of the sleeve. Also, ensure that the joined parts are held so that they will not move. After soldering the connection, wash the connection with hot water to prevent future corrosion.*

The heat source normally used to solder is heated using an oxyacetylene torch or some other high-temperature heat source.

4.4.2.1 SOLDERING POINTS TO REMEMBER

1. Always use the recommended flux when soldering.
2. Make sure parts to be soldered are clean, and their surfaces fit closely together.
3. During the soldering process, do not allow the parts to move while the solder is in a liquid state.

4. Be sure the soldering heat is adequate for the soldering job to be done, including the types of metal and the fluxes.

5. Wash the solder work in hot water to stop later corrosive action.

4.4.3 CONNECTING FLARED/NON-FLARED JOINTS

In addition to being connected by brazing or soldering, tubing can also be connected by either *flared* or *non-flared* joints. Flaring is accomplished by evenly spreading the end of the tube outward, as shown in Figure 4.10. The accuracy of the angle of flare is important; it must match the angle of the fitting being connected. The flaring tool (see Figure 4.8) is inserted into the squared end of the tubing and then hammered or impacted into the tube a short distance, spreading the tubing end as required.

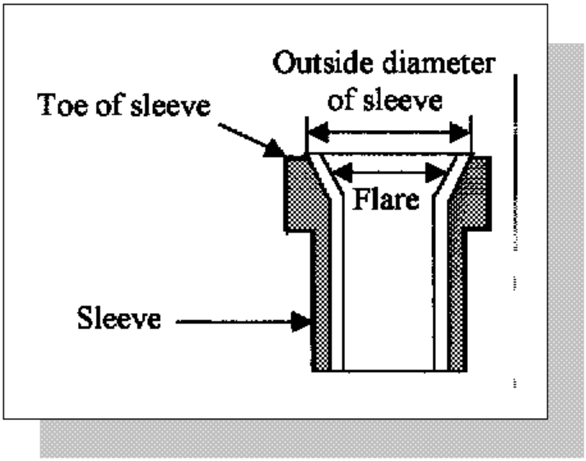


Figure 4.10
Flared tubing end.

4.4.3.1 FLARED CONNECTION

Figure 4.11 shows the resulting flared connection. As shown in Figure 4.11, the flared section is inserted into the fitting in such a way that the flared edge of the tube rests against the angled face of the male connector body—a sleeve supports the tubing. The nut is tightened firmly on the male connector body, making a firm joint that will not leak, even if the tubing ruptures because of excess pressure.

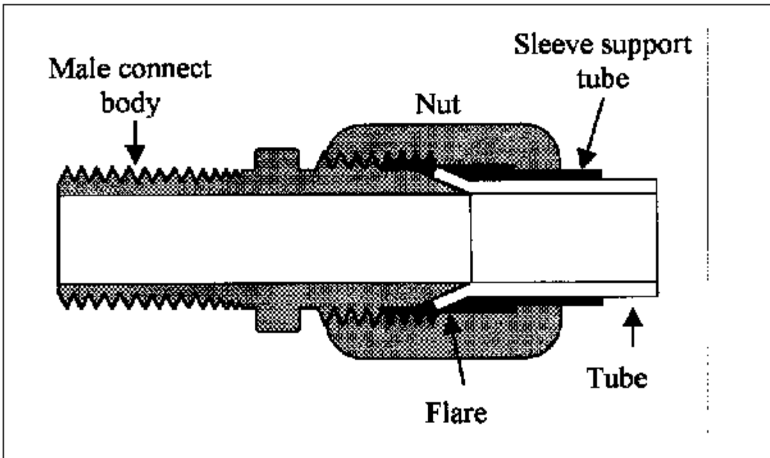


Figure 4.11
Flared fitting.

4.4.3.2 NON-FLARED CONNECTION

Figure 4.12 shows a flareless fitting. As shown, the plain tube end is inserted into the body of the fitting. Notice that there are two threaded outer sections with a *ferrule* or bushing located between them. As the threaded members are tightened, the ferrule bites into the tubing, making a tight connection.

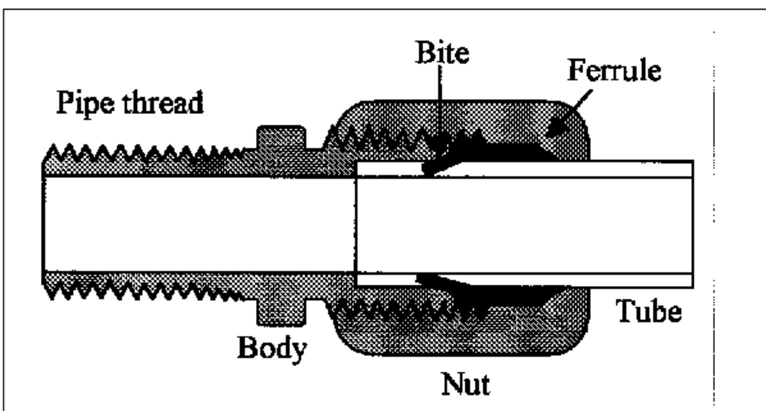


Figure 4.12
Flareless fitting.

4.4.4 BENDING TUBING

A type of tool typically used in water/wastewater maintenance applications for bending tubing is shown in Figure 4.3. As shown in the figure, the hand bender is nothing more than a specifically sized spring-type apparatus. Spring-type benders come in several different sizes (the size that fits the particular sized tubing to be bent is used to bend it). As shown in Figure 4.3, the spring-type tubing bender is slipped over the tubing section to be bent. Then, carefully, the spring and tubing are bent by hand to conform to the angle of bend desired.

In using any type of tubing bender, it is important to obtain the desired bend without damaging (flattening, kinking, or wrinkling) the tubing. As mentioned, any distortion of the smooth, inner wall of a tubing section causes turbulence in the flow, which lowers the pressure. Figure 4.13 shows three different kinds of incorrect bends and one correct bend. From the figure, it should be apparent how the incorrect bends constrict the flow, causing turbulence and lower pressure.

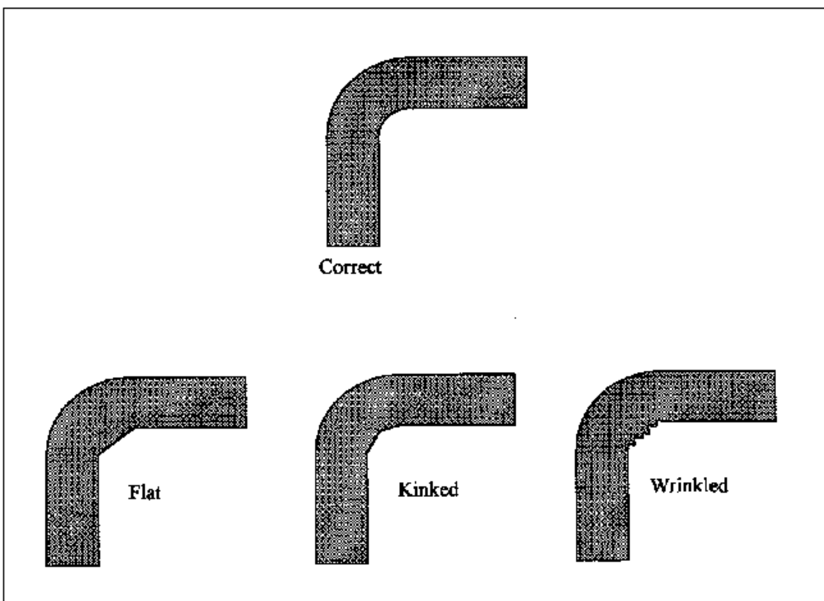


Figure 4.13
Correct and incorrect tubing bends.

4.5 TYPES OF TUBING

Common types of metal tubing in industrial service include the following:

- *copper* (seamless, fully annealed, furnished in coils or in straight lengths). In water treatment applications, copper tubing has replaced lead and galvanized iron in service line installations because it is flexible, easy to install, corrosion resistant in most soils, and able to withstand high pressure. It is not sufficiently soluble in most water to be a health hazard, but corrosive water may dissolve enough copper to cause green stains on plumbing fixtures. Copper water service tubing is usually connected by either flare or compression fittings. Copper plumbing is usually connected with solder joints (AWWA, 1996, p. 258).

IMPORTANT

Important Point: Annealing *is the process of reheating a metal and then letting it cool slowly. In the production of tubing, annealing is performed to make the tubing softer and less brittle.*

- *aluminum* (seamless, annealed, and suitable for bending and flaring)
- *steel* (seamless, fully annealed, also available as a welded type, suitable for bending and flaring)
- *stainless steel* (seamless, fully annealed, also available as a welded type, suitable for bending and flaring)
- *special alloy* (made for carrying corrosive materials)

Like metal piping, metal tubing is made in both welded and seamless styles. *Welded* tubing begins as flat strips of metal that are then rolled and formed into tubing. The seam is then welded.

Seamless tubing is formed as a long, hot metal ingot and then shaped into a cylindrical shape. The cylinder is then extruded (passed through a die), producing tubing in the larger sizes and wall thicknesses. If smaller tubing (with thinner walls and closer tolerances) is desired, the extruded tubing is reworked by drawing it through another die.

4.6 TYPICAL TUBING APPLICATIONS

In a typical water/wastewater operation, tubing is used in unit processes and/or machinery. Heavy-duty tubing is used for carrying gas, oxygen, steam, and oil, in many underground services, in interior plumbing, and in heating and cooling systems throughout the plant site. Steel tubing is used in high-pressure hydraulic systems. Stainless steel tubing is used in many of the plant's chemical systems. And in many plants, aluminum tubing is widely used as raceways or containers for electrical wires.

Plastics have become very important as nonmetallic tubing materials. The four most common types of plastic tubing are plexiglass (acrylic), polycarbonate, vinyl, and polyethylene (PE).

For plant operations, plastic tubing usage is most prevalent where it meets corrosion resistance demands, and the temperatures are within its working range—primarily used in chemical processes.

Plastic tubing is connected either by fusing with solvent-cement or by heating. Fused joints are made by reducing the plastic ends of the tubing to a soft, molten state, then pressing them together. In the solvent-cement method, the ends of the tubing are coated with a solvent that dissolves the plastic. The tube ends are firmly pressed together, and as the plastic hardens, they are securely joined. When heat fused, the tubes are held against a hot plate. When molten, the ends are joined, and the operation is complete.

Self-Test

4.1 What is meant by tinning?

4.2 During the soldering process, why should parts be held firmly in place?

4.3 A joint made so that the sections of tubing are __________ together is called a compression joint.

4.4 Incorrect tube bends can cause __________ flow and __________ pressure.

4.5 High-pressure hydraulic systems use __________ tubing.

4.6 One process used to join plastic tubing is called __________ welding.

4.7 Compared to pipe, tubing is more __________.

4.8 __________ tubing is most likely used in food-processing applications.

4.9 Before tubing can be bent or flared, it should be __________.

4.10 Plastic tubing is usually joined by __________.

4.11 The materials used most commonly for tubing are __________ and __________.

4.12 Smooth fluid flow is called __________ flow.

Industrial Hoses

Previous chapters in this text have described the uses and merits of piping and tubing. This chapter describes industrial hoses, which are classified as a slightly different tubular product. Their basic function is the same, however, and that is to carry fluids (liquids and gases) from one point to another.

The outstanding feature of industrial hose is its flexibility, which allows it to be used in applications where vibrations would make the use of rigid pipe impossible.

Most water/wastewater treatment plants use industrial hoses to convey steam, water, air, and hydraulic fluids over short distances. It is important to point out that each application must be analyzed individually, and an industrial hose must be selected that is compatible with the system specification.

In this chapter, we study industrial hoses—what they are, how they are classified and constructed, and the ways in which sections of hose are connected to one another and to piping or tubing. The maintenance requirements of industrial hoses and what to look for when making routine inspections or checks for specific problems are also discussed.

TOPICS

Hose Nomenclature
Factors Governing Hose Selection
Standards, Codes, and Sizes
Hose Classifications
Nonmetallic Hose
Metallic Hose
Hose Couplings
Hose Maintenance

5.1 INTRODUCTION

Industrial hoses, piping, and tubing are all used to convey a variety of materials under a variety of circumstances. Beyond this similar ability to convey a variety of materials, however, there are differences between

Key Terms Used in This Chapter

CARCASS	The reinforcement layers of a hose, between the inner tube and the outer cover.
MANDREL	A central core or spindle around which material may be shaped.
NEOPRENE	A synthetic material that is highly resistant to oil, flame, various chemicals, and weathering.
PLY	One of several thin sheets or layers of material.

industrial hoses and piping and tubing. For example, in their construction and in their advantages, industrial hoses are different from piping and tubing. As mentioned, the outstanding advantage of hose is its flexibility; its ability to bend means that hose can meet the requirements of numerous applications that cannot be met by rigid piping and some tubing systems. Two examples of this flexibility are Camel hose (used in wastewater collection systems to clean out interceptor lines and/or to remove liquid from excavations where broken lines are in need of repair), and the hose that supplies hydraulic fluids used on many forklifts. Clearly, rigid piping would be impractical to use in both situations.

Industrial hose is not only flexible but also has a dampening effect on vibration. Certain tools used in water/wastewater maintenance activities must vibrate to do their jobs. Probably the best and most familiar such tool is the power hammer, or jackhammer. Obviously, the built-in rigidity of piping and tubing would not allow vibrating tools to stand up very long under such conditions. Other commonly used tools and machines in water/wastewater operations have pneumatically or hydraulically driven components. Many of these devices are equipped with moving members that require the air or oil supply to move with them. In such circumstances, of course, rigid piping could not be used.

It is important to note that the flexibility of industrial hose is not the only consideration that must be taken to account when selecting hose over either piping or tubing. That is, hose must be selected according to the potential damaging conditions of an application. These conditions include the effects of pressure, temperature, and corrosion.

Hose applications range from the lightweight ventilating hose (commonly called "elephant trunk") used to supply fresh air to maintenance operators working in manholes, vaults, or other tight places. In water/wastewater treatment plants, hoses are used to carry water, steam, corrosive chemicals and gases, and hydraulic fluids under high pressure. To meet such service requirements, hoses are manufactured from a number of different materials.

5.2 HOSE NOMENCLATURE

To gain a fuller understanding of industrial hoses and their applications, it is important to be familiar with the nomenclature or terminology normally associated with industrial hoses. Accordingly, in this section, we explain the hose terminology water/wastewater maintenance operators should be familiar with.

Figure 5.1 is a cutaway view of a high-pressure air hose of the kind that supplies portable air hammers and drills and other pneumatic tools commonly used in water/wastewater maintenance operations. The hose is the most common type of reinforced nonmetallic hose in general use. Many of the terms given have already been mentioned. The I.D., which designates the hose size, refers to the inside diameter throughout the length of the hose body, unless the hose has enlarged ends. The O.D. is the diameter of the outside wall of the hose.

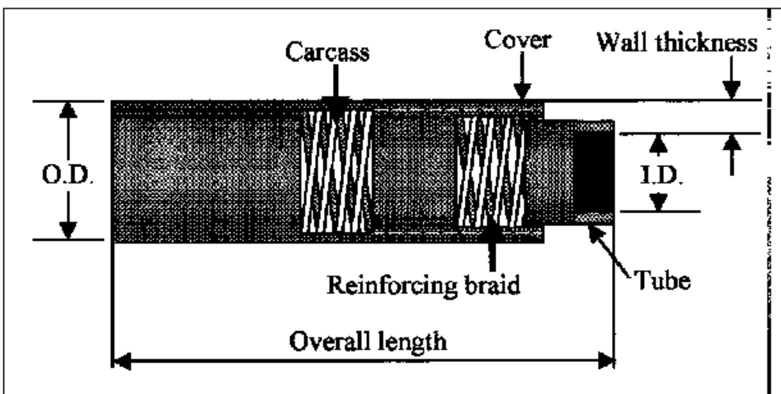


Figure 5.1
Common hose nomenclature.

Important Point: *If the ends of an industrial hose are enlarged, as shown in Figure 5.2, the letters E.E. are used (meaning* expanded or enlarged end*). Some hoses have enlarged ends to fit a fixed end of piping tightly (e.g., an automobile engine).*

IMPORTANT

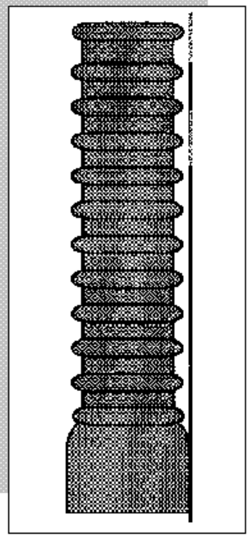
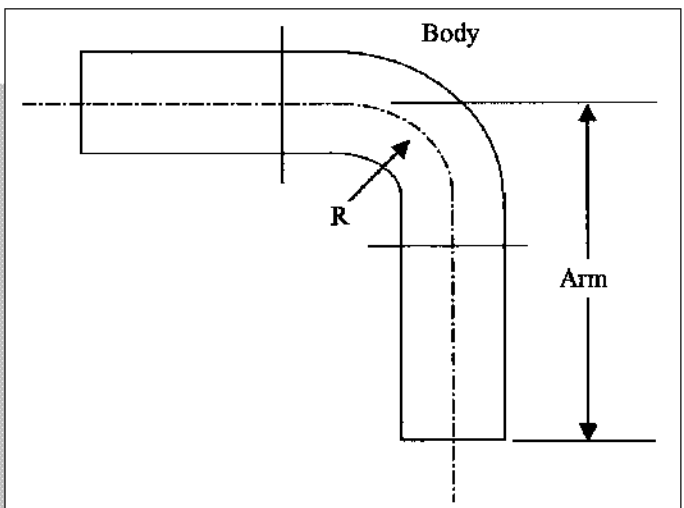


Figure 5.2
Expanded-end hose.

As shown in Figure 5.1, the *tube* is the inner section (i.e., the core) of the hose, through which the fluid flows. Surrounding the tube is the *reinforcement* material, which provides resistance to pressure, either from the inside or outside. Notice that the hose shown in Figure 5.1 has two layers of reinforcement *braid*. (This braid is fashioned from high-strength synthetic cord.) The hose is said to be *mandrel-braided*, because a spindle or core (the mandrel) is inserted into the tube before the reinforcing materials are put on. The mandrel provides a firm foundation over which the cords are evenly and tightly braided. The *cover* of the hose is an outer, protective covering. The hose in Figure 5.1 has a cover of tough, abrasion-resistant material.

The *overall length* is the true length of a straight piece of hose. Hose that is not too flexible is formed or molded in a curve (e.g., automobile hose used in heating systems; see Figure 5.3). As shown in Figure 5.3, the

Figure 5.3
Bend radius.



arm is the section of a curved hose that extends from the end of the hose to the nearest centerline intersection. The *body* is the middle section or sections of the curved hose. Figure 5.4 shows the *bend radius* (i.e., the radius of the bend measured to the centerline) of the curved hose, designated as the radius *R*. In a straight hose, bent on the job, the radius of the bend is measured to the surface of the hose (i.e., the radius *r* in Figure 5.4).

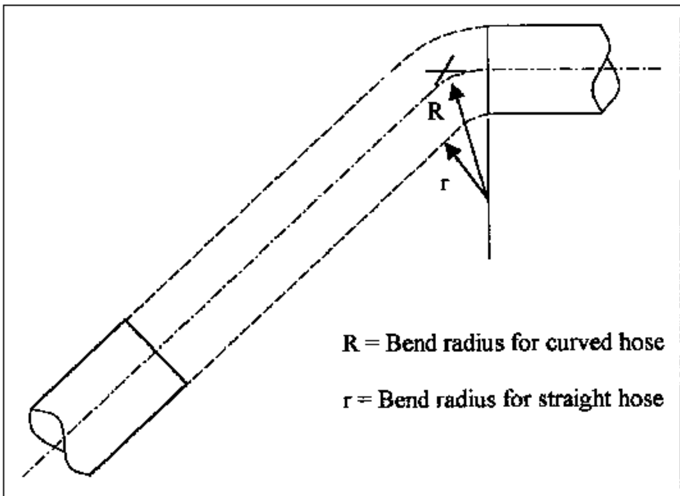


Figure 5.4
Bend radius: measurement.

IMPORTANT ***Important Point:*** *Much of the nomenclature used above does not apply to nonmetallic hose that is not reinforced. However, non-reinforced nonmetallic hose is not very common in water/wastewater treatment plant operations.*

5.3 FACTORS GOVERNING HOSE SELECTION

The amount of *pressure* that a hose will be required to convey is one of the important factors governing hose selection. Typically, pressure range falls in any of three general groups:

- <250 psi (low-pressure applications)
- 250 to 3000 psi (medium-pressure applications)
- 3000 to 6000+ psi (high-pressure applications)

IMPORTANT ***Important Point:*** *Note that some manufacturers have their own distinct hose pressure rating scheme; it cannot be assumed that a hose rated as "low-pressure" hose will automatically be useful at 100 or 200 psi. It may, in fact, be built for pressures not to exceed 50 psi, for example. Therefore, whenever a particular hose is replaced, it must be ensured that the same type of hose with the same pressure rating as the original hose is used. In high-pressure applications, this precaution is of particular importance.*

In addition to the pressure rating of a hose, for some applications, the *vacuum rating* of a hose must also be considered. "Vacuum rating" refers to suction hose applications in which the pressure outside the hose is greater than the pressure inside the hose. It is important, obviously, to know the degree of vacuum that can be created before a hose begins to collapse. A drinking straw, for example, collapses rather easily if too much vacuum is applied. Thus, it has a low vacuum rating. In contrast, the lower automobile radiator hose (also works under vacuum) has a relatively higher vacuum rating.

5.4 STANDARDS, CODES, AND SIZES

Just as they have for piping and tubing, authoritative standards organizations have devised standards and codes for hoses.

5.4.1 STANDARDS AND CODES

Standards and codes are safety measures designed to protect personnel and equipment. For example, specifications are provided for working pressures, sizes, and material requirements. The working pressure of a hose, for example, is typically limited to one-fourth, or 25%, of the amount of pressure needed to burst the hose. For example, a hose that has a maximum rated working pressure of 200 psi should not rupture until 800 psi has been reached, and possibly not even then. Thus, the use of hoses that meet specified standards or codes is quite evident.

5.4.2 HOSE SIZE

The parameter typically used to designate hose size is its inside diameter (I.D.). In regards to classification of hose, ordinarily, a *dash numbering* system is used. Current practice by most manufacturers is to use the dash system to identify both hose and fittings. In determining the size of a hose, we simply convert the size in 16ths. For example, a hose size of 1/2 inch (a hose with a 1/2-inch I.D.) is the same as 8/16 inch. The numerator of the fraction (the top number, or "8" in this case) is the dash size of the hose. In the same way, a 1 1/2-inch size can be converted to 24/16 inch and so is identified as a -24 (pronounced "dash 24") hose. By using the dash system, we can match a hose line to a tubing or piping section and be sure the I.D. of both will be the same. This means, of course, that the nonturbulent flow of fluid will not be interrupted. Based on I.D., hoses range in size from 3/16 inch to as large as 24 inches.

5.5 HOSE CLASSIFICATIONS

There are a number of ways in which hose is classified. For example, hose can be classified by type of service (hydraulic, pneumatic, corrosion-resistant), by material, by pressure, and by type of construction. Hose may also be classified by type. The three types include metallic, nonmetallic, and reinforced nonmetallic. Generally, terminology is the same for each type.

5.6 NONMETALLIC HOSE

Relatively speaking, the use of hose is not a recent development. Hoses, in fact, have been used for one application or another for hundreds of years. Approximately 100 years ago, after new developments in the processing of rubber, hoses were usually made by layering rubber around mandrels. Later, the mandrel was removed, leaving a fairly flexible rubber hose. However, these flexible hoses tended to collapse easily. Even so, they were an improvement over the earlier types. Manufacturers later added layers of rubberized canvas. This improvement gave hoses more strength, and gave them the ability to handle higher pressures. Later, after the development of synthetic materials, manufacturers had more rugged and more corrosion-resistant rubber-type materials to work with. Today, neoprene, nitrile rubber, and butyl rubber are commonly used in hose.

However, current manufacturing practice is not to make hoses from a single material. Instead, different materials form layers in the hose, reinforcing it in various ways for strength and resistance to pressure. Hose manufactured today usually has a rubber-type inner tube or a synthetic (e.g., plastic) lining surrounded by a *carcass* (usually braided) and cover, as we saw in Figure 5.1. The type of carcass braiding used is determined by the requirements of the application.

To reinforce a hose, two types of braiding are used, *vertical* braiding and *horizontal* braiding. Vertical braiding strengthens the hose against pressure applied at right angles to the centerline of the hose. Horizontal braiding strengthens the hose along its length, giving it greater resistance to expansion and contraction.

5.6.1 TYPES OF NONMETALLIC HOSE

Descriptions of the types of nonmetallic hose follow, with references to their general applications.

5.6.1.1 VERTICAL-BRAIDED HOSE

Vertical-braided hose has an inner tube of seamless rubber (see Figure 5.5). The reinforcing wrapping (carcass) around the tube is made of one or more layers of braided yarn. This type of hose is usually made in lengths of up to 100 feet with I.D.s of up to 1.5 inches. Considered a small hose, it is used in low-pressure applications to carry fuel oil, acetylene gas and oxygen for welding, water for lawns, gardens, and other household uses, and paint for spraying.

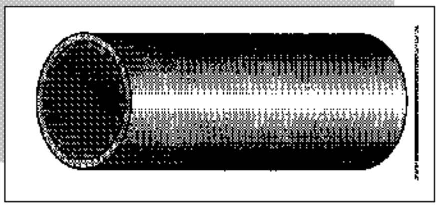


Figure 5.5
Vertical-braided hose.

5.6.1.2 HORIZONTAL-BRAIDED HOSE

Horizontal-braided hose is mandrel built; it is used to make hose with an I.D. of up to 3 inches (see Figure 5.6). Used in high-pressure applications, the seamless rubber tube is reinforced by one or more layers of braided fibers or wire. This hose is used to carry propane and butane gas and steam and for various hydraulic applications that require high working pressures.

5.6.1.3 REINFORCED HORIZONTAL BRAIDED-WIRE HOSE

In this type of hose, the carcasses around the seamless tube are made up of two or more layers of fiber braid with a steel wire reinforcement between them (see Figure 5.7). The I.D. may be up to 4 inches. Mechanically very strong, this hose is used where there are high working pressures and/or strong suction (vacuum) forces, such as in chemical transfer and petroleum applications.

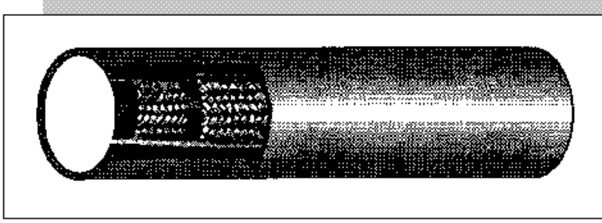


Figure 5.6
Horizontal-braided hose.

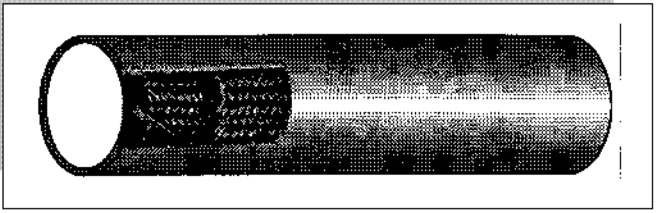


Figure 5.7 *Reinforced horizontal braided-wire hose.*

5.6.1.4 WRAPPED HOSE

Made in diameters up to 24 inches, wrapped hose is primarily used for pressure service rather than suction. The hose is constructed of mandrels and to close tolerances (see Figure 5.8). It also has a smooth bore, which encourages laminar flow and avoids turbulence. Several plies (layers) of woven cotton or synthetic fabric make up the reinforcement. Selected for their resistance to corrosive fluids, the tube is made from a number of synthetic rubbers. It is also used in sandblasting applications.

5.6.1.5 WIRE-REINFORCED HOSE

In this type of hose, wires wound in a spiral around the tube, or inside the carcass, in addition to a number of layers of wrapped fabrics, provide the reinforcement (see Figure 5.9). With I.D.s of 16 to 24 inches common, this type of hose is used in oil-suction and discharge situations that require special hose ends, maximum suction (without collapsing), or special flexing characteristics (must be able to bend in a small radius without collapsing), or a combination of these three requirements.

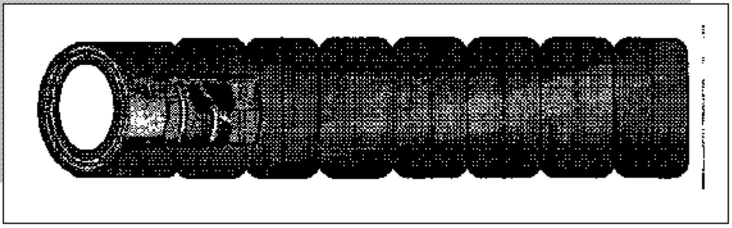


Figure 5.8 *Wrapped hose.*

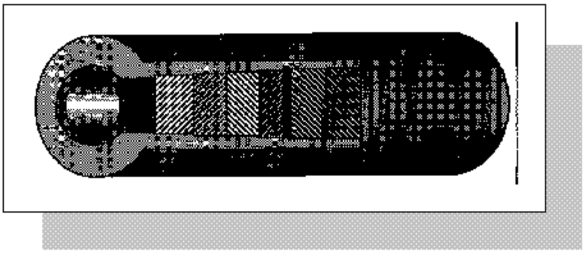


Figure 5.9
Wire-reinforced hose.

5.6.1.6 WIRE-WOVEN HOSE

Wire-woven hose (see Figure 5.10) has cords interwoven with wire running spirally around the tube, and is highly flexible, low in weight, and resistant to collapse even under suction conditions. This kind of hose is well suited for such negative-pressure applications.

5.6.2 OTHER TYPES OF NONMETALLIC HOSE

Hoses are also made of other nonmetallic materials, many of them non-reinforced. For example, materials like Teflon®, Dacron®, polyethylene, and nylon have been developed. Dacron® remains flexible at very low temperatures, even as low as –200+°C (up to –350°F), nearly the temperature of liquid nitrogen. Consequently, these hoses are used to carry liquefied gas in cryogenic applications.

Where corrosive fluids and fluids up to 230+°C (up to 450°F) are to be carried, Teflon® is often used. Teflon® can also be used at temperatures as low as –55°C (–65°F). Usually sheathed in a flexible, braided-metal covering, Teflon® hoses are well protected against abrasion; they also have added resistance to pressure.

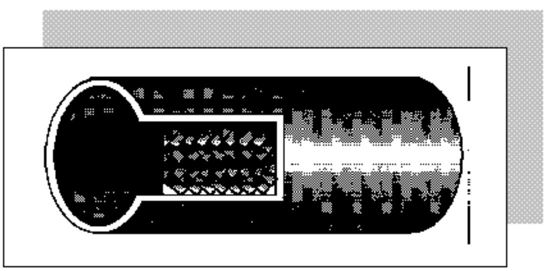


Figure 5.10
Wire-woven hose.

Nylon hoses (small diameter) are commonly used as air hoses, supplying compressed air to small pneumatic tools. The large plastic hoses (up to 24 inches) used to ventilate manholes are made of such neoprene-coated materials as nylon fabric, glass fabric, and cotton duck. The cotton duck variety is for light-duty applications. The glass-fabric-type is used with portable heaters and for other applications involving hot air and fumes.

Various hoses made from natural latex, silicone rubber, and pure gum are also available. The pure gum hose will safely carry acids, chemicals, and gases. Small hoses of natural latex, which can be sterilized, are used in hospitals, with pharmaceuticals, blood, and intravenous solutions, and in food-handling operations and laboratories. Silicone rubber hose is used in situations where extreme temperatures and chemical reactions are possible. It is also used for aircraft starters, to which it provides compressed air in very large volumes. Silicone rubber hose works successfully over a temperature range from –57°C (–70°F) to 232°C (450°F).

5.7 METALLIC HOSE

The construction of a braided, flexible all-metal hose includes a tube of corrugated bronze. The tube is covered with the woven metallic braid to protect against abrasion and to provide increased resistance to pressure. Metal hose is also available in steel, aluminum, Monel®, stainless steel, and other corrosion-resistant metals in diameters up to 3 inches and in lengths of 24 inches.

In addition to providing protection against abrasion and resistance to pressure, flexible metal hose also dampens vibration. For example, a plant air compressor produces a considerable amount of vibration. The flexible hoses from such machines increase mobility for portable equipment and also dampen the vibration. Other considerations such as constant bending at high temperatures and pressures are extremely detrimental on most other types of hoses.

Other common uses for metallic hoses include serving as steam lines, lubricating lines, gas and oil lines, and exhaust hose for diesel engines. The corrugated type, for example, is used for high-temperature, high-pressure leakproof service. Another type of construction is the *interlocked* flexible metal hose, used mainly for low-pressure applications. The standard shop oil can uses a flexible hose for the flexible spout. Other metal hose, with a liner of flexible, corrosion-resistant material, is available in diameters of up to 24 inches.

Another type of metallic hose is used in ductwork. This type is usually made of aluminum, galvanized steel, and stainless steel. The hoses are used to protect against corrosive fumes, as well as gases at extreme hot or cold temperatures. They are also fire resistant, because they usually do not burn.

5.8 HOSE COUPLINGS

The methods of connecting or coupling hoses vary. Hose couplings may be either permanent or reusable. They can also be manufactured for the obvious advantage of quick-connect or quick-disconnect. Probably the best example of the need for quick-connect is fire hose—quick-disconnect couplings permit rapid connection between separate lengths of hose and between hose ends and hydrants or nozzles. Another good example of where the quick-connect, quick-disconnect feature is user-friendly is in plant or mobile compressed air systems in which a single line may have a number of uses. Changes involve disconnecting one section and connecting another. In plant shops, for example, compressed air from a single source is used to power pneumatic tools, cleaning units, paint sprayers, and so on. Each unit has a hose that is equipped for rapid connecting and disconnecting at the fixed air line.

IMPORTANT **_Important Point:_** *CAUTION: Before connections are broken, unless quick-acting, self-closing connectors are used, pressure must be released first.*

For general low-pressure applications, a coupling like that shown in Figure 5.11 is used. To place this coupling on the hose by hand, first cut hose to proper length, then oil the inside of the hose and the outside of the coupling stem. Force the hose over the stem into the protective cap until

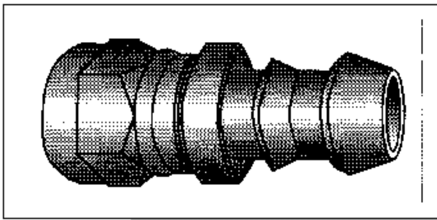


Figure 5.11
Low-pressure hose coupling.

it seats against the bottom of the cap. No brazing is involved, and the coupling can be used over and over again. After the coupling has been inserted in the hose, a yoke is placed over it in such a way that its arms are positioned along opposite sides of the hose behind the fitting. The arms are then tightly strapped or banded.

IMPORTANT ***Important Point:*** *CAUTION: Where the pressure demands are greater, such a coupling can be blown out of the tube. Hose couplings designed to meet high-pressure applications must be used.*

A variation of this type uses a clamp that is put over the inner end of the fitting and is then tightly bolted, thus holding the hose firmly. In other cases, a plain clamp is used. Each size clamp is designed for a hose of a specified size (diameter). The clamp slides snugly over the hose and is then crimped tight by means of a special hand tool or air-powered tool.

Coupling for all-metal hose, described earlier, involves two brazing operations, as shown in Figure 5.12. The sleeve is slipped over the hose end and brazed to it, then the nipple is brazed to the sleeve.

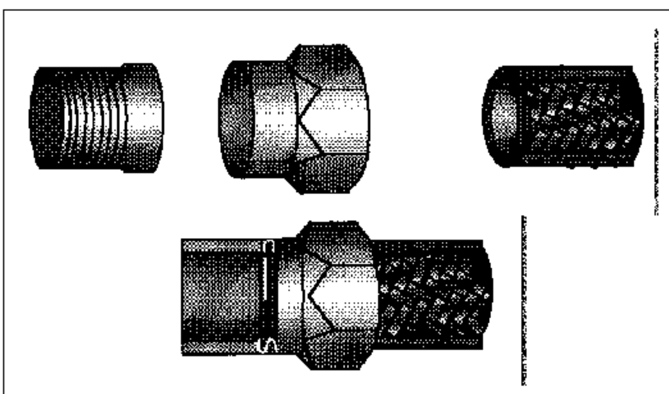


Figure 5.12
Coupling installation for all-metal hose.

Important Point: *For large hoses of rugged wall construction, it is not possible to insert push-on fittings by hand. Special bench tools are required.*

Quick-connect, quick-disconnect hose couplings provide flexibility in many plant process lines where a number of different fluids or dry chemicals from a single source are either to be blended or routed to different vats or other containers. The quick-connect coupling used on portable semirigid hoses is shown in Figure 5.13. These quick-connect couplings can be used to pump out excavations, manholes, and so forth. They would not be used, however, where highly corrosive materials are involved.

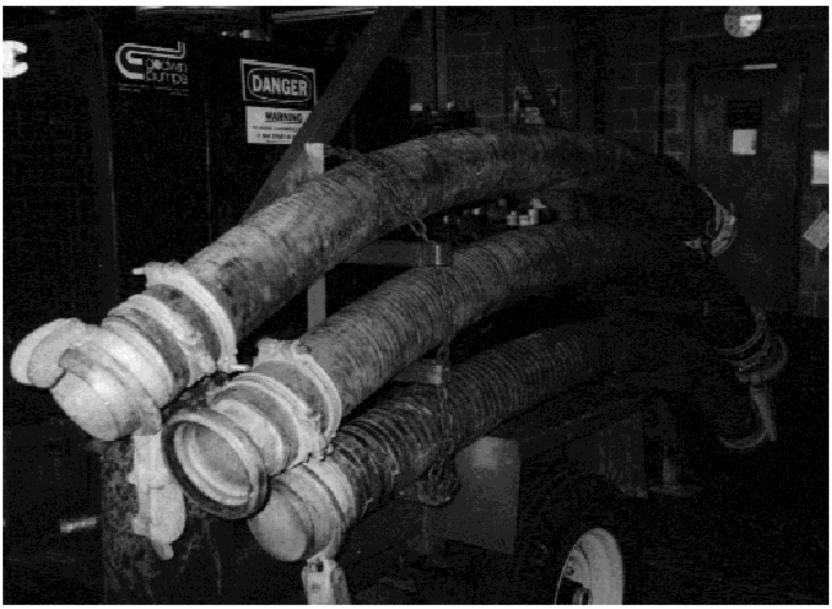


Figure 5.13
Flexible hose with quick-connect couplings.

5.9 HOSE MAINTENANCE

All types of equipment and machinery require proper care and maintenance, including hoses. Depending on the hose type and its application, some require more frequent checking than others. The maintenance procedures required for most hose are typical and are outlined here as an example.

- To maintain a hose, the following should be done:
- examine for cracks in the cover caused by weather, heat, oil, or usage
- look for a restricted bore because of tube swelling or foreign objects
- look for cover blisters, which permit material pockets to form between carcass and cover
- look for leaking materials (a leak is usually caused by improper couplings or faulty fastenings of couplings)
- look for corrosion damage to couplings
- look for kinked or otherwise damaged hose

IMPORTANT

Important Point: *CAUTION: Because any of the faults listed above can result in a dangerous hose failure, regular inspection is necessary. At the first sign of weakness or failure, replace the hose. System pressure and temperature gauges should be checked regularly. Do not allow the system to operate above design conditions, especially when hose is a component of the system.*

Self-Test

5.1 What is the dash number of a 1/4 inch hose?

5.2 What is the inside diameter of a -16 (dash) hose?

5.3 The __________ hose is the most common type of hose in general use.

5.4 The type of hose construction most suitable for maximum suction conditions is __________.

5.5 __________ is the nonmetallic hose best suited for use at extremely low temperatures.

5.6 Each size of hose clamp is designed for hose of a specific __________.

5.7 __________ is the outstanding advantage of hose.

5.8 Applied to hose, the letters __________ stand for enlarged end.

5.9 Hose is __________ in order to provide strength and greater resistance to __________.

5.10 Dacron® hose remains __________ at extremely low temperatures.

Pipe and Tube Fittings

The term *piping* refers to the overall network of pipes or tubing, fittings, flanges, valves, and other components that comprise a conduit system used to convey fluids. Whether a piping system is used to simply convey fluids from one point to another or to process and condition the fluids, piping components serve an important role in the composition and operation of the system. A system used solely to convey fluids may consist of relatively few components, such as valves and fittings, whereas a complex chemical processing system may consist of a variety of components used to measure, control, condition, and convey the fluids (Geiger, 2000, p. A.53). In this chapter, the characteristics and functions of various piping and tubing fittings are described.

TOPICS

Fittings
Functions of Fittings
Types of Connections
Tubing Fittings and Connections
Miscellaneous Fittings

6.1 FITTINGS

The primary function of *fittings* is to connect sections of piping and tubing and to change direction of flow. Whether used in piping or tubing, fittings are similar in shape and type, even though pipe fittings are usually heavier than tubing fittings. Several methods can be used to connect fittings to piping and tubing systems. However, most tubing is threadless, because it does not have the wall thickness needed to carry threads. Most pipes, on the other hand, because they have heavier walls, are threaded.

Key Terms Used in This Chapter

BUSHING	A removable cylindrical lining used to limit the size of an opening.
ELBOW	A fitting that connects two pipes at an angle, usually 45° or 90°.
GASKET	A packing used to make a pressure-tight joint between two parts.
REDUCER	A fitting that connects two or more pipes of different diameters.

In regard to changing direction of flow, the simplest way would be simply to bend the conduit, which, of course, is not always practical or possible. When piping is bent, it is usually accomplished by the manufacturer in the production process (in larger shops equipped with their own pipe-bending machines), not by the maintenance operator on the job. Tube bending, on the other hand, is a common practice. Generally, a tubing line requires fewer fittings than a pipeline; however, in actual practice many tube fittings are used.

IMPORTANT ***Important Point:*** *Recall that improperly made bends can restrict fluid flow by changing the shape of the pipe and weakening the pipe wall.*

Fittings are basically made from the same materials (and in the same broad ranges of sizes) as piping and tubing, including bronze, steel, cast iron, glass, and plastic.

Various established standards are in place to ensure that fittings are made from the proper materials and are able to withstand the pressures required; they are also made to specific tolerances, so that they will properly match the piping or tubing that they join. A fitting stamped "200" lb, for example, is suitable (and safe) for use up to 200 psi.

6.2 FUNCTIONS OF FITTINGS

Fittings in piping and tubing systems have five main functions:

- changing the direction of flow
- providing branch connections
- changing the sizes of lines
- closing lines
- connecting lines

6.2.1 CHANGING THE DIRECTION OF FLOW

Usually, a 45° or 90° *elbow* (or "ell") fitting is used to change the direction of flow. Elbows are among the most commonly used fittings in piping and are occasionally used in tubing systems.

Two types of 90° elbows are shown in Figure 6.1. From the figure, it is apparent that the *long-radius* fitting (the most preferred elbow) has the

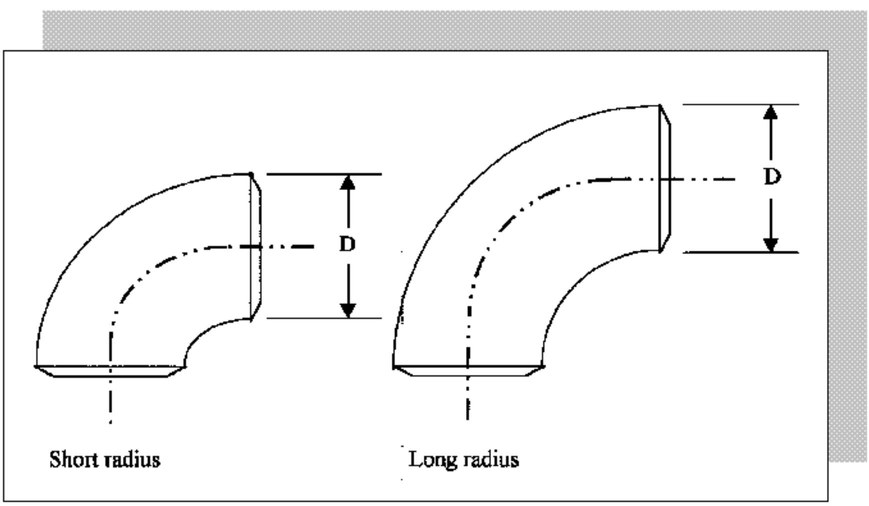


Figure 6.1
Short- and long-radius elbows.

more gradual curve of the two. This type of elbow is used in applications where the rate of flow is critical, and space presents no problem. Flow loss caused by turbulence is minimized by the gradual curve.

The *short-radius* elbow (see Figure 6.1) should not be used in a system made up of long lines with many changes in direction. Because of the greater frictional loss in the short-radius elbow, heavier, more expensive pumping equipment may be required.

Figure 6.2 shows a *return bend* fitting that carries fluid through a 180° ("hairpin") turn. This type of fitting is used for piping in heat exchangers and heater coils. Note that tubing, which can be bent into this form, does not require any fittings in this kind of application.

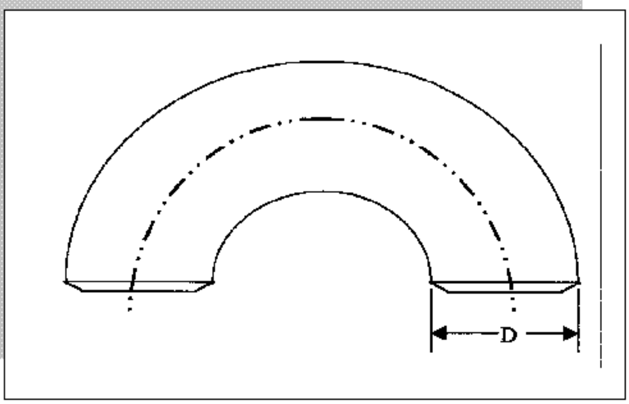


Figure 6.2
Long-radius return bend.

6.2.2 PROVIDING BRANCH CONNECTIONS

Because they are often more than single lines running from one point to another point, piping and tubing systems usually have a number of intersections. In fact, many complex piping and tubing systems resemble the layout of a town or city. (**Note:** Common types of pipe fittings are shown in Figure 6.3.)

Figure 6.3
Common types of pipe fittings. Starting at top left to right: coupling, cap, plug, nipple, 45°, street ell, tee, union, 90°, smaller tee.

6.2.3 CHANGING THE SIZES OF LINES

For certain applications, it is important to reduce the volume of fluid flow or to increase flow pressure in a piping or tubing system. To accomplish this, a *reducer* (which reduces a line to a smaller pipe size) is commonly used.

Important Point: *Reducing is also sometimes accomplished by means of a bushing inserted into the fitting.*

6.2.4 SEALING LINES

Pipe *caps* (see Figure 6.3) are used to seal or close off (similar to "corking" a bottle) the end of a pipe or tube. Usually, caps are used in a part of the system that has been dismantled.

To seal openings in fittings, *plugs* are used (see Figure 6.3). Plugs also provide a means of access into the piping or tubing system, in case the line becomes clogged.

6.2.5 CONNECTING LINES

To connect two lengths of piping or tubing, a coupling or union is used. A *coupling* is simply a threaded sleeve. A *union* is a three-piece device that includes a threaded end, an internally threaded bottom end, and a ring. A union does not change the direction of flow or close off the pipe or provide for a branch line. Unions make it easy to connect or disconnect pipes without disturbing the position of the pipes.

Figure 6.4 is a diagram of a shortened piping system, which illustrates how some of the fittings shown in Figure 6.3 are used in a piping system. (**Note:** Figure 6.4 is only for illustrative purposes; it is unlikely that such a system with so many fittings would actually be used.)

6.3 TYPES OF CONNECTIONS

Pipe connections may be screwed, flanged, or welded. Each method is widely used, and each has its own advantages and disadvantages.

6.3.1 SCREWED FITTINGS

Screwed fittings are joined to the pipe by means of threads. The main advantage of using threaded pipe fittings is that they can be easily replaced. The actual threading of a section of replacement pipe can be accomplished on the job. The threading process itself, however, which cuts right into the pipe material, may weaken the pipe in the joint area.

The weakest link in a piping system is the connection point(s). Because threaded joints can be potential problem areas, especially where higher pressures are involved, the threads must be properly cut to ensure that the "weakest" link is not further compromised.

Typically, the method used to ensure a good seal in a threaded fitting is to coat the threads with a paste dope. Another method is to wind the threads with Teflon® tape.

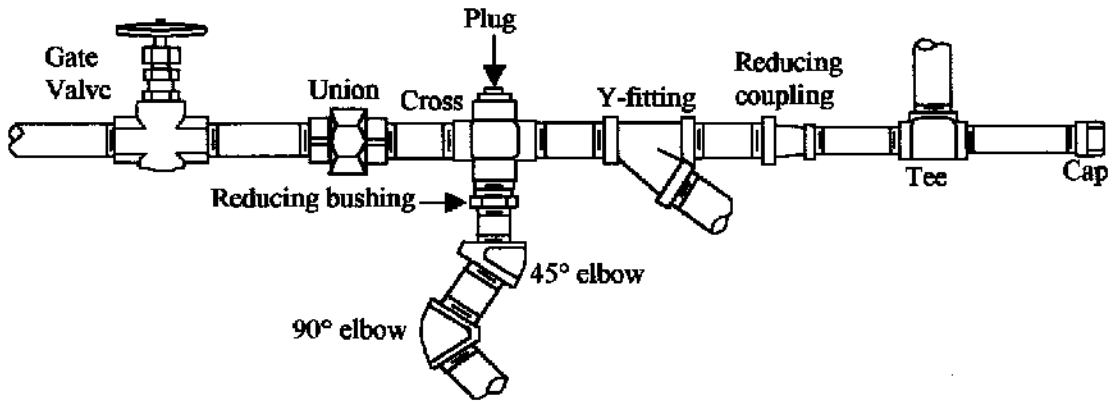


Figure 6.4
Diagram of a hypothetical shortened piping system.

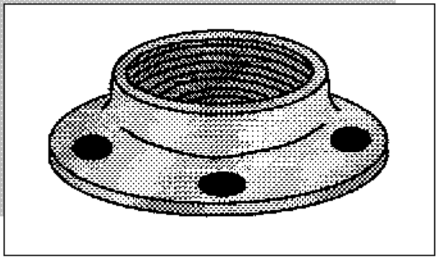


Figure 6.5
Flanged fitting.

6.3.2 FLANGED CONNECTIONS

Figure 6.5 shows a flanged fitting. *Flanged* fittings are forged of cast-iron pipe. The *flange* is a rim at the end of the fitting, which mates with another section. Pipe sections are also made with flanged ends.

Flanges are joined either by being bolted or welded together. The flange faces may be ground and lapped to provide smooth, flat mating surfaces. Obviously, a tight joint must be provided to prevent leakage of fluid and pressure.

Figure 6.6 shows a typical example of a flanged joint. The mating parts are bolted together with a gasket inserted between their faces to ensure a tight seal. The procedure requires proper alignment of clean parts and tightening of bolts.

IMPORTANT ***Important Point:*** *Some flanges have raised faces and others have plain faces. Like faces must be matched—a flange with a raised face should never be joined to one with a plain face.*

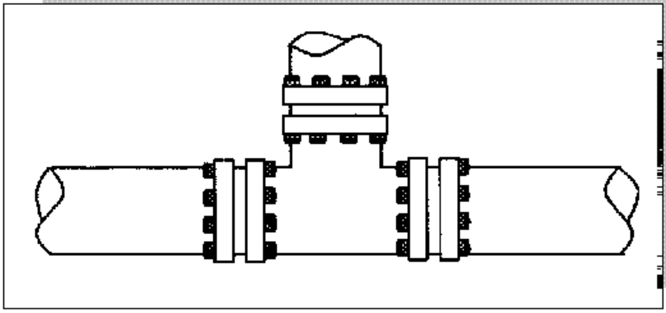


Figure 6.6
Flanged joint.

6.3.3 WELDED CONNECTIONS

Currently, because of improvements in piping technology and welding techniques/equipment, the practice of using welded joints is increasing. When properly welded, a piping system forms a continuous system, which combines piping, valves (see Chapter 7), flanges, and other fittings. Along with providing a long leakproof and maintenance-free life, the smooth joints simplify insulation and take up less room.

6.4 TUBING FITTINGS AND CONNECTIONS

Tubing is connected by brazed or welded flange fittings, compression fittings, and flare fittings.

The *welded flange* connection is a reliable means of connecting tubing components. The flange welded to the tube end fits against the end of the fitting. The locknut of the flange is then tightened securely onto the fitting.

The *compression fitting* connection uses a ferrule that pinches the tube as the locknut is tightened on the body of the fitting.

The *flare fitting* connection uses tubing flared on one end of the tubing that matches the angle of the fitting. The tube's flared end is butted against the fitting, and a locknut is screwed tightly onto the fitting, sealing the tube connection properly.

6.5 MISCELLANEOUS FITTINGS

Other fittings used for flanged connections include expansion joints and vibration dampeners.

Expansion joints function to compensate for slight changes in the length of pipe by allowing joined sections of rigid pipe to expand and contract with changes in temperature. They also allow pipe motion, either along the length of the pipe or to the side, as the pipe shifts around slightly after installation. Finally, expansion joints also help dampen vibration and noise carried along the pipe from distant equipment (e.g., pumps).

One type of expansion joint has a leakproof tube that extends through the bore and forms the outside surfaces of the flanges. Natural or synthetic rubber compounds are normally used, depending on the application.

Other types of expansion joints include metal corrugated types, slip-joint types, and spiral-wound types. In addition, high-temperature lines are usually made up with a large bend or loop to allow for expansion.

Vibration dampeners absorb vibrations that, unless reduced, could shorten the life of the pipe and the service life of the operating equipment. They also eliminate line humming and hammering (water hammer) carried by the pipes.

Self-Test

6.1 The __________ fitting allows for a certain amount of pipe movement.

6.2 The __________ fitting helps reduce the effects of water hammer.

6.3 A flange that has a plain face should be joined to a flange that has a __________ face.

6.4 Improperly made __________ restrict fluid flow in a pipeline.

6.5 The designation "200 lb" refers to the __________ at which a fitting can safely be used.

6.6 A(n) __________ is used to close off an unused outlet in a fitting.

6.7 A __________ has a more gradual curve than does the short-radius elbow.

6.8 An __________ connects two pipes at an angle, usually 45° or 90°.

6.9 A __________ connects two or more pipes of different diameters.

6.10 A __________ is used to make a pressure-tight joint between two parts.

Valves

Any water/wastewater operation will have many valves that require attention. Simply as a matter of routine, a maintenance operator must be able to identify and locate different valves in order to inspect them, to adjust them, and to repair or replace them. For this reason, the maintenance operator should be familiar with all valves, especially those that are vital parts of a piping system.

TOPICS

7.1 VALVES: DEFINITION AND FUNCTION[6]

A *valve* is defined as any device by which the flow of fluid may be started, stopped, or regulated by a movable part that opens or obstructs passage. As applied in fluid power systems, valves are used for controlling the flow, the pressure, and the direction of the fluid flow through a piping system. The fluid may be a liquid, a gas, or some loose material in bulk (like a biosolids slurry). Designs of valves vary, but all valves have two features in common: a passageway through which fluid can flow and some kind of movable (usually machined) part that opens and closes the passageway.

IMPORTANT

Important Point: *It is all but impossible, obviously, to operate a practical fluid power system without some means of controlling the volume and pressure of the fluid and directing the flow of fluid to the operating units. This is accomplished by the incorporation of different types of valves.*

[6]Adapted from Integrated Publishing's Official Web Page, *Valves*, corp@tpub.com, pp. 1–4, 1998.

Key Terms Used in This Chapter

BUTTERFLY VALVE	A valve in which a disk rotates on a shaft as the valve opens and closes. In the full open position, the disk is parallel to the axis of the pipe.
CHECK VALVE	A valve designed to open in the direction of normal flow and close with reversal of flow. An approved check valve has substantial construction and suitable materials, is positive in closing, and permits no leakage in a direction opposite to normal flow.
DIAPHRAGM VALVE	A valve in which the closing element is a thin, flexible disk often used in low-pressure systems.
GATE VALVE	A valve in which the closing element consists of a disk that slides across an opening to stop the flow of water.
GLOBE VALVE	A valve having a round, ball-like shell and horizontal disk.
PRESSURE-REGULATING VALVE	A valve with a horizontal disk for automatically reducing water pressures in a main to a preset valve.
SOLENOID	An electrically energized coil of wire surrounding a movable iron case.
THROTTLE	Controlling flow through a valve by means of intermediate steps between fully open and fully closed.

Whatever type of valve is used in a system, it must be accurate in the control of fluid flow and pressure and the sequence of operation. Leakage between the valve element and the valve seat is reduced to a negligible quantity by precision-machined surfaces, resulting in carefully controlled clearances. This is, of course, one of the important reasons for minimizing contamination in fluid power systems. Contamination causes valves to stick, plugs small orifices, and causes abrasions of the valve seating surfaces, which results in leakage between the valve element and valve seat when the valve is in the closed position. Any of these can result in inefficient operation or complete stoppage of the equipment. Valves may be controlled manually, electrically, pneumatically, mechanically, hydraulically, or by combinations of two or more of these methods. Factors that determine the method of control include the purpose of the valve, the design and purpose of the system, the location of the valve within the system, and the availability of the source of power.

Valves are made from bronze, cast iron, steel, Monel®, stainless steel, and other metals. They are also made from plastic and glass (see Table 7.1). Special valve trim is used where seating and sealing materials are different from the basic material of construction (see Table 7.2). (**Note:** *Valve trim* usually means those internal parts of a valve controlling the flow and in physical contact with the line fluid.) Valves are made in a full range of sizes that match pipe and tubing sizes. Actual valve size is based upon the internationally agreed-upon definition of nominal size. *Nominal size (DN)* is a numerical designation of size that is common to all components in a piping system other than components designated by outside diameters. It is a convenient number for reference purposes and is only loosely related to manufacturing dimensions. Valves are made for service at the same pressures and temperatures that piping and tubing are subject to. Valve pressures are based upon the internationally agreed upon definition of nominal pressure. *Nominal pressure (PN)* is a pressure that is conventionally accepted or used for reference purposes. All equipment of the same nominal size (DN) designated by the same nominal pressure (PN) number must have the same mating dimensions appropriate to the type of end connections. The permissible working pressure depends upon materials, design, and working temperature, and should be selected from the (relevant) pressure/temperature tables. The pressure rating of many valves is designated under the American (ANSI) class system. The equivalent class rating to PN ratings is based upon international agreement.

Usually, valve end connections are classified as flanged, threaded, or other (see Table 7.3).

Valves are also covered by various codes and standards, as are the other components of piping and tubing systems.

Many valve manufacturers offer valves with special features. Table 7.4 lists a few of these special features, however, this is not an exhaustive list, and for more details of other features, the manufacturer should be consulted.

The different types of valves used in fluid power systems, their classifications, and their applications are discussed in this chapter.

TABLE 7.1. Valves: Materials of Construction.	
Cast iron	Grey cast iron. Also referred to as flake graphite iron.
Ductile iron	May be malleable iron or spheroidal graphite (nodular) cast iron.
Carbon steel	May be as steel forgings, or steel castings, according to the method of manufacture. Carbon steel valves may also be manufactured by fabrication using wrought steels.
Stainless steel	May also be in the form of forgings, castings, or wrought steels for fabrication.
Copper alloy	May be gunmetal, bronze, or brass. Aluminum bronze may also be used.
High-duty alloys	Are usually those nickel or nickel molybdenum alloys manufactured under various trade names.
Other metals	Are those pure metals having extreme corrosion resistance such as titanium or aluminum.
Nonmetals	Are typically the plastics materials such as PVC or polypropylene.

TABLE 7.2. Valve Trim.	
Metal seating	Is commonly used in gate and globe valves, and in the latter particularly for control applications where seatings may additionally be coated with hard metal.
Soft seating	Is commonly used in ball, butterfly, and diaphragm valves. Seatings may be made from a wide variety of elastomers and polymers including fluorocarbons.
Lined	Valves are usually made in cast iron with an internal lining of elastomer of polymer material. Inorganic materials such as glass, together with metals such as titanium, are also used for lining. Lining thickness will depend upon design and the type of material used. In many cases, the valve lining will also form the seating trim.

TABLE 7.3. Valve End Connections.	
Flanged	Valves will normally be supplied with flanges confirming to either BS4505 (Equivalent to DIN) or BS 1560 (equivalent to ANSI) according to specification. Manufacturers may be able to supply valves with flanges to other standards.
Threaded	Valves will normally be supplied with threads to BS21 (ISO/7) parallel or taper.
Other	End connections include butt or socket weld ends and wafer valves designed to fit between pipe flanges.

7.1.1 VALVE CONSTRUCTION

Figure 7.1 shows the basic construction and principle of operation of a common valve type. Fluid flows into the valve through the inlet. The fluid flows through passages in the body and past the opened element that closes the valve. It then flows out of the valve through the outlet or discharge.

TABLE 7.4. Valve Special Features.	
High temperature	Valves are those usually able to operate continuously on services above 250°C.
Cryogenic	Valves are those that will operate continuously on services in the range −50°C to 196°C.
Bellows sealed	Valves are glandless designs having a metal bellows for stem sealing.
Actuated	Valves may be operated by a gearbox, pneumatic or hydraulic cylinder (including diaphragm actuator) or electric motor and gearbox.
Fire-tested design	Refers to a valve that has passed a fire test procedure specified in an appropriate inspection standard.

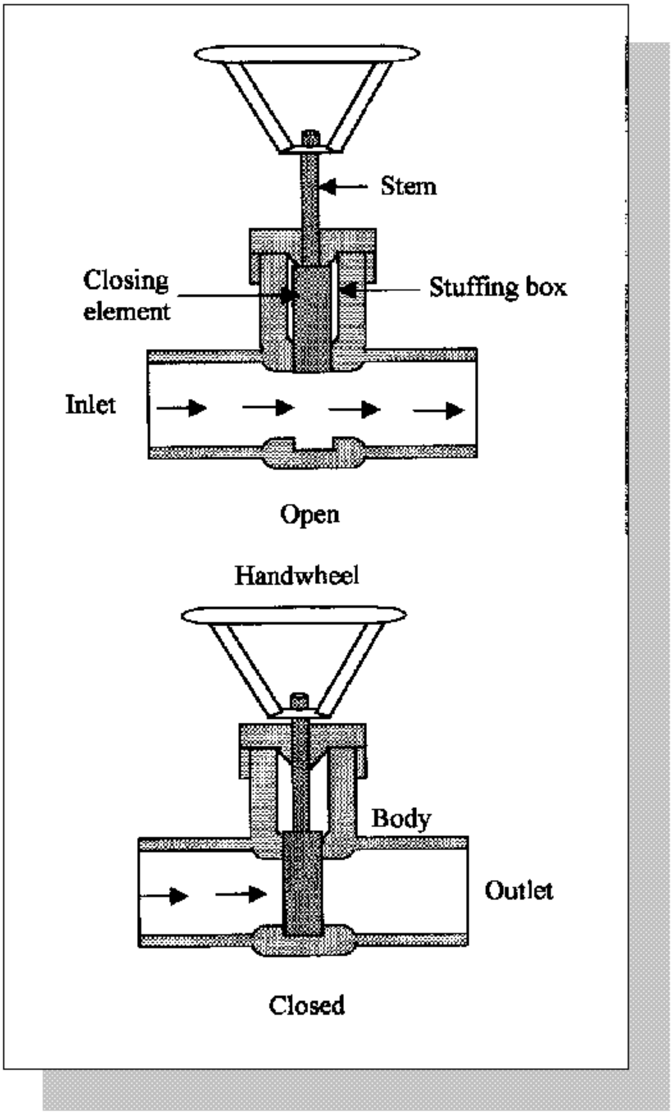


Figure 7.1 Basic valve operation.

If the closing element is in the closed position, the passageway is blocked. Fluid flow is stopped at that point. The closing element keeps the flow blocked until the valve is opened again. Some valves are opened automatically, and others are controlled by manually operated handwheels. Other valves, such as check valves (see Section 7.2.7), operate in response to pressure or the direction of flow.

To prevent leakage whenever the closing element is positioned in the closed position, a seal is used. In Figure 7.1, the seal consists of a *stuff-*

ing box fitted with packing. The closing element fits against the *seat* in the valve body to keep the valve tightly closed.

7.2 TYPES OF VALVES

The types of valves covered in this text include the following:

- ball valves
- gate valves
- globe valves
- needle valves
- butterfly valves
- plug valves
- check valves
- quick-opening valves
- diaphragm valves
- regulating valves
- relief valves
- reducing valves

Each of these valves is designed to perform control of the flow, the pressure, the direction of fluid flow, or some other special application. With a few exceptions, these valves take their names from the type of internal element that controls the passageway. The exceptions are the check valve, quick-opening valve, regulating valve, relief valve, and reducing valves.

7.2.1 BALL VALVES

Ball valves, as the name implies, are stop valves that use a ball to stop or start fluid flow (see Figure 7.2). The ball performs the same function as the disk in other valves. As the valve handle is turned to open the valve,

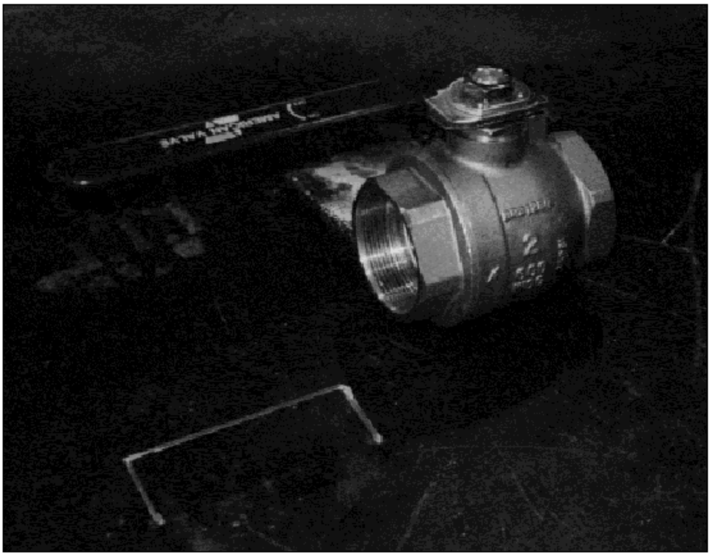


Figure 7.2
Standard ball valve.

the ball rotates to a point where part or all of the hole through the ball is in line with the valve body inlet and outlet, allowing fluid to flow through the valve. When the ball is rotated so the hole is perpendicular to the flow openings of the valve body, the flow of fluid stops.

Most ball valves are the quick-acting type. They require only a 90-degree turn to either completely open or close the valve. However, many are operated by planetary gears. This type of gearing allows for the use of a relatively small handwheel and operating force to operate a fairly large valve. The gearing does, however, increase the operating time for the valve. Some ball valves also contain a swing check located within the ball to give the valve a check valve feature.

The two main advantages of using ball valves are that the fluid can flow through it in either direction, as desired, and that when closed, pressure in the line helps to keep it closed.

7.2.2 GATE VALVES

Gate valves are used when a straight-line flow of fluid and minimum flow restriction are needed; they are the most common type of valve found in a water distribution system. Gate valves are so-named because the part that either stops or allows flow through the valve acts somewhat like a gate (see Figure 7.3). The gate is usually wedge-shaped. When the valve is wide open, the gate is fully drawn up into the valve bonnet. This leaves an opening for flow through the valve the same size as the pipe in which the valve is installed. For these reasons, the pressure loss (pressure drop) through these types of valves is about equal to the loss in a piece of pipe of the same length. Gate valves are not suitable for throttling (means to control the flow as desired, by means of intermediate steps between fully open and fully closed) purposes. The control of flow is difficult

Figure 7.3
The top photo shows a small gate valve; the bottom photo shows a large gate valve.

because of the valve's design, and the flow of fluid slapping against a partially open gate can cause extensive damage to the valve.

IMPORTANT

Important Point: *Gate valves are well suited to service on equipment in distant locations, where they may remain in the open or closed position for a long time. Generally, gate valves are not installed where they will need to be operated frequently, because they require too much time to operate from fully open to closed (AWWA, 1996, p. 61). This fact is best appreciated by viewing the large gate valve shown in Figure 7.3; its gear-driven operator facilitates easier opening or closing but also tends to slow either operation.*

7.2.3 GLOBE VALVES

Probably the most common valve type in existence, the *globe* valve principle is commonly used for water faucets and other household plumbing. As illustrated in Figure 7.4, the valves have a circular disk (the "globe") that presses against the valve seat to close the valve. The disk is the part of the globe valve that controls flow. The disk is attached to the valve stem. As shown in Figure 7.4, fluid flow through a globe valve is at right angles to the direction of flow in the conduits. Globe valves seat very tightly and can be adjusted with fewer turns of the wheel than gate valves; thus, they are preferred for applications that call for frequent

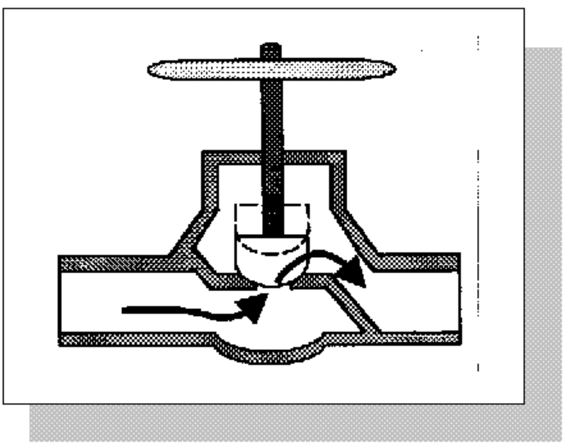


Figure 7.4
Globe valve.

opening and closing. On the other hand, globe valves create high head loss when fully open; thus, they are not suited in systems where head loss is critical.

IMPORTANT

Important Point: *The globe valve should never be jammed in the open position. After a valve is fully opened, the handwheel should be turned toward the closed position approximately one-half turn. Unless this is done, the valve is likely to seize in the open position, making it difficult, if not impossible, to close the valve. Another reason for not leaving globe valves in the fully open position is that it is sometimes difficult to determine if the valve is open or closed.*[7]

7.2.4 NEEDLE VALVES

Although similar in design and operation to the globe valve (a variation of globe valves), the *needle* valve has a closing element in the shape of a long tapered point, which is at the end of the valve stem. Figure 7.5 shows a cross-sectional view of a needle valve. As you can see in Figure 7.5, the long taper of the valve closing element permits a much smaller seating surface area than that of the globe valve; accordingly, the needle valve is more suitable as a throttle valve. In fact, needle valves are used for very accurate throttling.

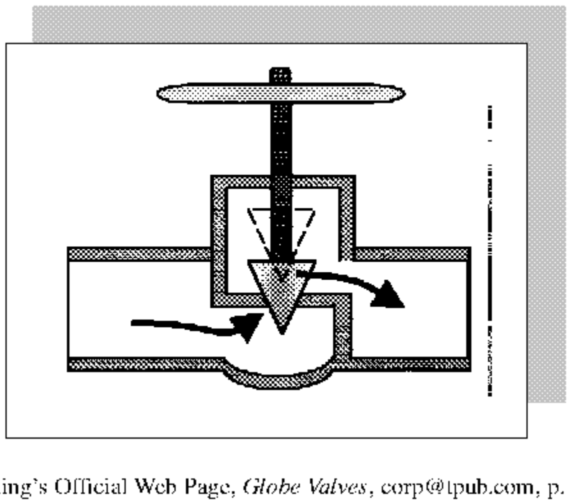


Figure 7.5
Common needle value.

[7]Integrated Publishing's Official Web Page, *Globe Valves*, corp@tpub.com, p. 2, 1998.

7.2.5 BUTTERFLY VALVES

Figure 7.6 shows a cross-sectional view of a butterfly valve. The valve itself consists of a body in which a disk ("butterfly") rotates on a shaft to open or close the valve. Butterfly valves may be flanged or wafer design, the latter intended for fitting directly between pipeline flanges. In the fully open position, the disk is parallel to the axis of the pipe and the flow of fluid. In the closed position, the disk seals against a rubber gasket-type material bonded either on the valve seat of the body or on the edge of the disk. Because the disk of a butterfly valve stays in the fluid path in the open position, the valve creates more turbulence (higher resistance to flow, equaling a higher pressure loss) than a gate valve.

On the other hand, butterfly valves are compact. They can also be used to control flow in either direction. This feature is useful in water treatment plants that periodically backwash to clean filter systems.

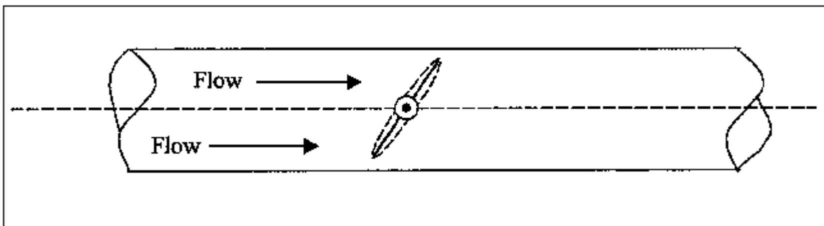


Figure 7.6
Cross section of a butterfly valve.

7.2.6 PLUG VALVES

A *plug* valve (also known as a *cock* or *petcock*) is similar to a ball valve. Plug valve properties include the following:

- high capacity operation, 1/4 turn operation
- use either a cylindrical or conical plug as the closing member
  directional

- moderate vacuum service
- flow throttling with interim positioning
- simple construction; o-ring seal
- not necessarily full on and off
- easily adapted to automatic control
- can safely handle gases and liquids

7.2.7 CHECK VALVES

Check valves are usually self-acting and designed to allow the flow of fluid in one direction only (see Figure 7.7). They are commonly used at the discharge of a pump to prevent backflow when the power is turned off. When the direction of flow is moving in the proper direction, the valve remains open. When the direction of flow reverses, the valve closes automatically from the fluid pressure against it.

There are several types of check valves used in water/wastewater operations, including the following:

- slanting disk check valves
- cushioned swing check valves

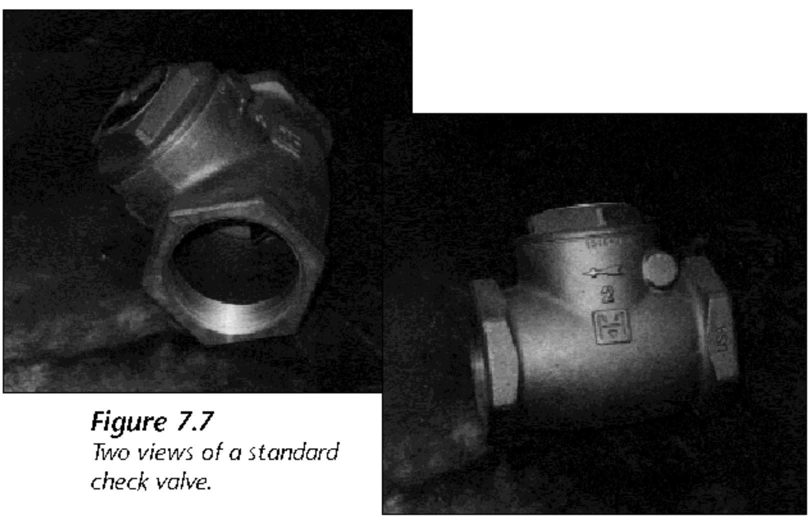


Figure 7.7
Two views of a standard check valve.

- rubber flapper swing check valves
- double-door check valves
- ball check valves
- foot valves
- backflow prevention devices

In each case, pressure from the flow in the proper direction pushes the valve element to an open position. Flow in the reverse direction pushes the valve element to a closed position.

IMPORTANT

Important Point: *Check valves are also commonly referred to as non-return or reflux valves.*

7.2.8 QUICK-OPENING VALVES

Quick-opening valves are nothing more than adaptations of some of the valves already described. Modified to provide a quick on/off action, they use a lever device in place of the usual threaded stem and control handle to operate the valve. This type of valve is commonly used in water/wastewater operations where deluge showers and emergency eye-wash stations are installed in work areas where chemicals are loaded, transferred, and/or where chemical systems are maintained. They also control the air supply for some emergency alarm horns around chlorine storage areas, for example. Moreover, they are usually used to cut off the flow of gas to a main or to individual outlets.

7.2.9 DIAPHRAGM VALVES

Diaphragm valves are glandless valves that use a flexible elastomeric diaphragm (a flexible disk) as the closing member, which, in addition, affects an external seal. They are well suited to service in applications where tight, accurate closure is important. The tight seal is effective whether the fluid is a gas or a liquid. This tight closure feature makes these valves useful in vacuum applications. Diaphragm valves operate similar to globe valves and are usually multi-turn in operation; they are available as weir-type and full bore. A common application of diaphragm valves in water or wastewater operations is to control fluid flow to an elevated tank.

7.2.10 REGULATING VALVES

As their name implies, *regulating* valves regulate either pressure or temperature in a fluid line, keeping it very close to a preset level. If the demands and conditions of a fluid line remained steady at all times, no regulator valve would be needed. In the real world, however, ideal conditions do not occur.

Pressure-regulating valves regulate fluid pressure levels to meet flow demand variations. Flow variations vary with the number of pieces of equipment in operation and the change in demand as pumps and other machines operate. In such fluid line systems, demands are constantly changing. Probably the best example of this situation is seen in the operation of the plant's low-pressure air supply system. For shop use, no more than 30 psi air is usually required (depending on required usage, of course). This air is supplied by the plant's air compressor, which normally operates long enough to fill an accumulator with pressurized air at a set pressure level. When shop air is required, for whatever reason, compressed air is drawn from the connection point in the shop. The shop connection point is usually connected via a pressure reducer (sets the pressure at the desired usage level) that, in turn, is fed from the accumulator, where the compressed air is stored. If the user draws a large enough quantity of compressed air from the system (from the accumulator), a sensing device within the accumulator will send a signal to the air compressor to start, which will produce compressed air to recharge the accumulator.

As well as providing service in air lines, pressure-regulating valves are also used in liquid lines. The operating principle is much the same for both types of service. Simply, the valve is set to monitor the line and to make needed adjustments in response to a signal from a sensing device.

Temperature-regulating valves (also referred to as *thermostatic control* valves) are closely related to pressure-regulating valves (see Figure 7.8). Their purpose is to monitor the temperature in a line or process solution tank and to regulate it, to raise or lower the temperature as required.

In water/wastewater operations, probably the most familiar application whereby temperature-regulating valves (see Figure 7.9) are used is in heat exchangers. A *heat exchanger-type* water system utilizes a water-to-coolant heat exchanger for heat dissipation. This is an efficient and effective method to dispose of unwanted heat. Heat exchangers are equipped with temperature regulating valves that automatically modulate the shop process water, limiting usage to just what is required to achieve the desired coolant temperature.

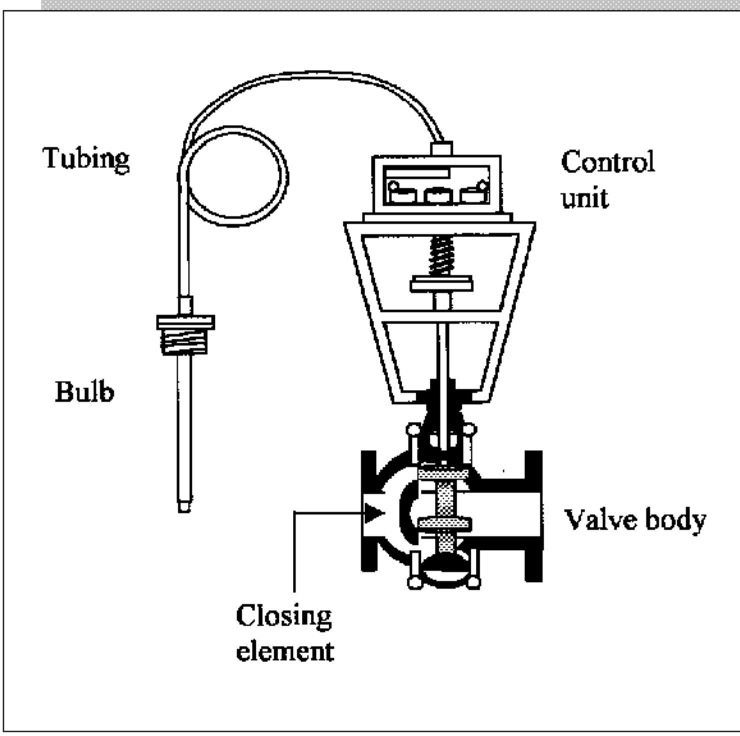


Figure 7.8
Temperature-regulating valve assembly.

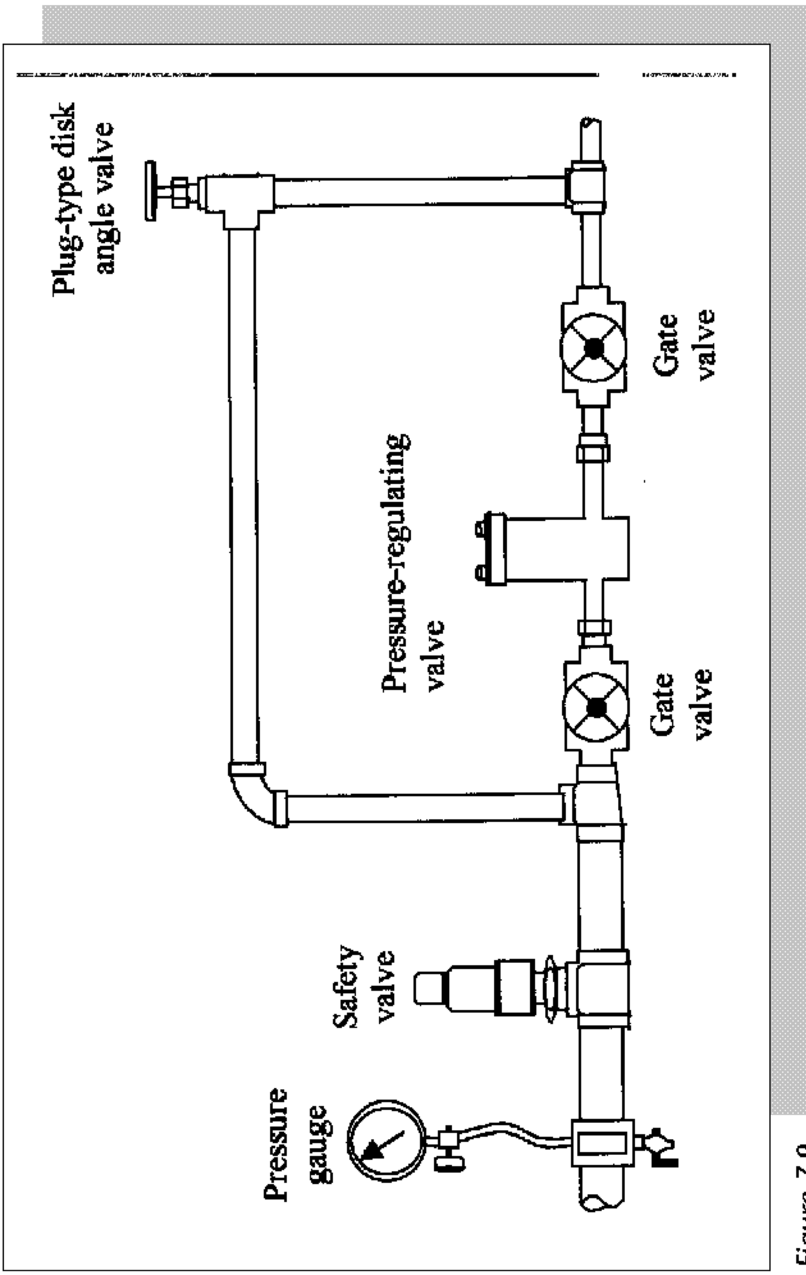


Figure 7.9
Pressure-regulating valve system.

7.2.11 RELIEF VALVES

Some fluid power systems, even when operating normally, may temporarily develop excessive pressure. For example, whenever an unusually strong work resistance is encountered, dangerously high pressure may develop. *Relief* valves are used to control this excess pressure. Such valves are automatic valves; they start to open at a preset pressure but require a 20% overpressure to open wide. As the pressure increases, the valve continues to open farther until it has reached its maximum travel. As the pressure drops, it starts to close and finally shuts off at about the set pressure.

Main system relief valves are generally installed between the pump or pressure source and the first system isolation valve. The valve must be large enough to allow the full output of the hydraulic pump to be delivered back to the reservoir.

IMPORTANT

Important Point: *Relief valves do not maintain flow or pressure at a given amount, but they prevent pressure from rising above a specific level when the system is temporarily overloaded.*

7.2.12 REDUCING VALVES

Pressure-reducing valves provide steady pressure into a system that operates at a lower pressure than the supply system. In practice, they are very much like pressure-regulating valves. A pressure-reducing valve reduces pressure by throttling the fluid flow. A reducing valve can normally be set for any desired downstream pressure within the design limits of the valve. Once the valve is set, the reduced pressure will be maintained regardless of changes in supply pressure (as long as the supply pressure is at least as high as the reduced pressure desired) and regardless of the system load, providing the load does not exceed the design capacity of the reducer.

7.3 VALVE OPERATORS

In many modern water/wastewater operations, many valves are mechanically operated by devices called *operators* or *actuators*. These devices may be operated by air, electricity, or fluid; that is, pneumatic, hydraulic, and magnetic operators.

7.3.1 PNEUMATIC AND HYDRAULIC VALVE OPERATORS

Pneumatic and *hydraulic* valve operators are much the same in appearance and work in much the same way. Valves in treatment plants and pumping stations are frequently operated by hydraulic cylinders using either plant water pressure or hydraulic fluid (AWWA, 1996, p. 77). In a typical pneumatic ball-valve actuator, the cylinder assembly is attached to the ball-valve stem close to the pipe. A piston inside the cylinder can move in either direction. The piston rod is linked to the valve stem, opening or closing the valve, depending on the direction in which the piston is traveling. As a fail-safe feature, some of these valves are spring-loaded. In case of hydraulic or air pressure failure, the valve operator returns the valve to the safe position.

IMPORTANT

Note: *According to Casada, valve operators and positioners usually require more maintenance than the valves themselves (Casada, 2000, pp. 1–3).*

7.3.2 MAGNETIC VALVE OPERATORS

Magnetic valve operators use electric solenoids. A *solenoid* is a coil of magnetic wire, roughly in the shape of a doughnut. When a bar of iron is inserted as a plunger mechanism inside an energized coil, it moves along the coil because of the magnetic field that is created. If the plunger (the iron bar) is fitted with a spring, it returns to its starting point when the electric current is turned off.

Solenoids are used as operators for many different types of valves used in water/wastewater operations. For example, in a direct-operating valve, the solenoid plunger is used in place of a valve stem and handwheel. The plunger is connected directly to the disk of a globe valve. As the solenoid coil is energized or deenergized, the plunger rises or falls, operating or closing the valve.

7.4 VALVE MAINTENANCE

As with any other mechanical device, effective valve maintenance begins with its correct operation. As an example of incorrect operation, consider the standard household water faucet. As the faucet washers age, they harden and deteriorate. The valve becomes more difficult to operate properly, and eventually, the valve begins to leak. A common practice is simply to apply as much force as possible to the faucet handle. Doing so, however, damages the valve stem and the valve body.

Good maintenance includes preventive maintenance, which, in turn, includes inspection of valves, correct lubrication of all moving parts, and the replacement of seals or stem packing.

Self-Test

7.1 __________ control fluid flow through piping systems.

7.2 Valves can be used to __________, __________, and __________ flow.

7.3 A __________ valve is better suited for throttling service than is a gate valve.

7.4 A __________ valve is a fast-operating shut-off valve commonly used in large water-circulating systems.

7.5 A __________ valve ensures that fluid flow will be in one direction only.

7.6 An emergency deluge shower is usually controlled by a(n) __________.

7.7 Most valves are named after the __________element.

7.8 __________ valves are also referred to as thermostatic control valves.

7.9 The best valve to use for a vacuum application is a __________ valve.

7.10 A pressure-regulating valve keeps the __________ at a __________ level.

Piping System: Protective Devices

Piping systems must be protected from the harmful effects of undesirable impurities (solid particles) entering the fluid stream. Because of the considerable variety of materials carried by piping systems, there is an equal range of choices in protective devices. Such protective devices include strainers, filters, and traps.

In this lesson, we describe the design and function of strainers, filters, and traps. The major maintenance considerations of these protective devices are also explained.

TOPICS

Piping Protective Devices: Applications
Strainers
Filters
Traps

8.1 PIPING PROTECTIVE DEVICES: APPLICATIONS

Filters, strainers, and traps are normally thought of in terms of specific components used in specific systems. However, it is important to keep in mind that the basic principles apply in many systems. While the examples used in this chapter include applications found in water/wastewater treatment, collection, and distribution systems, the applications are also found in almost every plant—hot and cold water lines, lubricating lines, pneumatic and hydraulic lines, and steam lines.

In regard to steam lines, it is important to point out that in our discussion of traps, their primary application is in steam systems where they remove unwanted air and condensate from lines.

IMPORTANT **_Important Point:_** *A very large percentage (estimated to be >70%) of all plant facilities in the United States make use of steam in some applications.*

Key Terms Used in This Chapter

CONDENSATE	Steam that condenses into water in a piping system.
DIFFERENTIAL PRESSURE	The difference between the inlet and outlet pressures in a piping system.
FILTER	An accessory fitting used to remove solids from a fluid stream.
STRAINER	An accessory fitting used to remove large particles of foreign matter from a fluid.
TRAP	An accessory fitting used to remove condensate from steam lines.

Other system applications of piping protective devices include conveyance of hot and chilled water for heating and air conditioning and lines that convey fluids for various processes. Any foreign contamination in any of these lines can cause potential trouble. Piping systems can become clogged, thereby causing greatly increased friction and lower line pressure. Foreign contaminants (dirt and other particles) can also damage valves, seals, and pumping components.

IMPORTANT

Important Point: *Foreign particles in a high-pressure line can damage a valve by clogging the valve so that it cannot close tightly. In addition, foreign particles may wear away the closely machined valve parts.*

8.2 STRAINERS[8]

Strainers, usually wire mesh screens, are used in piping systems to protect equipment sensitive to contamination that may be carried by the fluid. Strainers can be used in pipelines conveying air, gas, oil, steam, water, wastewater, and nearly any other fluid conveyed by pipes. Generally, strainers are installed ahead of valves, pumps, regulators, and

[8]Sections 8.2 and 8.3 adapted from Geiger, 2000, pp. A.53–A.83; Frankel, 2000, pp. C.755–C.777.

traps in order to protect them against the damaging effects of corrosion products that may become dislodged and conveyed throughout the piping system.

A common strainer is shown in Figure 8.1. This type of strainer is generally used upstream of traps, control valves, and instruments. This strainer resembles a lateral branch fitting with the strainer element installed in the branch. The end of the lateral branch is removable, to permit servicing of the strainer.

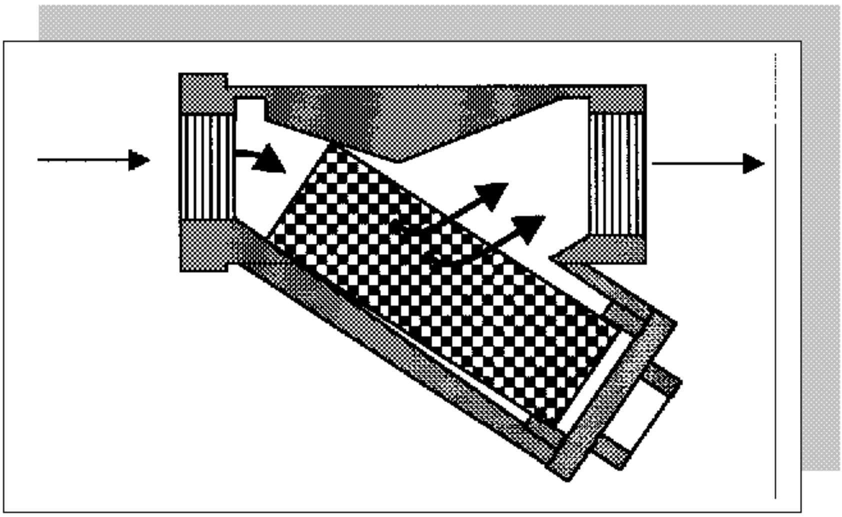


Figure 8.1
A common strainer.

In operation, the fluid passes through the strainer screen, which catches most of the contaminants. Then, the fluid passes back into the line. Contaminants in the fluid are caught in two ways. Either they do not make it through the strainer screen, or they do not make the sharp turn that the fluid must take as it leaves the unit. The bottom of the unit serves as a sump where the solids collect. A blowout connection may be provided in the end cap to flush the strainer. The blowout plug can be removed, and the pressure in the line can be used to blow the fixture clean.

IMPORTANT

Important Point: *Before removing the blowout plug, the valve system must be locked out/tagged out first.*

8.3 FILTERS

The purpose of any *filter* is to reduce or remove impurities or contaminants from a fluid (liquid or gas) to an acceptable or predetermined level. This is accomplished by passing the fluid through some kind of porous barrier. Filter cartridges have replaceable elements made of paper, wire cloth, nylon cloth, or fine-mesh nylon cloth between layers of coarse wire. These materials filter out unwanted contaminants, which collect on the entry side of the filter element. When clogged, the element is replaced.

Most filters operate in two ways: (1) they cause the fluid to make sharp changes in direction as it passes through (this is important, because the larger particles are too heavy to change direction quickly), and (2) they contain some kind of barrier that will not let larger contaminants pass.

8.4 TRAPS[9]

Traps, used in steam processes, are automatic valves that release condensate (condensed steam) from a steam space while preventing the loss of live steam. Condensate is undesirable because water produces rust, and water plus steam leads to water hammer. In addition, steam traps remove air and non-condensate from the steam space.

The operation of a trap depends on what is called *differential pressure* (or delta-P), in psi. Differential pressure is the difference between the inlet and outlet pressures. A trap will not operate correctly at a differential pressure higher than the one of which it was designed.

There are many types of steam traps because there are many different types of applications. Each type of trap has a range of applications for which it is best suited. For example, thermostatic and float-and-thermostatic are the names given to the two general types of traps.

Thermostatic traps have a corrugated bellows-operating element that is filled with an alcohol mixture that has a boiling point lower than that

[9]Adapted from Bandes and Gorelick, 2000, pp. 1–4.

of water (see Figure 8.2). The bellows contracts when in contact with condensate and expands when steam is present. If a heavy condensate load occurs, the bellows will remain in the contracted state, allowing condensate to flow continuously. As steam builds, the bellows closes. Thus, at times, the trap acts as a "continuous flow" type, while at other times, it acts intermittently as it opens and closes to condensate and steam, or it may remain totally closed.

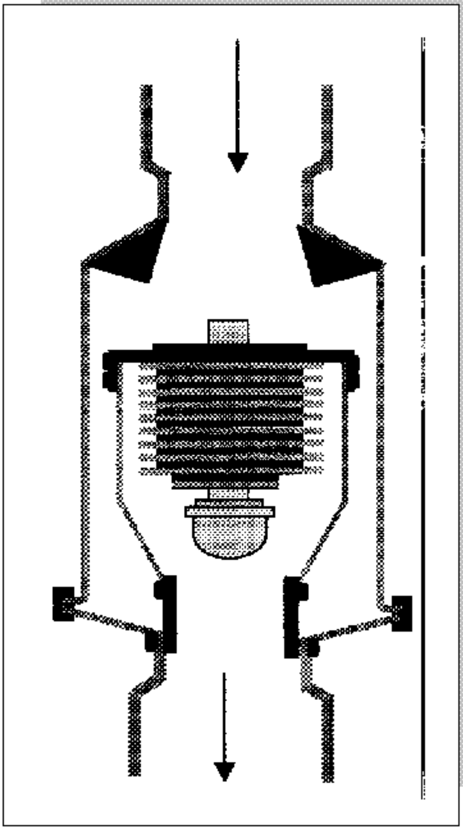


Figure 8.2
A thermostatic trap (shown in the open position).

IMPORTANT **Important Point:** *The thermostatic trap is designed to operate at a definite temperature drop a certain number of degrees below the saturated temperature for the existing steam pressure.*

A *float-and-thermostatic* trap is shown in Figure 8.3. It consists of a ball float and a thermostatic bellows element. As condensate flows through the body, the float rises and falls, opening the valve according to the flow rate. The thermostatic element discharges air from the steam lines. They are suitable in heavy and light loads and on high and low pressure, but they are not recommended where water hammer is a possibility.

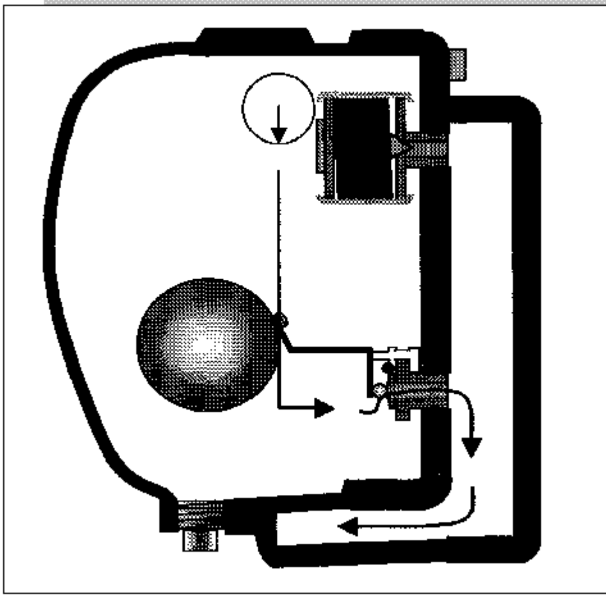


Figure 8.3
A float-and-thermostatic trap.

8.4.1 TRAP MAINTENANCE AND TESTING

Because they operate under constantly varying pressure and temperature conditions, traps used in steam systems require maintenance. Just as significant, because of these varying conditions, traps can fail. When they do fail, most traps fail in the open mode, which may require the boiler to work harder to perform a task that, in turn, can create high backpressure to the condensate system. This inhibits discharge capacities of some traps, which may be beyond their rating and cause system inefficiency.

IMPORTANT ***Important Point:*** *While it is true that most traps operate with backpressure, it is also true that they do so only at a percentage of their rating, affecting everything down the line of the failed trap. Steam quality and product can be affected.*

A closed trap produces condensate backup into the steam space. The equipment cannot produce the intended heat. Consider, as an example, a four-coil dryer with only three coils operating. In this setup, it will take longer for the dryer to dry a product, which has a negative effect on production.

8.4.1.1 TRAP MAINTENANCE

Excluding design problems, two of the most common causes of trap failure are oversizing and dirt. Oversizing causes traps to work too hard. In some cases, this can result in blowing of live steam. For example, certain trap types can lose their prime due to an abrupt change in pressure. This will cause the valve to open.

Traps tend to accumulate dirt (sludge) that prevents tight closing. The moving parts of the traps are subject to wear. Because the moving parts of traps operate in a mixture of steam and water, or sometimes in a mixture of compressed air and water, they are difficult to lubricate.

IMPORTANT

Important Point: *Dirt (sludge) is generally produced from pipe scale or from overtreatment of chemicals in a boiler.*

Trap maintenance includes periodic cleaning, removing dirt that interferes with valve action, adjusting the mechanical linkage between moving parts and valves, and reseating the valves when necessary. If these steps are not taken, the trap will not operate properly.

8.4.1.2 TRAP TESTING

IMPORTANT

Important Point: *A word of caution is advised before testing any steam trap. Inspectors should be familiar with the particular function, review types of traps, and know the various pressures within the system. This can help to ensure inspector safety, help avoid misdiagnosis, and allow proper interpretation of trap conditions.*

There are three main categories of online trap inspection: visual, thermal, and acoustic. *Visual* inspection depends on a release valve situated downstream of certain traps. A maintenance operator opens these valves and looks to see if the trap is discharging condensate or steam. *Thermal* inspection relies on upstream/downstream temperature variations in a trap. It includes pyrometry, infrared, heat bands (wrapped around a trap, they change color as temperature increases), and heat sticks (which melt at various temperatures). *Acoustic* techniques require a maintenance operator to listen to and detect steam trap operations and malfunction. This method includes various forms of listening devices such as medical stethoscopes, screwdrivers, mechanical stethoscopes, and ultrasonic detection instruments.

IMPORTANT ***Important Point:*** *A simple trap test, just listening to the trap action, tells us how the trap is opening and closing. Moreover, if the trap has a bypass line around it, leaky valves will be apparent when the main line to the trap is cut off, forcing all the fluid through the bypass.*

Self-Test

8.1 __________ in a fluid line can clog the closing element of a valve.

8.2 Before removing a strainer for cleaning, the line should be __________.

8.3 Because steam traps operate in a mixture of steam and water, it is often difficult to __________ steam traps.

8.4 Steam traps are used to remove __________ or __________ from steam lines.

8.5 The two basic types of steam traps are __________ and __________.

8.6 In most cases, the fluid __________ direction as it passes through a filter.

8.7 __________ usually are installed in pipelines before pumps and valves.

8.8 A __________ is a device made of wire mesh screens.

8.9 __________ can damage valves by causing clogging and wear.

8.10 __________ is steam that condenses into water in a piping system.

Piping Ancillaries

In Chapter 8, we described various devices associated with process piping systems designed to protect the system. In this chapter, some of the most widely used ancillaries (or accessories) designed to improve the operation and control the system are discussed. These include pressure and temperature gauges, vacuum breakers, accumulators, receivers, and heat exchangers. As maintenance operators, it is important to know how these ancillary devices work, how to care for them, and, more importantly, how to use them.

TOPICS

Gauges
Pressure Gauges
Temperature Gauges
Vacuum Breakers
Accumulators
Air Receivers
Heat Exchangers

9.1 GAUGES

In order to properly operate a system, certain things must be known, including the equipment or system being operated. A basic understanding of how the equipment functions, and most importantly, the equipment or system operating parameters must be known.

System operating parameters refer to those physical indications of system operation. The term, *parameter*, refers to a system's limitations or restrictions. For example, consider a plant's air compressor. Obviously, it is important to know how the air compressor operates, or at least how to start and place the compressor on-line properly. But, it is also important to be able to determine if the compressor is working as per design. To ensure that the air compressor is operating correctly (i.e., as per design), the air compressor's operation is monitored by observing certain parameters. However, before starting any machine or system, a pre-start check

Key Terms Used in This Chapter

ABSOLUTE PRESSURE	Gauge pressure plus atmospheric pressure.
BACKSIPHONAGE	A condition in which the pressure in the distribution system is less than atmospheric pressure, which allows contamination to enter a water system through a cross-connection.
BELLOWS GAUGE	A device that uses a bellows for measuring pressure.
BIMETALLIC	Made of two different types of metal.
BOURDON TUBE	A semicircular tube of elliptical cross section, used to sense pressure changes.
GAUGE PRESSURE	The amount by which the total absolute pressure exceeds the ambient atmospheric pressure.
VACUUM BREAKER	A mechanical device that allows air into the piping system, thereby preventing backflow that could otherwise be caused by the siphoning action created by a partial vacuum.

must be performed to ensure that it has the proper level of lubricating oil, etc. Then, after starting the compressor, it must be determined (observed) if the compressor is actually operating (normally, this is not difficult to discern considering that most air compressor systems make a lot of noise while in operation). Once in operation, the system line-up must be double checked to ensure that various valves in the system are correctly positioned (opened or closed). We might even go to a remote plant compressed air service outlet to make sure that the system is producing compressed air. (**Note:** Keep in mind that some compressed air systems have a supply of compressed air stored in an air receiver; thus, when an air outlet is opened, air pressure might be present even if the compressor is not functioning as per design.) On the other hand, instead of using a remote outlet to test for compressed air supply, all we need to do is look at the compressor air pressure gauge. This gauge should indicate that the compressor is producing compressed air.

Gauges are the main devices that provide parameter indications that are needed to determine equipment or system operation.

In regard to the air compressor, the parameter of most concern at the moment is air pressure (gauge pressure). Not only is correct pressure generation by the compressor important, but also, correct pressure in system pipes, tubes, and hoses is essential. Keeping air pressure at the proper level is necessary mainly for four reasons:

- safe operation
- efficient, economic conveyance of air through the entire system, without waste of energy
- delivery of compressed air to all outlet points in the system (the places where the air is to be used) at the required pressure
- prevention of too much or too little pressure (either condition can damage the system and become hazardous to personnel).

We pointed out that before starting the air compressor, certain prestart checks must be made. This is important for all machinery, equipment, and systems. In the case of the air compressor example, we want to ensure that proper lubricating oil pressure is maintained. This is important, of course, because pressure failure in the lubricating line that serves the compressor can mean inadequate lubrication of bearings, and, in turn, expensive mechanical repairs.

9.2 PRESSURE GAUGES

As mentioned, many pressure-measuring instruments are called *gauges*. Generally, pressure gauges are located at key points in piping systems. Usually expressed in pounds per square inch (psi), there is a difference between *gauge pressure* (psig) and *absolute pressure* (psia). Simply, "gauge pressure" refers to the pressure level indicated by the gauge. However, even when the gauge reads zero, it is subject to ambient atmospheric pressure (i.e., 14.7 psi at sea level). When a gauge reads 50 psi, that is 50 pounds *gauge pressure* (psig). The true pressure is the 50 pounds shown plus the 14.7 pounds of atmospheric pressure acting on the gauge. The total "actual" pressure is called the *absolute pressure*: gauge pressure plus atmospheric pressure (50 psi + 14.7 psi = 64.7). It is written 64.7 psia.

IMPORTANT ***Important Point:*** *Pressure in any fluid pushes equally in all directions. The total force on any surface is the psi multiplied by the area in square inches. For example, a fluid under a pressure of 10 psi, pushing against an area of 5 in², produces a total force against that surface of 50 lb (10 x 5).*

9.2.1 SPRING-OPERATED PRESSURE GAUGES

Pressure, by definition, must operate against a surface. Thus, the most common method of measuring pressure in a piping system is to have the fluid press against some type of surface—a flexible surface that moves slightly. This movable surface, in turn, is linked mechanically to a gear-lever mechanism that moves the indicator arrow to indicate the pressure on the dial (i.e., a pressure gauge).

The surface that the pressure acts against may be a disk or diaphragm, the inner surface of a coiled tube, a set of bellows, or the end of a plunger. No matter the element type, if the mechanism is fitted with a spring that resists the pressure and returns the element (i.e., the indicator pointer) to the zero position when the spring drops to zero, it is called a *spring-loaded* gauge.

9.2.2 BOURDON TUBE GAUGES

Many pressure gauges in use today use a coiled tube as a measuring element called a *Bourdon tube*. (The gauge is named for its inventor, Eugene Bourdon, a French engineer.) The Bourdon tube is a device that senses pressure and converts the pressure to displacement. Under pressure, the fluid fills the tube (see Figure 9.1). Because the Bourdon-tube displacement is a function of the pressure applied, it may be mechanically amplified and indicated by a pointer. Thus, the pointer position indirectly indicates pressure.

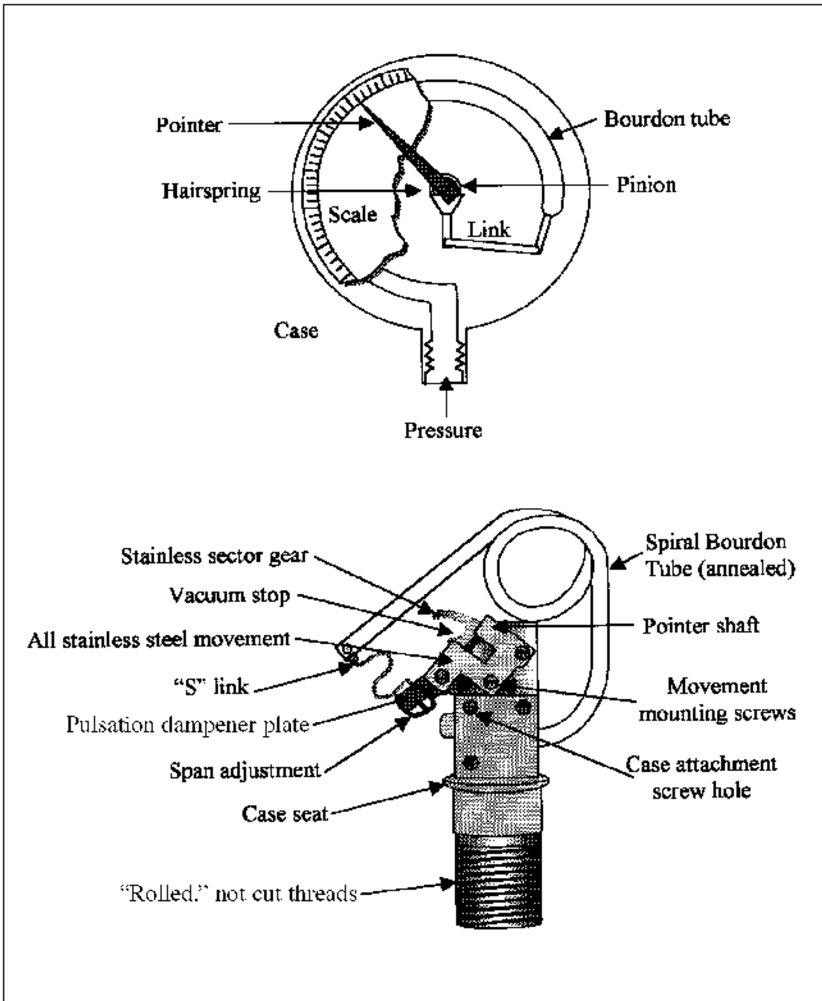


Figure 9.1
(Top) Bourdon tube gauge; (bottom) internal components.

IMPORTANT ***Important Point:*** *The Bourdon-tube gauge is available in various tube shapes: helical, C-shaped or curved, and spiral. The size, shape, and material of the tube depend on the pressure range and the type of gauge desired.*

9.2.3 BELLOWS GAUGE

Figure 9.2 shows how a simplified *bellows* gauge works. The bellows itself is a convoluted unit that expands and contracts axially with changes in pressure. The pressure to be measured can be applied to either the outside or the inside of the bellows; in practice, most bellows measuring devices have the pressure applied to the outside of the bellows. When pressure is released, the spring returns the bellows and the pointer to the zero position.

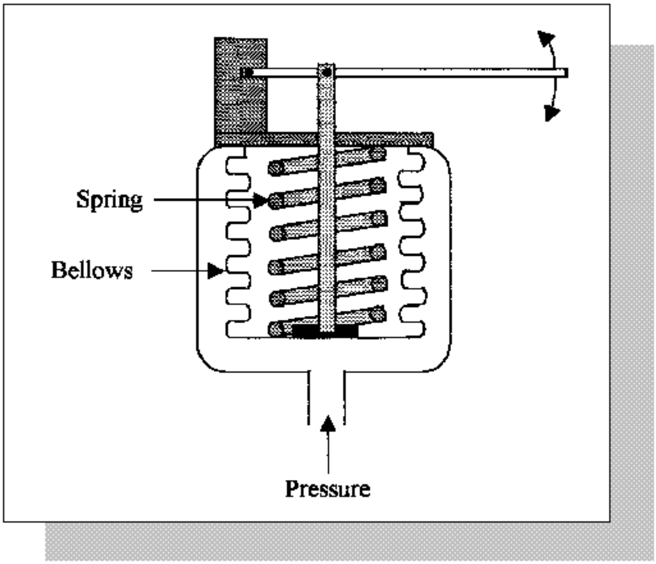


Figure 9.2
Bellows gauge.

9.2.4 PLUNGER GAUGE

Most of us are familiar with the simple tire-pressure gauge. This device is a type of plunger gauge. Figure 9.3 shows a *plunger* gauge used in industrial hydraulic systems. The bellows gauge is a spring-loaded gauge, where pressure from the line acts on the bottom of a cylindrical plunger in the center of the gauge and moves it upward. At full pressure, the plunger extends above the gauge, indicating the measured pressure. As the pressure drops, the spring contracts to pull the plunger downward, back into the body (the zero reading indication).

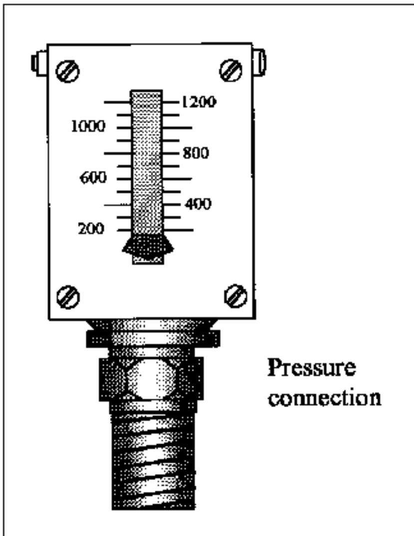


Figure 9.3
Plunger gauge.

IMPORTANT **Note:** *Spring-loaded gauges are not extremely accurate, but they are entirely adequate where there is no need for more precise readings.*

9.3 TEMPERATURE GAUGES

As mentioned, ensuring that system pressures are properly maintained in equipment and piping systems is critical to safe and proper operation. Likewise, ensuring that the temperature of fluids in industrial equipment and piping systems is correct is just as critical. For measuring the temperature of fluids in industrial systems, various temperature measuring devices are available.

Temperature is the degree of hotness or coldness of a substance measured on a definite scale. Temperature is measured when a measuring instrument is brought into contact with the medium being measured (e.g., a thermometer). All temperature-measuring instruments use some change in a material to indicate temperature. Some of the effects that are used to indicate temperature are changes in physical properties and altered physical dimensions (e.g., the change in the length of a material in the form of expansion and contraction).

9.3.1 INDUSTRIAL THERMOMETERS

Figure 9.4 shows an *industrial-type thermometer* that is commonly used for measuring the temperature of fluids in industrial piping systems. This type of measuring instrument is nothing more than a rugged version of the familiar mercury thermometer. The bulb and capillary tube are contained inside a protective metal tube called a *well*. The thermometer is attached to the piping system (vat, tank, or other component) by a union fitting.

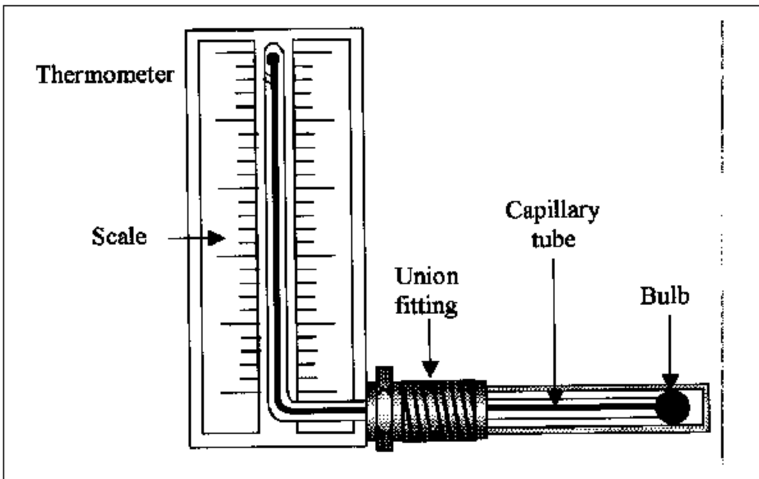


Figure 9.4
Industrial thermometer.

9.3.2 BIMETALLIC GAUGE THERMOMETER

Another common type of temperature gauge is the *bimetallic* gauge shown in Figure 9.5. Bimetallic means that if two materials with different linear coefficients of expansion (i.e., how much a material expands with

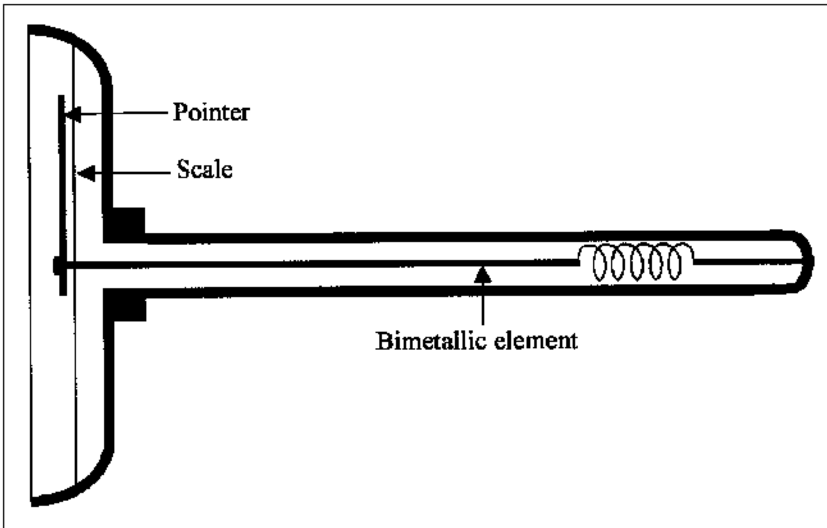


Figure 9.5
Bimetallic gauge.

heat) are bonded together, as the temperature changes, their rate of expansion will be different. This will cause the entire assembly to bend in an arc. When the temperature is raised, an arc is formed around the material with the smaller expansion coefficient. The amount of arc is reflected in the movement of the pointer on the gauge. Because the assembly is formed by two dissimilar materials, it is known as a bimetallic element, which is also commonly used in thermostats.

9.4 VACUUM BREAKERS

Another common ancillary device found in pipelines is a *vacuum breaker* (components are shown in Figure 9.6). Simply, a vacuum breaker is a mechanical device that allows air into the piping system, thereby preventing backflow that could otherwise be caused by the siphoning action created by a partial vacuum. In other words, a vacuum breaker is designed to admit air into the line whenever a vacuum develops. A vacuum, obviously, is the absence of air. Vacuum in a pipeline can be a serious problem. For example, it can cause fluids to run in the wrong direction, possibly mixing contaminants with purer solutions. [**Note:** In water systems, backsiphonage can occur when a partial vacuum pulls nonpotable liquids back into the supply lines (AWWA, 1996, pp. 336-337).] In addition, it can cause the collapse of tubing or equipment.

As illustrated in Figure 9.6, this particular type of vacuum breaker uses a ball that usually is held against a seat by a spring. The ball is contained in a retainer tube mounted inside the piping system or inside the component being protected. If a vacuum develops, the ball is forced (sucked) down into the retainer tube, where it works against the spring. Air flows into the system to fill the vacuum. [**Note:** In water systems, when air enters the line between a cross-connection and the source of the vacuum, then the vacuum will be broken, and backsiphonage is prevented (AWWA, 1996, p. 336).] The spring then returns the ball to its usual position, which acts to seal the system again.

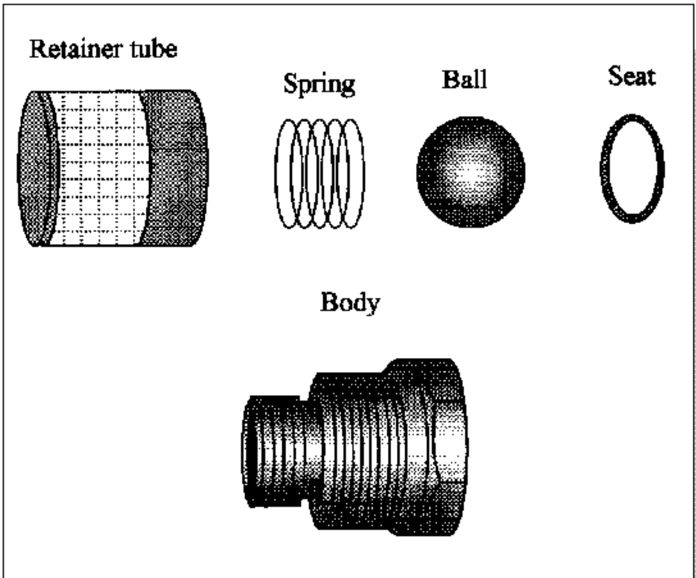


Figure 9.6
Vacuum breaker components.

9.5 ACCUMULATORS

As mentioned, in a plant compressed air system, a means of storing and delivering air as needed is usually provided. This is normally accomplished by an ancillary unit called an air receiver (see Section 9.6). In a hydraulic system, the functions provided by an air receiver for an air system are provided by an *accumulator*. That is, the accumulator (usually a dome-shaped or cylindrical chamber or tank attached to a hydraulic line) in a hydraulic system works to help store and deliver energy as required. Moreover, accumulators work to help keep pressure in the line smoothed out. For example, if pressure in the line rises suddenly, the accumulator absorbs the rise, preventing shock to the piping. If pressure in the line drops, the accumulator acts to bring it up to normal.

IMPORTANT

Important Point: *The primary function of an accumulator in a hydraulic system is to supplement pump flow.*

9.6 AIR RECEIVERS

As shown in Figure 9.7, an *air receiver* is a tank or cylindrical-type vessel used for a number of purposes. Most important is their ability to store compressed air. Much like accumulators, they cushion shock from sudden pressure rises in an air line. That is, the air receiver serves to absorb the shock of valve closure and load starts, stops, and reversals. There is no liquid in an air receiver. The air compresses as pressure rises. As pressure drops, the air expands to maintain pressure in the line.

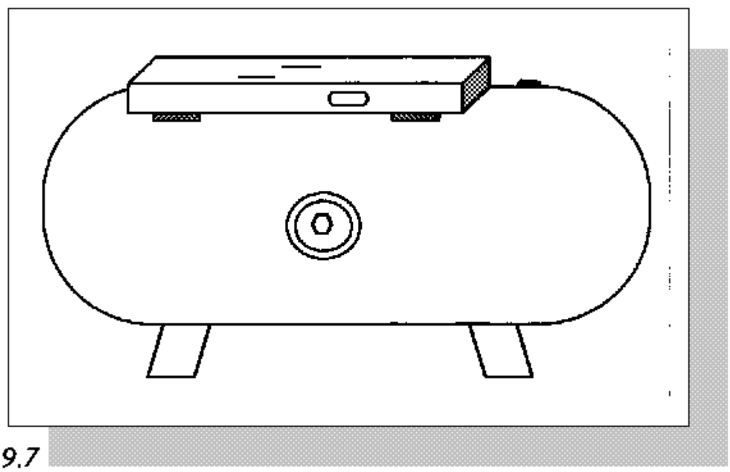


Figure 9.7
Air receiver.

IMPORTANT ***Important Note:*** *OSHA has a standard, 29 CFR 1910.169(a), requiring that air receivers be drained. Specifically, the standard states, "a drain pipe and valve shall be installed at the lowest point of every air receiver to provide for the removal of accumulated oil and water" (OSHA, 1978). This is an item that should be taken seriously, not only for safety reasons, but also because it is a compliance item that OSHA inspectors often check.*

9.7 HEAT EXCHANGERS

Operating on the principle that heat flows from a warmer body to a cooler one, *heat exchangers* are devices used for adding or removing heat and cold from a liquid or gas. The purpose may be to cool one body or to warm the other; nonetheless, whether used to warm or to cool, the principle remains the same. Various designs are used in heat exchangers. The simplest form consists of a tube, or possibly a large coil of tubing, placed inside a larger cylinder. In an oil lubrication system, the purpose of a heat exchanger is to cool the hot oil. However, a heat exchanger system can also be used to heat a process fluid circulating through part of the heat exchanger while steam circulates through its other section.

IMPORTANT ***Final Note:*** *In this chapter, we have discussed the major ancillary or accessory equipment used in many piping systems. It is important to point out that there are other accessories commonly used in piping systems (e.g., rotary pressure joints, actuators, intensifiers, pneumatic pressure line accessories, and so forth); however, discussion of these accessories is beyond the scope of this text.*

Self-Test

9.1 __________ pressure is equal to gauge pressure plus atmospheric pressure.

9.2 Fluid pressure pushes equally in all __________.

9.3 __________ pressure gauges do not provide extremely accurate readings.

9.4 The value that represents how much a material is called the coefficient of expansion.

9.5 The purpose of a __________ is to admit air into the system.

9.6 Both accumulators and receivers help maintain the line pressure if a __________ develops.

9.7 Heat flows from a(n) __________ body to a(n) __________ body.

9.8 If a pressure gauge reads 40 psig at sea level, the absolute pressure is __________.

9.9 A fluid pressure of 15 psi is pushing against an area of 4 in^2, the total force against the area is __________.

9.10 An accumulator installed in a hydraulic system helps the line pressure from __________ suddenly.

Final Review Examination

The answers for the comprehensive examination are contained in Appendix B.

10.1 The fitting normally used to allow a pipeline to make a turn is called a(n) __________.

10.2 When steam cools, the resulting water is called __________.

10.3 Spring hangers in piping systems help absorb __________.

10.4 Heat passes from a(n) __________ surface to a(n) __________ surface.

10.5 If the speed of fluid in a pipe is doubled, the friction is __________.

10.6 The most important factor in maintaining a piping system and keeping it operating efficiently is __________.

10.7 If corrosion reduces the inside diameter of a pipe, the pressure __________.

10.8 A __________ is used in a steam line to collect condensate.

10.9 The major problems in piping and tubing systems are caused by __________ and __________.

10.10 __________ allow for expansion and contraction of piping.

10.11 Pipe sizes above __________ inches are usually designated by outside diameter.

10.12 The difference in __________ numbers represents the difference in the wall thickness of pipes.

10.13 When pipe wall thickness __________, the I.D. decreases.

10.14 A __________ metal contains iron.

10.15 A Schedule 40S pipe is made of __________ steel.

10.16 As __________ increases, the viscosity of a liquid __________.

10.17 __________ metals are usually connected by soldering or brazing.

10.18 __________ is sometimes known as hard soldering.

10.19 As fluid __________ decreases, friction in a pipeline decreases.

10.20 __________ in a pipeline occurs when the flow is suddenly slowed or stopped.

10.21 The most corrosion-proof pipe available for carrying industrial and sewage wastes is __________ pipe.

10.22 Liquid flow in drainpipes normally depends on __________.

10.23 Cast-iron pipe can be lined with __________ to increase its resistance to corrosion.

10.24 As temperature increases, the strength of plastic pipe __________.

10.25 One advantage of glass pipe is its resistance to __________ shock.

10.26 The strongest, most pressure-resistant kind of concrete pipe is called __________ pipe.

10.27 One characteristic of __________ piping is its light weight.

10.28 Nonmetallic piping can be joined to metal piping by __________.

10.29 In regard to metal piping and metal tubing, pound for pound, metal __________ is stronger.

10.30 __________ fluid flow is called laminar flow.

10.31 __________ tubing is resistant to high pressures, extreme temperatures, and corrosion.

10.32 One process to join __________ tubing is called fusion welding.

10.33 The size of a hose is usually specified in terms of its __________.

10.34 Each size of hose clamp is designed for hose of a specific __________.

10.35 The __________ section of hose is called the tube.

10.36 __________ are used to close off unused outlets.

10.37 Improperly made bends restrict __________ in a pipeline.

10.38 An __________ allows for a certain amount of pipe movement.

10.39 A __________ is used to connect two sections of pipe.

10.40 Valves can be used to __________, __________, and __________ flow.

10.41 A __________ ensures that fluid flow will be in one direction only.

10.42 A __________ valve is best suited for an application that requires fast on/off operation, low pressure drop, good sealing, and flow in both directions.

10.43 __________ valves are set for about 50% of the maximum flow that can pass through them.

10.44 The best valve for a vacuum application is a __________ valve.

10.45 The control unit of a temperature-regulating valve includes a __________.

10.46 Strainers are usually installed in pipelines __________ pumps and valves.

10.47 Atmospheric pressure is equal to __________ psi.

10.48 A __________ causes action in response to changes in temperature.

10.49 If a pressure gauge reads 60 psig at sea level, the absolute pressure is __________.

10.50 If a fluid pressure of 20 psi is pushing against an area of 5 in^2, the total force against the area is __________.

Appendix A

Answers to Chapter Self-Tests

CHAPTER 1

1.1 a flexible piping component that absorbs thermal and/or terminal movement

1.2 fluid

1.3 fluid

1.4 connected

1.5 flow

1.6 pressure loss

1.7 increases

1.8 automatically

1.9 insulation

1.10 leakage

1.11 four times

1.12 routine preventive maintenance

CHAPTER 2

2.1 12

2.2 schedule; thickness

2.3 increases

2.4 ferrous

2.5 increases

2.6 iron oxide

2.7 cast-iron

2.8 when used for high-temperature and high-pressure applications

2.9 by soldering and brazing

2.10 service

2.11 when flow is suddenly slowed or stopped

2.12 iron

CHAPTER 3

3.1 corrosion

3.2 high corrosion resistance; rarely needs to be painted or insulated; light weight; ease of joining; freedom from rust and rot; will not readily burn; low cost; long service life; easy to maintain.

3.3 limited temperature range and used only in low psi applications.

3.4 decreases

3.5 clay, concrete, plastic, glass, or wood

3.6 corrosion-proof

3.7 non-reinforced, reinforced, and reinforced and prestressed

3.8 cement

3.9 respiratory

3.10 welding, threading, flanges

CHAPTER 4

4.1 covering metal to be soldered with a thin coat of solder to work properly.

4.2 So there is no movement. Any movement during the heating will cause the pieces to be misaligned, and the slightest disturbance of the soldering will cause it to solidify without forming a bond. The result is a weak joint.

4.3 pressed

4.4 turbulent; lower

4.5 steel

4.6 fusion

4.7 flexible

4.8 aluminum

4.9 annealed

4.10 fusion

4.11 metals; plastics

4.12 laminar

CHAPTER 5

5.1 4

5.2 1 inch

5.3 reinforced nonmetallic

5.4 wire-reinforced

5.5 Dacron®

5.6 diameter

5.7 flexibility

5.8 E.E.

5.9 reinforced; pressure

5.10 flexible

CHAPTER 6

6.1 expansion joint

6.2 vibration dampener

6.3 plain

6.4 bends

6.5 pressure

6.6 plug

6.7 long-radius elbow

6.8 elbow

6.9 reducer

6.10 gasket

CHAPTER 7

7.1 valves

7.2 throttle; start; stop

7.3 globe

7.4 butterfly

7.5 check

7.6 quick-opening valve

7.7 internal closing

7.8 temperature-regulating

7.9 diaphragm

7.10 pressure; preset

CHAPTER 8

8.1 solid particles

8.2 shut off

8.3 lubricate

8.4 water; condensate

8.5 thermostatic; float-and-thermostatic

8.6 changes

8.7 strainers

8.8 strainer

8.9 solid particles

8.10 condensate

CHAPTER 9

9.1 absolute

9.2 directions

9.3 spring-loaded

9.4 expands

9.5 vacuum breaker

9.6 leak

9.7 warmer; cooler

9.8 54.7 psig

9.9 60 lb

9.10 changing

Appendix B

Answers to Chapter 10—Final Review Examination

10.1 elbow

10.2 condensate

10.3 vibration

10.4 warmer; colder

10.5 increased four times

10.6 routine preventive maintenance

10.7 decreases

10.8 steam trap

10.9 leakage; corrosion

10.10 expansion joints

10.11 12

10.12 schedule

10.13 increases

10.14 ferrous

10.15 stainless

10.16 temperature; decreases

10.17 nonferrous

10.18 brazing

10.19 viscosity

10.20 water hammer

10.21 vitrified clay

10.22 gravity

10.23 cement

10.24 decreases

10.25 thermal

10.26 reinforced and prestressed

10.27 lightweight

10.28 flanges

10.29 tubing

10.30 laminar

10.31 stainless steel

10.32 plastic

10.33 I.D.

10.34 diameter

10.35 innermost

10.36 plugs

10.37 fluid flow

10.38 expansion joint

10.39 union

10.40 start; stop; throttle

10.41 check valve

10.42 ball

10.43 pressure-regulating

10.44 diaphragm

10.45 thermostat

10.46 before

10.47 14.7

10.48 thermostat

10.49 74.7 psig

10.50 100 lb

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