Piping Designs and Systems

(Engineering Discipline)

Sierra Montague

First Edition, 2012

ISBN 978-81-323-4207-6

Published by:
White Word Publications
4735/22 Prakashdeep Bldg,
Ansari Road, Darya Ganj,
Delhi - 110002
Email: info@wtbooks.com

Table of Contents

Chapter 1

Piping

Large-scale piping system in an HVAC mechanical room

Within industry, **piping** is a system of pipes used to convey fluids (liquids and gases) from one location to another. The engineering discipline of piping design studies the efficient transport of fluid.

Industrial process piping (and accompanying in-line components) can be manufactured from wood, fiberglass, glass, steel, aluminum, plastic, copper, and concrete. The in-line components, known as fittings, valves, and other devices, typically sense and control the pressure, flow rate and temperature of the transmitted fluid, and usually are included in the field of Piping Design (or Piping Engineering). Piping systems are documented in piping and instrumentation diagrams (P&IDs). If necessary, pipes can be cleaned by the tube cleaning process.

"Piping" sometimes refers to Piping Design or the performance of the actual layout of the physical piping within a process plant or commercial building. In earlier days, this was sometimes called Drafting, Technical drawing, Engineering Drawing, and Design but is commonly performed by Designers who have learned to used automated computer aided drawing/computer aided design (CAD) software.

Plumbing is a piping system that most people are familiar with, as it constitutes the form of fluid transportation that is used to provide potable water and fuels to their homes and business. Plumbing pipes also remove waste in the form of sewage, and allow venting of sewage gases to the outdoors. Fire sprinkler systems also use piping, and may transport potable or nonpotable water, or other fire-suppression fluids.

Piping also has many other industrial applications, which are crucial for moving raw and semi-processed fluids for refining into more useful products. Some of the more exotic materials of construction are Inconel, Titanium, chrome-moly and various other steel alloys.

Piping Branches

Generally, Industrial piping has three major branches as follows:

- Piping Material field
- Piping Design field
- Stress analysis field

Pipe stress analysis

Process piping and power piping are typically checked by pipe stress engineers to verify that the routing, nozzle loads, hangers, and supports are properly placed and selected such that allowable pipe stress is not exceeded under different situation such as sustain, operating, hydro test etc as per the ASME or any other legislative code and local government standards. It is necessary to evaluate the mechanical behavior of the piping under regular loads (internal pressure and thermal stresses) as well under occasional and intermittent loading cases such as earthquake, high wind or special vibration, water hammer. This evaluation is usually performed with the assistance of a specialized (finite element) pipe stress analysis computer program such as Caesar II, ROHR2, CAEPIPE and AUTOPIPE.

Wooden piping history

Early wooden pipes were constructed out of logs that had a large hole bored lengthwise through the center. Later wooden pipes were constructed with staves and hoops similar to wooden barrel construction. Stave pipes have the advantage that they are easily transport as a compact pile of parts on a wagon and then assembled as a hollow structure at the job site. Wooden pipes were especially popular in mountain regions where transport of heavy iron or concrete pipes would have been difficult.

Wooden pipes were easier to maintain than metal, because the wood did not expand or contract with temperature changes as much as metal and so consequently expansion joints and bends were not required. The thickness of wood afforded some insulating properties to the pipes which helped prevent freezing as compared to metal pipes. Wood used for water pipes also does not rot very easily. Electrolysis that bugbear many iron pipe systems, doesn't affect wood pipes at all, since wood is a much better electrical insulator.

In the Western United States where redwood was used for pipe construction, it was found that redwood had "peculiar properties" that protected it from weathering, acids, insects, and fungus growths. Redwood pipes stayed smooth and clean indefinitely while iron pipe by comparison would rapidly begin to scale and corrode and could eventually plug itself up with the corrosion.

Chapter 2

Valve

These water valves are operated by handles.

A **valve** is a device that regulates the flow of a fluid (gases, liquids, fluidized solids, or slurries) by opening, closing, or partially obstructing various passageways. Valves are technically pipe fittings, but are usually discussed as a separate category. In an open valve, fluid flows in a direction from higher pressure to lower pressure.

Valves are also found in the human body. For example, there are several heart valves which control the flow of blood in the chambers of the heart and maintain the correct pumping action.

Valves are used in a variety of contexts, including industrial, military, commercial, residential, and transport.

The industries in which the majority of valves are used are oil and gas, power generation, mining, water reticulation, sewerage and chemical manufacturing.

Plumbing valves, such as taps for hot and cold tap water are the most noticeable types of valves. Other valves encountered on a daily basis include gas control valves on cookers, small valves fitted to washing machines and dishwashers, and safety devices fitted to hot water systems.

Valves may be operated manually, either by a handle, lever or pedal. Valves may also be automatic, driven by changes in pressure, temperature, or flow. These changes may act upon a diaphragm or a piston which in turn activates the valve, examples of this type of valve found commonly are safety valves fitted to hot water systems or boilers.

More complex control systems using valves requiring automatic control based on an external input (i.e., regulating flow through a pipe to a changing set point) require an actuator. An actuator will stroke the valve depending on its input and set-up, allowing the valve to be positioned accurately, and allowing control over a variety of requirements.

Valves are also found in the Otto cycle (internal combustion) engines driven by a camshaft, tappets or push rods where they play a major role in engine cycle control.

Applications

Valves vary widely in form and application. Sizes typically range from 0.1 mm 60 cm (2 ft). Special valves can have a diameter exceeding 5 meters.

Valve cost ranges from simple inexpensive disposable valves to specialized valves cost thousands of US dollars per inch of diameter.

Disposable valves may be found inside common household items including mini-pump dispensers and aerosol cans.

Types

The inside of an extremely large butterfly valve

Valves are quite diverse and may be classified into a number of basic types. Valves may also be classified by how they are actuated:

- Hydraulic
- Pneumatic
- Manual
- Solenoid
- Motor

Basic types

Valves can be categorized into the following basic types:

Duplex ball valve

- Ball valve, for on/off control without pressure drop, and ideal for quick shut-off since a 90º turn offers complete shut-off angle, compared to multiple turns required on most manual valves.
- Butterfly valve, for flow regulation in large pipe diameters.
- Ceramic Disc valve, used mainly in high duty cycle applications or on abrasive fluids. Ceramic disc can also provide Class IV seat leakage
- Check valve or non-return valve, allows the fluid to pass in one direction only.

Hastelloy check valve

- Choke valve, a valve that raises or lowers a solid cylinder which is placed around or inside another cylinder which has holes or slots. Used for high pressure drops found in oil and gas wellheads.
- Diaphragm valve, some are sanitary predominantly used in the pharmaceutical and food-industry.
- Gate valve, mainly for on/off control, with low pressure drop.

Stainless steel gate valve

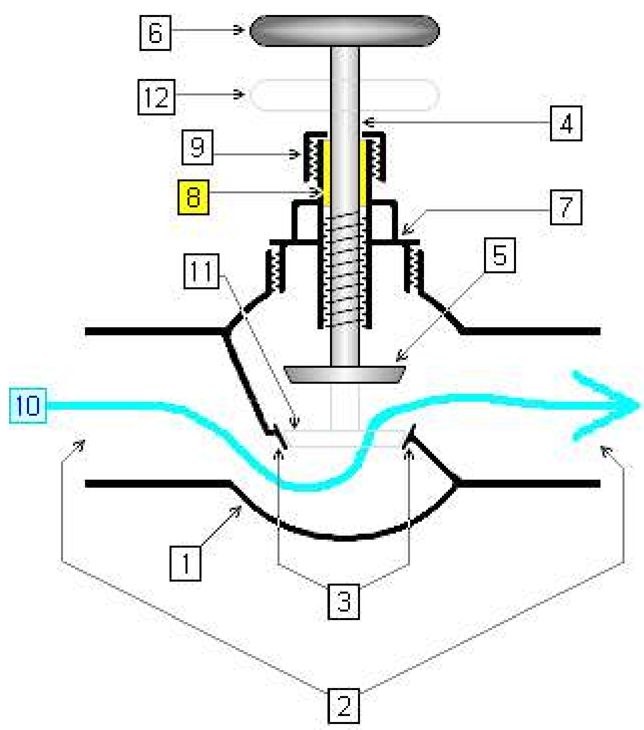
- Globe valve, good for regulating flow.
- Knife valve, for slurries or powders on/off control.
- Needle valve for accurate flow control.
- Pinch valve, for slurry flow regulation.
- Piston valve, for regulating fluids that carry solids in suspension.
- Plug valve, slim valve for on/off control but with some pressure drop.
- Poppet valve
- Spool valve, for hydraulic control
- Thermal expansion valve, used in refrigeration and air conditioning systems.

Specific types

- Aspin valve: a cone-shaped metal part fitted to the cylinder head of an engine
- Ball cock: often used as a water level controller (cistern)
- Bibcock: provides a connection to a flexible hosepipe
- Blast valve: prevents rapid overpressures in a fallout shelter or a bunker
- Cock: colloquial term for a small valve or a stopcock
- Demand valve: on a diving regulator
- Double beat valve
- Double check valve
- Duckbill valve
- Flipper valve
- Flow control valve: an application which maintains a variable flow rate through the valve
- Heimlich valve: a specific one-way valve used on the end of chest drain tubes to treat a pneumothorax
- Foot valve: a check valve on the foot of a suction line to prevent backflow
- Four-way valve: was used to control the flow of steam to the cylinder of early double-acting steam engines
- Freeze seal/Freeze plug: in which freezing and melting the fluid creates and removes a plug of frozen material acting as the valve
- Gas pressure regulator regulates the flow and pressure of a gas
- Heart valve: regulates blood flow through the heart in many organisms
- Leaf valve: one-way valve consisting of a diagonal obstruction with an opening covered by a hinged flap
- Pilot valve: regulate flow or pressure to other valves
- Poppet valve and sleeve valve: commonly used in piston engines to regulate the fuel mixture intake and exhaust
- Pressure regulator or pressure reducing valve (PRV): reduces pressure to a preset level downstream of the valve
- Pressure sustaining valve, or back-pressure regulator: maintains pressure at a preset level upstream of the valve
- Presta and Schrader valves are used to hold the air in bicycle tires
- Reed valve: consists of two or more flexible materials pressed together along much of their length, but with the influx area open to allow one-way flow, much like a heart valve
- Regulator: used in SCUBA diving equipment and in gas cooking equipment to reduce the high pressure gas supply to a lower working pressure
- Rocker valve
- Rotary valves and piston valves: parts of brass instruments used to change their pitch
- Rupture disc: a one time use replaceable valve for rapid pressure relief, used to protect piping systems from excessive pressure or vacuum; more reliable than a safety valve
- Saddle valve: where allowed, is used to tap a pipe for a low-flow need

- Safety valve or relief valve: operates automatically at a set differential pressure to correct a potentially dangerous situation, typically over-pressure
- Schrader valve: used to hold the air inside automobile tires
- Solenoid valve: an electrically controlled hydraulic or pneumatic valve
- Stopcock: restricts or isolates flow through a pipe
- Swirl valve: A specially designed Joule-Thompson pressure reduction/expansion valve imparting a centrifugal force upon the discharge stream for improving gas-liquid phase separation
- Tap (British English), faucet (American English): the common name for a valve used in homes to regulate water flow
- Thermal expansion valve, used in air conditioning and refrigeration systems.
- Thermostatic Mixing Valve
- Thermostatic Radiator Valve
- Trap primer: sometimes include other types of valves, or are valves themselves
- Vacuum breaker valve: prevents the back-siphonage of contaminated water into pressurized drinkable water supplies

Components



Cross-sectional diagram of an open globe **valve**.
1. **body**
2. **ports**
3. **seat**
4. **stem**
5. **disc** when valve is open

6. **handle** or **handwheel** when valve is open
7. **bonnet**
8. **packing**
9. **gland nut**
10. **fluid flow** when valve is open
11. position of disc if valve were shut
12. position of handle or handwheel if valve were shut

The main parts of a valve are the **body** and the **bonnet**. These two parts form the casing that holds the fluid going through the valve.

Body

The valve's **body** is the outer casing of most or all of the valve that contains the internal parts or *trim*. The bonnet is the part of the encasing through which the stem passes and that forms a guide and seal for the stem. The bonnet typically screws into or is bolted to the valve body.

Valve bodies are usually metallic or plastic. Brass, bronze, gunmetal, cast iron, steel, alloy steels and stainless steels are very common. Seawater applications, like desalination plants, often use duplex valves, as well as super duplex valves, due to their corrosion resistant properties, particularly against warm seawater. Alloy 20 valves are typically used in sulphuric acid plants, whilst monel valves are used in hydrofluoric acid (HF Acid) plants. Hastelloy valves are often used in high temperature applications, such as nuclear plants, whilst inconel valves are often used in hydrogen applications. Plastic bodies are used for relatively low pressures and temperatures. PVC, PP, PVDF and glass-reinforced nylon are common plastics used for valve bodies.

Bonnet

A **bonnet** acts as a cover on the valve body. It is commonly semi-permanently screwed into the valve body or bolted onto it. During manufacture of the valve, the internal parts are put into the body and then the bonnet is attached to hold everything together inside. To access internal parts of a valve, a user would take off the bonnet, usually for maintenance. Many valves do not have bonnets; for example, plug valves usually do not have bonnets. Many ball valves do not have bonnets since the valve body is put together in a different style, such as being screwed together at the middle of the valve body.

Ports

Ports are passages that allow fluid to pass through the valve. Ports are obstructed by the **valve member** or **disc** to control flow. Valves most commonly have 2 ports, but may have as many as 20. The valve is almost always connected at its ports to pipes or other components. Connection methods include threadings, compression fittings, glue, cement, flanges, or welding.

Handle or actuator

A **handle** is used to manually control a valve from outside the valve body. Automatically controlled valves often do not have handles, but some may have a handle (or something similar) anyway to manually override automatic control, such as a stop-check valve. An **actuator** is a mechanism or device to automatically or remotely control a valve from outside the body. Some valves have neither handle nor actuator because they automatically control themselves from inside; for example, check valves and relief valves may have neither.

Disc

Valve disc

A **disc** or **valve member** is a movable obstruction inside the stationary body that adjustably restricts flow through the valve. Although traditionally disc-shaped, discs come in various shapes. Depending on the type of valve, a disc can move linearly inside a valve, or rotate on the stem (as in a butterfly valve), or rotate on a hinge or trunnion (as in a check valve). A *ball* is a round valve member with one or more paths between ports passing through it. By rotating the ball, flow can be directed between different ports. Ball valves use spherical rotors with a cylindrical hole drilled as a fluid passage. Plug valves use cylindrical or conically tapered rotors called **plugs**. Other round shapes for rotors are possible as well in **rotor valves**, as long as the rotor can be turned inside the valve body.

However not all round or spherical discs are rotors; for example, a ball check valve uses the ball to block reverse flow, but is not a rotor because operating the valve does not involve rotation of the ball.

Seat

The **seat** is the interior surface of the body which contacts the disc to form a leak-tight seal. In discs that move linearly or swing on a hinge or trunnion, the disc comes into contact with the seat only when the valve is shut. In disks that rotate, the seat is always in contact with the disk, but the area of contact changes as the disc is turned. The seat always remains stationary relative to the body.

Seats are classified by whether they are cut directly into the body, or if they are made of a different material:

- **Hard seats** are integral to the valve body. Nearly all hard seated metal valves have a small amount of leakage.
- **Soft seats** are fitted to the valve body and made of softer materials such as PTFE or various elastomers such as NBR, EPDM, or FKM depending on the maximum operating temperature.

The shut off butterfly valve for a Francis turbine at Gordon Power Station, Tasmania

Ball valve

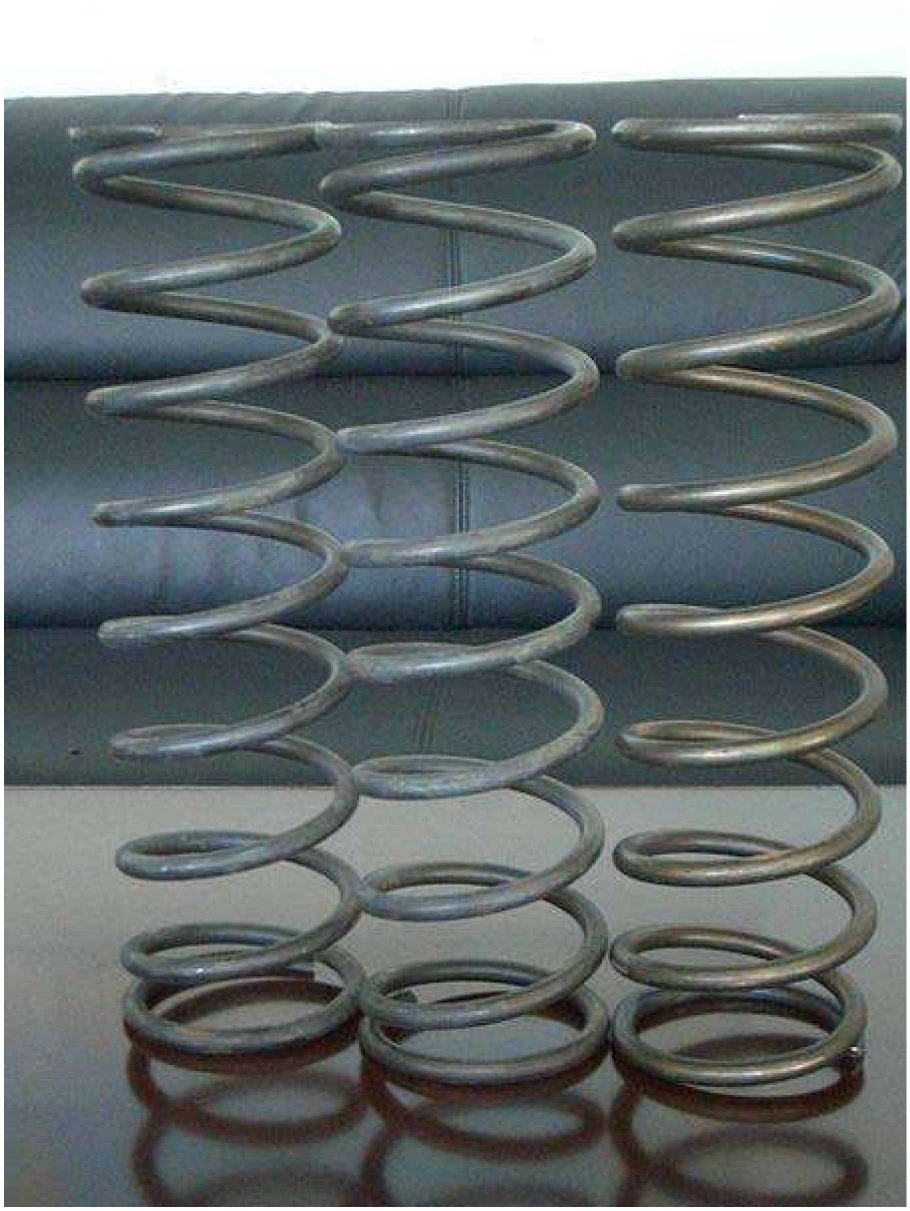
A closed soft seated valve is much less liable to leak when shut while hard seated valves are more durable. Gate, globe, and check valves are usually hard seated while butterfly, ball, plug, and diaphragm valves are usually soft seated.

Stem

The **stem** transmits motion from the handle or controlling device to the disc. The stem typically passes through the bonnet when present. In some cases, the stem and the disc can be combined in one piece, or the stem and the handle are combined in one piece.

The motion transmitted by the stem may be a linear force, a rotational torque, or some combination of these(Angle valve using torque reactor pin and Hub Assembly). The valve and stem can be threaded such that the stem can be screwed into or out of the valve by turning it in one direction or the other, thus moving the disc back or forth inside the body. Packing is often used between the stem and the bonnet to maintain a seal. Some valves have no external control and do not need a stem as in most check valves.

Valves whose disc is between the seat and the stem and where the stem moves in a direction into the valve to shut it are **normally-seated** or **front seated**. Valves whose seat is between the disc and the stem and where the stem moves in a direction out of the valve to shut it are **reverse-seated** or **back seated**. These terms don't apply to valves with no stem or valves using rotors.



Inconel X750 Spring

Gaskets

The seals or packings used to prevent the escape of a gas or fluids from valves.

Valve balls

A valve ball is also used for severe duty, high-pressure, high-tolerance applications. They are typically made of stainless steel, titanium, Stellite, Hastelloy, brass, or nickel. They can also be made of different types of plastic, such as ABS, PVC, PP or PVDF.

Spring

Many valves have a spring for spring-loading, to normally shift the disc into some position by default but allow control to reposition the disc. Relief valves commonly use a spring to keep the valve shut, but allow excessive pressure to force the valve open against the spring-loading. Coil springs are normally used. Typical spring materials include zinc plated steel, stainless steel, and for high temperature applications Inconel X750.

Trim

The internal elements of a valve are collectively referred to as a valve's **trim**. According to API Standards 600, "Steel Gate Valve-Flanged and Butt-welding Ends, Bolted Bonnets", the trim consists of stem, seating surface in the body, gate seating surface, bushing or a deposited weld for the backseat and stem hole guide, and small internal parts that normally contact the service fluid, excluding the pin that is used to make a stem-to-gate connection (this pin shall be made of an austenitic stainless steel material).

Valve operating positions

A seacock for cooling seawater, on a marine diesel engine.

Valve **positions** are operating conditions determined by the position of the disc or rotor in the valve. Some valves are made to be operated in a gradual change between two or more positions. Return valves and non-return valves allow fluid to move in 2 or 1 directions respectively.

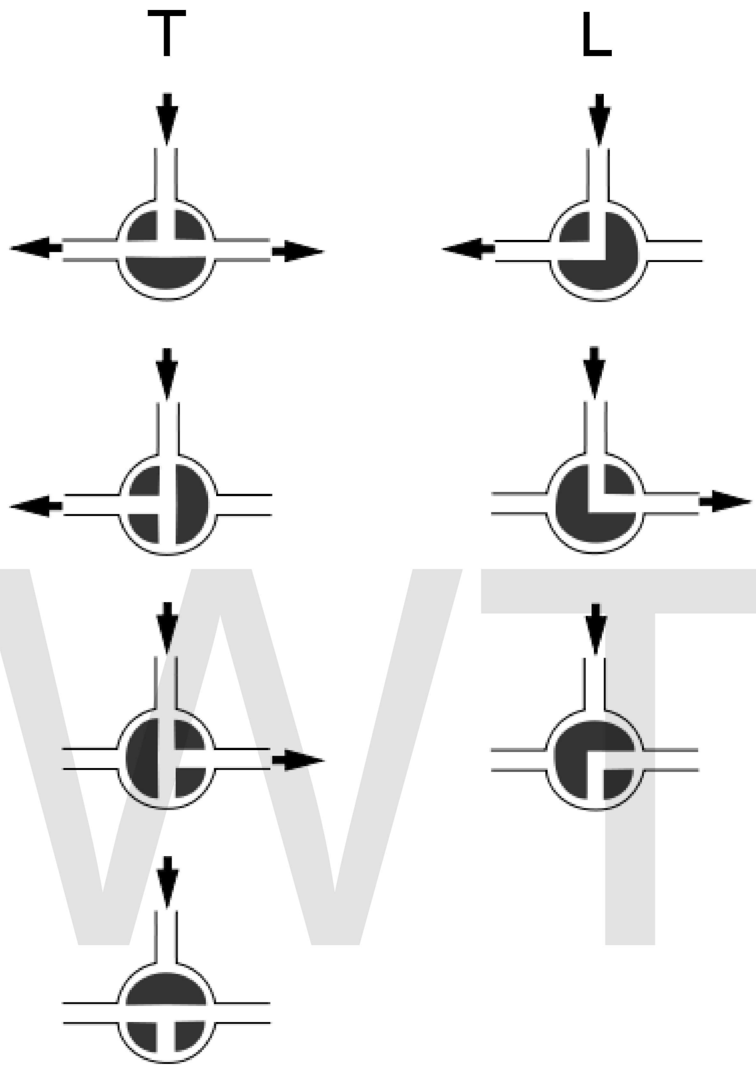
Two-port valves

Operating positions for 2-port valves can be either shut (closed) so that no flow at all goes through, fully open for maximum flow, or sometimes partially open to any degree in between. Many valves are not designed to precisely control intermediate degree of flow; such valves are considered to be either open or shut. Some valves are specially designed to regulate varying amounts of flow. Such valves have been called by various names such as *regulating*, *throttling*, *metering*, or *needle valves*. For example, needle valves have elongated conically-tapered discs and matching seats for fine flow control. For some valves, there may be a mechanism to indicate by how much the valve is open, but in many cases other indications of flow rate are used, such as separate flow meters.

In plants with remote-controlled process operation, such as oil refineries and petrochemical plants, some 2-way valves can be designated as normally closed (NC) or normally open (NO) during regular operation. Examples of normally closed valves are *sampling valves*, which are only opened while a sample is taken. Examples of normally open valves are *isolation valves*, which are usually only shut when there is a problem with a unit or a section of a fluid system such as a leak in order to isolate the problem from the rest of the system.

Although many 2-way valves are made in which the flow can go in either direction between the two ports, when a valve is placed into a certain application, flow is often expected to go from one certain port on the **upstream** side of the valve, to the other port on the **downstream** side. Pressure regulators are variations of valves in which flow is controlled to produce a certain downstream pressure, if possible. They are often used to control flow of gas from a gas cylinder. A back-pressure regulator is a variation of a valve in which flow is controlled to maintain a certain upstream pressure, if possible.

Three-port valves



Schematic 3 way ball valve: L-shaped ball right, T-shaped left

Valves with three ports serve many different functions. A few of the possibilities are listed here.

Three-way ball valves come with a T- or L- shaped fluid passageways inside the rotor. The T valve might be used to permit connection of one inlet to either or both outlets or connection of the two outlets. The L valve could be used to permit disconnection of both or connection of either but not both of two inlets to one outlet.

Shuttle valves automatically connect the higher pressure inlet to the outlet while (in some configurations) preventing flow from one inlet to the other.

Single handle mixer valves produce a variable mixture of hot and cold water at a variable flow rate under control of a single handle.

Thermostatic mixing valves mix hot and cold water to produce a constant temperature in the presence of variable pressures and temperatures on the two input ports.

Four-port valves

A 4-port valve is a valve whose body has four ports equally spaced round the body and the disc has two passages to connect adjacent ports. It is operated with two positions.

It can be used to isolate and to simultaneously bypass a sampling cylinder installed on a pressurized water line. It is useful to take a fluid sample without affecting the pressure of a hydraulic system and to avoid degassing (no leak, no gas loss or air entry, no external contamination)....

Control

A sailor aboard a ship operates the wheel controlling a fuel valve.

Many valves are controlled manually with a handle attached to the stem. If the handle is turned ninety degrees between operating positions, the valve is called a **quarter-turn valve**. Butterfly, ball valves, and plug valves are often quarter-turn valves. If the handle is circular with the stem as the axis of rotation in the center of the circle, then the handle is called a **handwheel**. Valves can also be controlled by actuators attached to the stem.

They can be electromechanical actuators such as an electric motor or solenoid, pneumatic actuators which are controlled by air pressure, or hydraulic actuators which are controlled by the pressure of a liquid such as oil or water. Actuators can be used for the purposes of automatic control such as in washing machine cycles, remote control such as the use of a centralised control room, or because manual control is too difficult such as when the valve is very large. Pneumatic actuators and hydraulic actuators need pressurised air or liquid lines to supply the actuator: an inlet line and an outlet line. Pilot valves are valves which are used to control other valves. Pilot valves in the actuator lines control the supply of air or liquid going to the actuators.

The fill valve in a toilet water tank is a liquid level-actuated valve. When a high water level is reached, a mechanism shuts the valve which fills the tank.

In some valve designs, the pressure of the flow fluid itself or pressure difference of the flow fluid between the ports automatically controls flow through the valve.

Other considerations

Valves are typically rated for maximum temperature and pressure by the manufacturer. The wetted materials in a valve are usually identified also. Some valves rated at very high pressures are available. When a designer, engineer, or user decides to use a valve for an application, he/she should ensure the rated maximum temperature and pressure are never exceeded and that the wetted materials are compatible with the fluid the valve interior is exposed to. In Europe, valve design and pressure ratings are subject to statutory regulation under the Pressure Equipment Directive 97/23/EC (PED)

Some fluid system designs, especially in chemical or power plants, are schematically represented in piping and instrumentation diagrams. In such diagrams, different types of valves are represented by certain symbols.

Valves in good condition should be leak-free. However, valves may eventually wear out from use and develop a leak, either between the inside and outside of the valve or, when the valve is shut to stop flow, between the disc and the seat. A particle trapped between the seat and disc could also cause such leakage.

Globe valve

A valve controlled by a wheel

Large butterfly valve

Cast iron butterfly valve

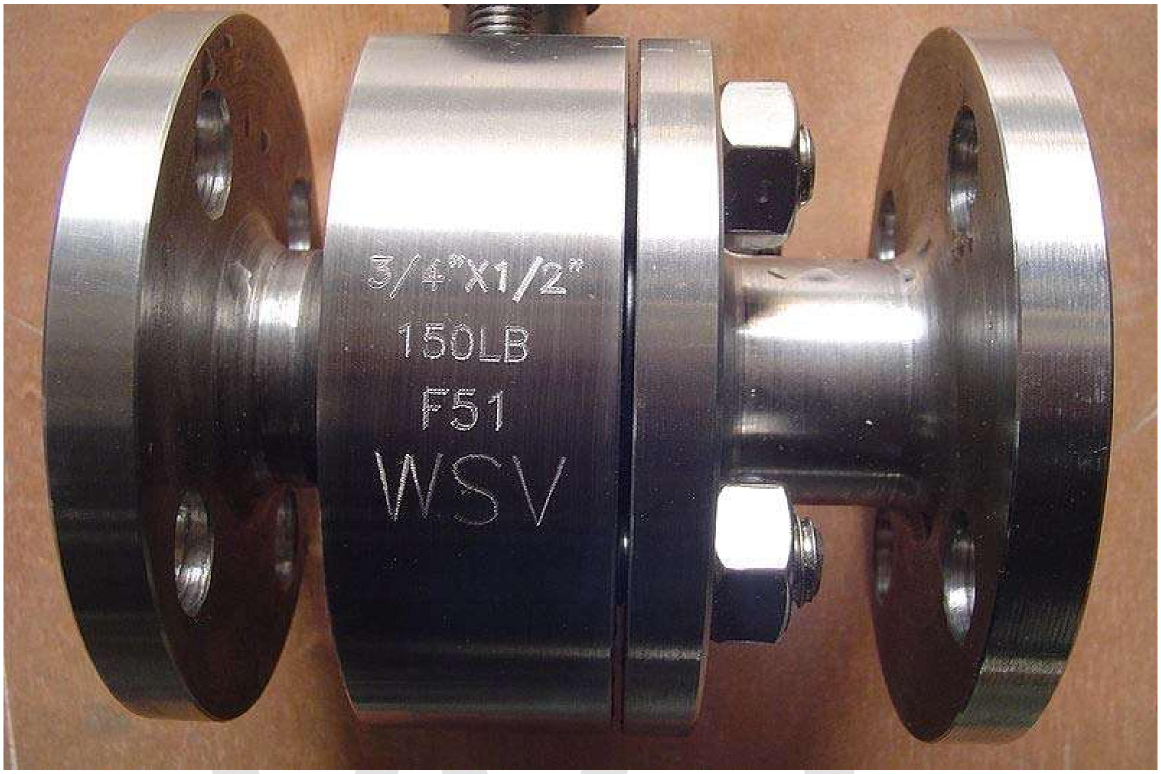
Cast iron butterfly valve

Hastelloy ball valve

Stainless steel gate valve

Stainless steel gate valve

Hastelloy check valves



Duplex ball valve

Inconel gate valve

Stainless steel wafer check valve

Inconel check valve

Stainless steel ball valve

Cryogenic 254 SMO gate valve

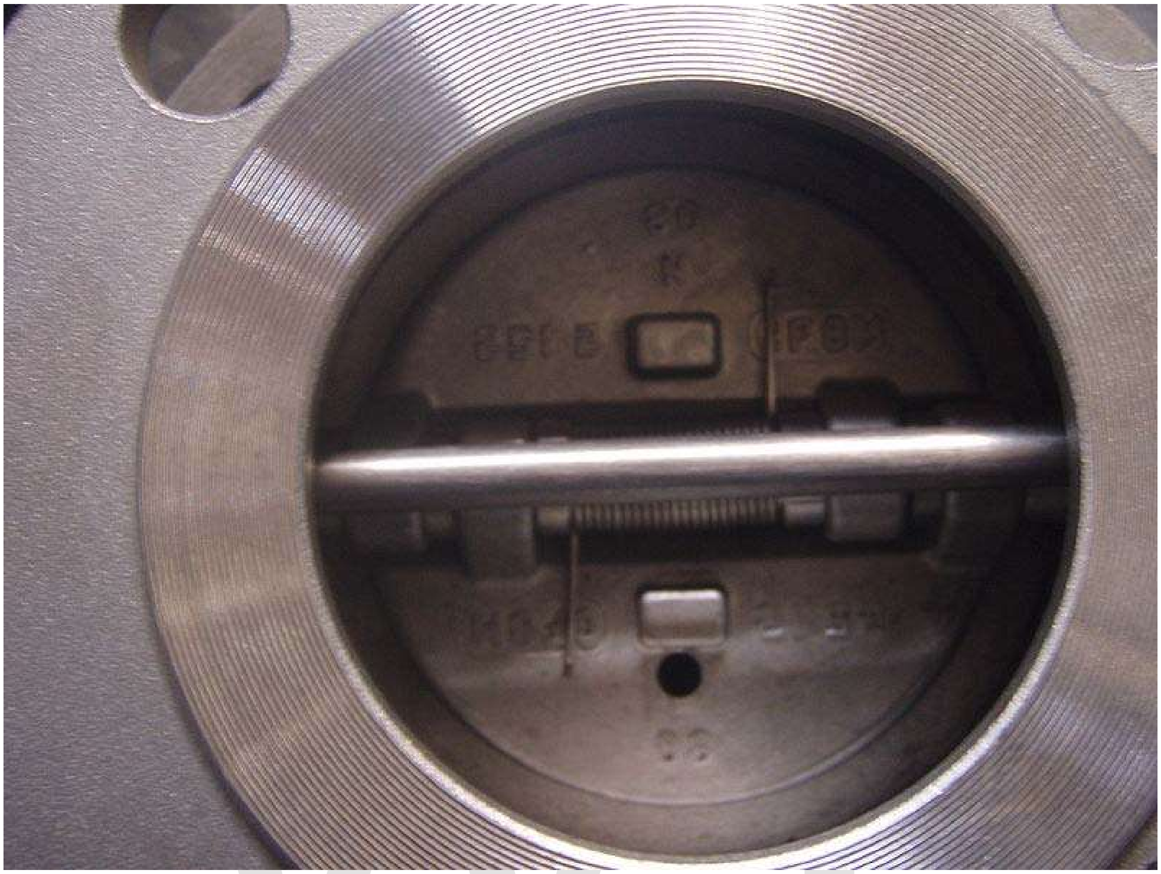
Inside view of a tilting disc inconel check valve

Duplex ball valves

Cryogenic super duplex gate valve frozen up during operation

Super duplex ball valves

Flanged nozzle inconel check valve or axial check valve



Inside hastelloy check valve, wafer configuration

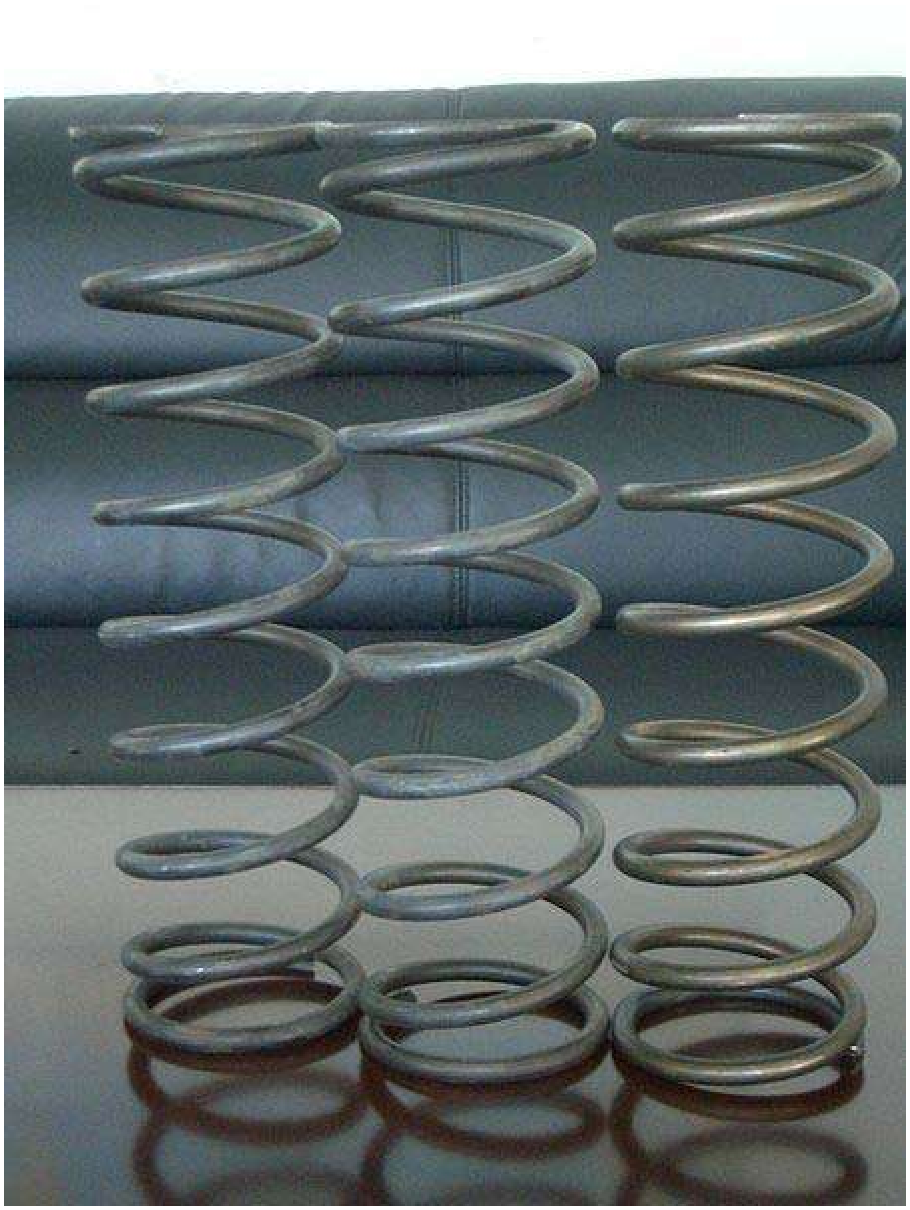
Large carbon steel swing check valve

Disc for an alloy check valve also known as axial check valve

Balls for alloy ball valves

Wafer check valve

Nuts and bolts for incoloy valves

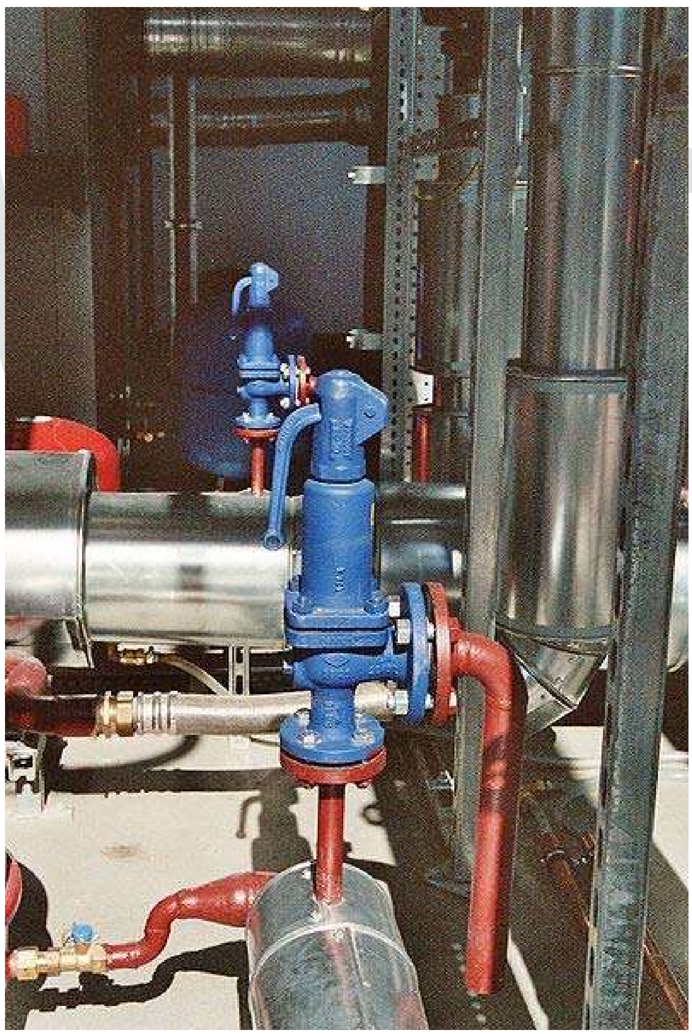


Inconel check valve springs

Ball for a titanium ball valve

Chapter 3

Relief Valve



A relief valve

The **relief valve** (RV) is a type of valve used to control or limit the pressure in a system or vessel which can build up by a process upset, instrument or equipment failure, or fire.

The pressure is relieved by allowing the pressurised fluid to flow from an auxiliary passage out of the system. The relief valve is designed or set to open at a predetermined set pressure to protect pressure vessels and other equipment from being subjected to pressures that exceed their design limits. When the set pressure is exceeded, the relief valve becomes the "path of least resistance" as the valve is forced open and a portion of the fluid is diverted through the auxiliary route. The diverted fluid (liquid, gas or liquid-gas mixture) is usually routed through a piping system known as a *flare header* or *relief header* to a central, elevated gas flare where it is usually burned and the resulting combustion gases are released to the atmosphere. As the fluid is diverted, the pressure inside the vessel will drop. Once it reaches the valve's reseating pressure, the valve will close. The *blowdown* is usually stated as a percentage of set pressure and refers to how much the pressure needs to drop before the valve reseats. The blowdown can vary from roughly 2-20%, and some valves have adjustable blowdowns.

In high-pressure gas systems, it is recommended that the outlet of the relief valve is in the open air. In systems where the outlet is connected to piping, the opening of a relief valve will give a pressure build up in the piping system downstream of the relief valve. This often means that the relief valve will not re-seat once the set pressure is reached. For these systems often so called "differential" relief valves are used. This means that the pressure is only working on an area that is much smaller than the openings area of the valve. If the valve is opened the pressure has to decrease enormously before the valve closes and also the outlet pressure of the valve can easily keep the valve open. Another consideration is that if other relief valves are connected to the outlet pipe system, they may open as the pressure in exhaust pipe system increases. This may cause undesired operation.

In some cases, a so-called *bypass valve* acts as a relief valve by being used to return all or part of the fluid discharged by a pump or gas compressor back to either a storage reservoir or the inlet of the pump or gas compressor. This is done to protect the pump or gas compressor and any associated equipment from excessive pressure. The bypass valve and bypass path can be internal (an integral part of the pump or compressor) or external (installed as a component in the fluid path). Many fire engines have such relief valves to prevent the overpressurization of fire hoses.

In other cases, equipment must be protected against being subjected to an internal vacuum (i.e., low pressure) that is lower than the equipment can withstand. In such cases, *vacuum relief valves* are used to open at a predetermined low pressure limit and to admit air or an inert gas into the equipment so as control the amount of vacuum.

Technical Terms

In the petroleum refining, petrochemical and chemical manufacturing, natural gas processing and power generation industries, the term **relief valve** is associated with the terms **pressure relief valve (PRV)**, **pressure safety valve (PSV)** and **safety valve**.

In practice, people often do not stick to the technical distinctions between the most common abbreviations: SRV, PRV, SV and RV

Pressure Relief Valve (PRV) or Pressure Safety Valve (PSV). The difference being that PSVs have a manual lever to activate the valve in case of emergency. Most PRV are spring operated. At lower pressures some use a diaphragm in place of a spring. The oldest PRV designs use a weight to seal the valve.

Set Pressure: When increasing system pressure reaches this value the PRV opens. Accuracy of set pressure often follows guidelines set by the ASME.

Relief valve (RV): A valve used on a liquid service, which opens proportionally as the increasing pressure overcomes the spring pressure.

Safety valve (SV): Used in gas service. Most SV are full lift or snap acting, they pop open all the way.

Safety relief valve (SRV): A PRV that can be used for gas or liquid service. But set pressure will usually only be accurate for one type of fluid at a time (the type it was set with).

Pilot-operated relief valve (POSRV, PORV, POPRV): device that relieves by remote command from a pilot valve that is connected to the upstream system pressure. Low pressure safety valve (LPSV): automatic system that relieves by static pressure on a gas. The pressure is small and near the atmospheric pressure.

Vacuum pressure safety valve (VPSV): automatic system that relieves by static pressure on a gas. The pressure is small, negative and near the atmospheric pressure.

Low and vacuum pressure safety valve (LVPSV): automatic system that relieves by static pressure on a gas. The pressure is small, negative or positive and near the atmospheric pressure.

Snap Acting: The opposite of modulating, refers to a valve that "pops" open, it goes into full lift in milliseconds. Usually accomplished with a skirt on the disc so that the fluid passing the seat suddenly affects a larger area and creates more lifting force.

Modulating: Opens in proportion to the overpressure formed.

Legal and code requirements in industry

In most countries, industries are legally required to protect pressure vessels and other equipment by using relief valves. Also in most countries, equipment design codes such as those provided by the American Society of Mechanical Engineers (ASME), American Petroleum Institute (API) and other organizations like ISO (ISO 4126) must be complied with and those codes include design standards for relief valves.

The main standards, laws or directives are:

- ASME (American Society of Mechanical Engineers) Boiler & Pressure Vessel Code, Section VIII Division 1 and Section I
- API (American Petroleum Institute) Recommended Practice 520/521, API Standard 2000 et API Standard 526
- ISO 4126 (International Organisation for Standardisation)
- EN 764-7 (European Standard based on pressure Equipment Directive 97/23/EC)
- AD Merkblatt (German)
- PED 97/23/EC (Pressure Equipment Directive - European Union)

DIERS

Formed in 1976, the Design Institute for Emergency Relief Systems was a consortium of 29 companies under the auspices of the American Institute of Chemical Engineers (AIChE) that developed methods for the design of emergency relief systems to handle runaway reactions. Its purpose was to develop the technology and methods needed for sizing pressure relief systems for chemical reactors, particularly those in which exothermic reactions are carried out. Such reactions include many classes of industrially important processes including polymerizations, nitrations, diazotizations, sulphonations, epoxidations, aminations, esterifications, neutralizations and many others. Pressure relief systems can be difficult to design, not least because what is expelled can be gas/vapour, liquid, or a mixture of the two - just as with a can of carbonated drink when it is suddenly opened. For chemical reactions, it requires extensive knowledge of both chemical reaction hazards and fluid flow.

DIERS investigated the two-phase vapor-liquid onset / disengagement dynamics and the hydrodynamics of emergency relief systems with extensive experimental and analysis work. Of particular interest to DIERS were the prediction of two-phase flow venting and the applicability of various sizing methods for two-phase vapor-liquid flashing flow. DIERS became a user's group in 1985.

European DIERS Users' Group (EDUG) is a group of mainly European industrialists, consultants and academics who use the DIERS technology. The EDUG started in the late 1980s and has an annual meeting. A summary of many of key aspects of the DIERS technology has been published in the UK by the HSE.

Chapter 4

Cast Iron Pipe

Cast iron pipe is a historical pipe which found widespread use as a pressure pipe for transmission of water, gas and sewage, and as a water drainage pipe, during the 19th and 20th centuries. It comprises predominantly a gray cast iron tube and was frequently used uncoated, although later developments did result in various coatings and linings to reduce corrosion and improve hydraulics. Cast iron pipe was gradually superseded by ductile iron pipe, which is a direct development, with most existing manufacturing plants transitioning to the new material during the 1970s and 1980s. There is currently almost no new manufacture of cast iron pipe.

History

Early Use

The first use of cast iron pipe is not recorded. Cast iron tubes were first manufactured in the 14th century in Europe for cannon and it is presumed that similar tubes would have found use as water pipes at the same time, however, it was not until 1455 in Siegerland that the first officially recorded cast iron water pipe was produced for use in Dillenburg Castle (since destroyed).

The oldest extant water pipes date from the 17th century and were installed to distribute water throughout the gardens of the Chateau de Versailles. These amount to some 35 km of pipe, typically 1m lengths with flanged joints. The extreme age of these pipes make them of considerable historical value. Following extensive refurbishment in 2008 by Saint-Gobain PAM, 80% remain original.

Manufacture

Vertically Cast

The first cast iron pipe was produced in horizontal molds which resulted in an uneven distribution of metal around the pipe circumference. In 1845, the first pipe was cast vertically and by the turn of the century, all pipe was manufactured to this method.

Centrifugally Cast

Subsequent to its invention by Dimitri Sensaud deLavaud, a French-Brazilian, in 1918, much cast iron pipe manufacture shifted to the dramatically different technique of centrifugal casting. Modern ductile iron pipe production continues to use this method of casting.

Standardization

The first standardization of cast iron water pipes in Britain occurred in 1917 with the publishing of BS 78. This standard specified a dimensionless nominal size, which approximately corresponded with the internal diameter in inches of the pipe, and four pressure classes, Class A, Class B, Class C and Class D, each with a specified wall thickness and outer diameter. It is noted that the outer diameter is identical between classes with the exception of sizes 12 to 27, where Classes A and B share one diameter and Classes C and D have another, larger diameter.

Nominal Size	Class									
	A & B	A		B		C & D	C		D	
	Outer Diameter [in (mm)]	Wall Thickness [in (mm)]	Internal Diameter [in (mm)]	Wall Thickness [in (mm)]	Internal Diameter [in (mm)]	Outer Diameter [in (mm)]	Wall Thickness [in (mm)]	Internal Diameter [in (mm)]	Wall Thickness [in (mm)]	Internal Diameter [in (mm)]
3	3.76 (95.504)	0.38 (9.652)	3.00 (76.200)	0.38 (9.652)	3.00 (76.200)	3.76 (95.504)	0.38 (9.652)	3.00 (76.200)	0.40 (10.160)	2.96 (75.184)
4	4.80 (121.920)	0.39 (9.906)	4.02 (102.108)	3.76 (95.504)	4.02 (102.108)	4.80 (121.920)	0.40 (10.160)	4.00 (101.600)	0.46 (11.684)	3.88 (98.552)
5	5.90 (149.860)	0.41 (10.414)	5.08 (129.032)	0.41 (10.414)	5.08 (129.032)	5.90 (149.860)	0.45 (11.430)	5.00 (127.000)	0.52 (13.208)	4.86 (123.444)
6	6.98 (177.292)	0.43 (10.922)	6.12 (155.448)	0.43 (10.922)	6.12 (155.448)	6.98 (177.292)	0.49 (12.446)	6.00 (152.400)	0.57 (14.478)	5.84 (148.336)
7	8.06 (204.724)	0.45 (11.430)	7.16 (181.864)	0.45 (11.430)	7.16 (181.864)	8.06 (204.724)	0.53 (13.462)	7.00 (177.800)	0.61 (15.494)	6.84 (173.736)
8	9.14 (232.156)	0.47 (11.938)	8.20 (208.280)	0.47 (11.938)	8.20 (208.280)	9.14 (232.156)	0.57 (14.478)	8.00 (203.200)	0.65 (16.510)	7.84 (199.136)
9	10.20 (259.080)	0.48 (12.192)	9.22 (234.188)	0.49 (12.446)	9.22 (234.188)	10.20 (259.080)	0.60 (15.240)	9.00 (228.600)	0.69 (17.526)	8.82 (224.028)
10	11.26 (286.004)	0.52 (13.208)	10.22 (259.588)	0.52 (13.208)	10.22 (259.588)	11.26 (286.004)	0.63 (16.002)	10.00 (254.000)	0.73 (18.542)	9.80 (248.920)
12	13.14 (333.756)	0.55 (13.970)	12.04 (305.816)	0.57 (14.478)	12.00 (304.800)	13.60 (345.440)	0.69 (17.526)	12.22 (310.388)	0.80 (20.320)	12.00 (304.800)
14	15.22 (386.588)	0.57 (14.478)	14.08 (357.632)	0.61 (15.494)	14.00 (355.600)	15.72 (399.288)	0.75 (19.050)	14.22 (361.188)	0.86 (21.844)	14.00 (355.600)
15	16.26 (413.004)	0.59 (14.986)	15.08 (383.032)	0.63 (16.002)	15.00 (381.000)	16.78 (426.212)	0.77 (19.558)	15.24 (387.096)	0.89 (22.606)	15.00 (381.000)
16	17.30 (439.420)	0.60 (15.240)	16.10 (408.940)	0.65 (16.510)	16.00 (406.400)	17.84 (453.136)	0.80 (20.320)	16.24 (412.496)	0.92 (23.368)	16.00 (406.400)
18	19.38 (492.252)	0.63 (16.002)	18.12 (460.248)	0.69 (17.526)	18.00 (457.200)	19.96 (506.984)	0.85 (21.590)	18.26 (463.804)	0.98 (24.892)	18.00 (457.200)

20	21.46 (545.084)	0.65 (16.510)	20.16 (512.064)	0.73 (18.542)	20.00 (508.000)	22.06 (560.324)	0.89 (22.606)	20.28 (515.112)	1.03 (26.162)	20.00 (508.000)
21	22.50 (571.500)	0.67 (17.018)	21.16 (537.464)	0.75 (19.050)	21.00 (533.400)	23.12 (587.248)	0.92 (23.368)	21.28 (540.512)	1.03 (26.162)	21.00 (533.400)
24	25.60 (650.240)	0.71 (18.034)	24.18 (614.172)	0.80 (20.320)	24.00 (609.600)	26.26 (667.004)	0.98 (24.892)	24.30 (617.220)	1.13 (28.702)	24.00 (609.600)
27	28.70 (728.980)	0.75 (19.050)	27.20 (690.880)	0.85 (21.590)	27.00 (685.800)	29.40 (746.760)	1.04 (26.416)	27.32 (693.928)	1.20 (30.480)	27.00 (685.800)
30	32.52 (826.008)	0.79 (20.066)	30.94 (785.876)	0.89 (22.606)	30.74 (780.796)	32.52 (826.008)	1.09 (27.686)	30.34 (770.636)	1.26 (32.004)	30.00 (762.000)
33	35.66 (905.764)	0.83 (21.082)	34.00 (863.600)	0.94 (23.876)	33.78 (858.012)	35.66 (905.764)	1.15 (29.210)	33.36 (847.344)	1.33 (33.782)	33.00 (838.200)
36	38.76 (984.504)	0.87 (22.098)	37.02 (940.308)	0.98 (24.892)	36.80 (934.720)	38.76 (984.504)	1.20 (30.480)	36.36 (923.544)	1.38 (35.052)	36.00 (914.400)
40	42.92 (1,090.168)	0.92 (23.368)	41.08 (1,043.432)	1.03 (26.162)	40.86 (1,037.844)	42.92 (1,090.168)	1.26 (32.004)	40.40 (1,026.160)	1.46 (37.084)	40.00 (1,016.000)
42	45.00 (1,143.000)	0.95 (24.130)	43.10 (1,094.740)	1.06 (26.924)	42.88 (1,089.152)	45.00 (1,143.000)	1.30 (33.020)	42.40 (1,076.960)	1.50 (38.100)	42.00 (1,066.800)
45	48.10 (1,221.740)	0.99 (25.146)	46.12 (1,171.448)	1.09 (27.686)	45.92 (1,166.368)	48.10 (1,221.740)	1.35 (34.290)	45.40 (1,153.160)	1.55 (39.370)	45.00 (1,143.000)
48	51.20 (1,300.480)	1.03 (26.162)	49.14 (1,248.156)	1.13 (28.702)	48.94 (1,243.076)	51.20 (1,300.480)	1.38 (35.052)	48.44 (1,230.376)	1.68 (42.672)	47.84 (1,215.136)

BS 78 was finally superseded when the U.K. harmonised with incompatible European standards, however, the specified outer dimensions continue to remain in effect (albeit in metric form) as the standard pipe outer diameter for ductile iron pipe in Australia and New Zealand through the descendant specification, AS/NZS 2280.

Chapter 5

Cured-in-Place Pipe and Drill Pipe

Cured-in-place pipe

A **cured-in-place pipe** (CIPP) is one of several trenchless rehabilitation methods used to repair existing pipelines. CIPP is a jointless, seamless, pipe-within-a-pipe with the capability to rehabilitate pipes ranging in diameter from 0.1 - 2.8 meter (4"-110"). As one of the most widely used rehabilitation methods CIPP has application in water, sewer, gas, and chemical pipelines.

The CIPP Process

A resin-saturated felt tube made of polyester is inverted or pulled into a damaged pipe. It is usually done from the upstream access point (manhole or excavation). It is possible to invert the liner upstream (eg from the downstream access point) but this carried greater risk. It is possible to install a liner from the downstream access point, upstream to a blind end however this carried the highest risk of all the CIPP installation methodologies. Little to no digging is involved in this trenchless process, making for a more environmentally friendly method than traditional "dig and replace" pipe repair methods. The liner can be inverted using water or air pressure. The pressure required for inversion can be generated using pressure vessels, scaffolds or a "Chip unit". Hot water, UV light, ambient cured or steam is used to cure the resin and form a tight-fitting, jointless and corrosion-resistant replacement pipe. Service laterals are restored internally with robotically controlled cutting devices. These can be sealed with additional seals into the lateral connection (Lateral Junction Repair). The rehabilitated pipe is then inspected by closed-circuit television (CCTV). CIPP is considered a trenchless technology.

History

In 1971, Eric Wood implemented the first cured-in-place pipe technology in London, England. He called the CIPP process *insit u form*, derived from the Latin meaning "form in place." Wood applied for US patent no. 4009063 on January 29, 1975. The patent was granted February 22, 1977 and was commercialized by Insituform Technologies until it entered the public domain on February 22, 1994.

Advantages

As a trenchless technology, CIPP does not require excavation to rehabilitate a pipeline that is either leaking or structurally unsound. Depending upon design considerations an excavation may be made, but the liner is often installed through a manhole or other existing access point. Anything larger than 60" must be excavated in order to install. Liner is installed as it is wet out on site in these instances. In the case of sewerlines, lateral connections are also restored without excavation via a remote controlled device that drills a hole in the liner at the point of the lateral connection. If larger than 24" and it is safe to do so someone will reinstate laterals by hand. CIPP has a smooth interior and no joints. While CIPP can repair a pipe with bends, special design considerations must be taken into account to prevent wrinkling and stretching. CIPP can effectively reduce infiltration and leaks in pipeline systems without digging.

Disadvantages and Limitations

Except for very common sizes, liners are not usually stocked and must be made specifically for each project. CIPP requires bypass of the flow in the existing pipeline while the liner is being installed. The curing may take from five hours to 30 hours depending on pipe diameter and must be carefully monitored, inspected, and tested. Obstructions in the existing pipeline, such as protruding laterals, must be removed prior to installation. Cost should be compared with similar methods such as Shotcrete, thermoformed pipe, close-fit pipe, spiral wound pipe and sliplining as these other methods can provide a similar design solution for similar or less cost in certain situations. CIPP must also be carefully monitored for release of chemical agents utilized in the reaction process for contamination downstream of rehabilitated pipes. The liner material used for common sizes is normally a felted fabric (weave) and does not go around bends well without wrinkling adn going out of round on corners. Liners used for pipes with bends (particularly 100mm pipes) are made from a woven fabric allowing it to go around bends with minimal wrinkling. The more flexible the liner, the more care needs to be taken during inversion to ensure the liner remains on the correct alignment.

Drill pipe

Drill pipe, also known as **Drill stem** is hollow, thick-walled, steel piping that is used on drilling rigs to facilitate the drilling of a wellbore and comes in a variety of sizes, strengths, and weights but are typically 30 to 33 feet in length. They are hollow to allow drilling fluid to be pumped through them, down the hole, and back up the annulus.

Because it is designed to support its own weight for combined lengths that often exceed 1 mile down into the Earth's crust, the case-hardened steel tubes are expensive, and owners spend considerable efforts to reuse them after finishing a well, replacing the drill stems with thinner walled tubular casing, tapping the natural resources of oil reservoirs. Used drill stem is often sent to a yard for inspection, sorted, and stored until new drill sites can be explored. Modified instruments similar to the spherometer are used at inspection sites to identify defects in the metallurgy, in order to prevent fracture of the drill stem during future wellboring.

Chapter 6

Ductile Iron Pipe

Ductile iron pipe is a pipe commonly used for potable water and sewage distribution. The predominant wall material is ductile iron, a spheroidized graphite cast iron, although an internal cement mortar lining usually serves to inhibit corrosion from the fluid being distributed, and various types of external coating are used to inhibit corrosion from the environment. Ductile iron pipe is a direct development of earlier cast iron pipe which it has superseded. Ductile iron has proven to be a better pipe material, being stronger and more fracture resistant; however, like most ferrous materials, it is susceptible to corrosion and retains some brittle characteristics. Relatively recent developments such as polyethylene sleeving and/or zinc and polymer coatings have done much to mitigate corrosion concerns, and a typical life expectancy is in excess of 75 years.

Dimensions

Ductile iron pipe is sized according to a dimensionless term known as the Pipe Size or Nominal Diameter (known by its French abbreviation, DN). This is roughly equivalent to the pipe's internal diameter in inches or millimeters. However, it is the external diameter of the pipe that is kept constant between changes in wall thickness, in order to maintain compatibility in joints and fittings. Consequently the internal diameter varies, sometimes significantly, from its nominal size. Nominal pipe sizes vary from 3 inches up to 64 inches, in increments of at least 1 inch, in the USA.

Pipe dimensions are standardised to the mutually incompatible AWWA C151 (U.S. Customary Units) in the USA, ISO 2531 / EN 545/598 (metric) in Europe, and AS/NZS 2280 (metric) in Australia and New Zealand. Although both metric, European and Australian are not compatible and pipes of identical nominal diameters have quite different dimensions.

North America

Pipe dimensions according to the American AWWA C-151

Pipe Size	Outside Diameter [in (mm)]
3	3.96 (100.584)
4	4.80 (121.92)
6	6.90 (175.26)
8	9.05 (229.87)
10	11.10 (281.94)
12	13.20 (335.28)
Pipe Size	**Outside Diameter [in (mm)]**
14	15.30 (388.62)
16	17.40 (441.96)
18	19.50 (495.3)
20	21.60 (548.64)
24	25.80 (655.32)
30	32.00 (812.8)

Europe

European pipe is standardized to ISO 2531 and its descendent specifications EN 545 (potable water) and EN 598 (sewage). European pipes are sized to approximately match the internal diameter of the pipe, following internal lining, to the nominal diameter. ISO 2531 maintains dimensional compatibility with older German cast iron pipes. Older British pipes, however, which used the incompatible imperial standard, BS 78, require adapter pieces when connecting to newly installed pipe. Coincidentally, the British harmonization with European pipe standards occurred at approximately the same time as its transition to ductile iron, so almost all cast iron pipe is imperial and all ductile pipe is metric.

DN	Outside Diameter [mm (in)]	Wall thickness [mm (in)]		
		Class 40	K9	K10
40	56 (2.205)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)
50	66 (2.598)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)
60	77 (3.031)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)
65	82 (3.228)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)
80	98 (3.858)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)
100	118 (4.646)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)
125	144 (5.669)	4.8 (0.189)	6.0 (0.236)	6.0 (0.236)

150	170 (6.693)	5.0 (0.197)	6.0 (0.236)	6.5 (0.256)
200	222 (8.740)	8.4 (0.331)	6.3 (0.248)	7.0 (0.276)
250	274 (10.787)	5.8 (0.228)	6.8 (0.268)	7.5 (0.295)
300	326 (12.835)	6.2 (0.244)	7.2 (0.283)	8.0 (0.315)
350	378 (14.882)	7.0 (0.276)	7.7 (0.303)	8.5 (0.335)
400	429 (16.890)	7.8 (0.307)	8.1 (0.319)	9.0 (0.354)
450	480 (18.898)	-	8.6 (0.339)	9.5 (0.374)

DN	**Outside Diameter [mm (in)]**	**Wall thickness [mm (in)]**		
		Class 40	K9	K10
500	532 (20.945)	-	9.0 (0.354)	10.0 (0.394)
600	635 (25.000)	-	9.9 (0.390)	11.1 (0.437)
700	738 (29.055)	-	10.9 (0.429)	12.0 (0.472)
800	842 (33.150)	-	11.7 (0.461)	13.0 (0.512)
900	945 (37.205)	-	12.9 (0.508)	14.1 (0.555)
1000	1,048 (41.260)	-	13.5 (0.531)	15.0 (0.591)
1100	1,152 (45.354)	-	14.4 (0.567)	16.0 (0.630)
1200	1,255 (49.409)	-	15.3 (0.602)	17.0 (0.669)
1400	1,462 (57.559)	-	17.1 (0.673)	19.0 (0.748)
1500	1,565 (61.614)	-	18.0 (0.709)	20.0 (0.787)
1600	1,668 (65.669)	-	18.9 (0.744)	51.0 (2.008)
1800	1,875 (73.819)	-	20.7 (0.815)	23.0 (0.906)
2000	2,082 (81.969)	-	22.5 (0.886)	25.0 (0.984)

Jordan

Australian and New Zealand pipes are sized to an independent specification, AS/NZS 2280, that is not compatible with European pipes even though the same nomenclature is used. Australia adopted at an early point the imperial British cast iron pipe standard BS 78, and when this was retired on British adoption of ISO 2531, rather than similarly harmonizing with Europe, Australia opted for a 'soft' conversion from imperial units to metric, published as AS/NSZ 2280, with the physical outer diameters remaining unchanged, allowing continuity of manufacture and backwards compatibility. Therefore the inner diameters of lined pipe differ widely from the nominal diameter, and hydraulic calculations require some knowledge of the pipe standard.

Nominal Size (DN)	Outside Diameter [mm (in)]	Nominal Wall Thickness [mm (in)]		Flange Class
		PN 20	PN 35	
100	122 (4.803)	-	5.0 (0.197)	7.0
150	177 (6.969)	-	5.0 (0.197)	8.0
200	232 (9.134)	-	5.0 (0.197)	8.0
225	259 (10.197)	5.0 (0.197)	5.2 (0.205)	9.0
250	286 (11.260)	5.0 (0.197)	5.6 (0.220)	9.0
300	345 (13.583)	5.0 (0.197)	6.3 (0.248)	10.0
375	426 (16.772)	5.1 (0.201)	7.3 (0.287)	10.0
450	507 (19.961)	5.6 (0.220)	8.3 (0.327)	11.0
500	560 (22.047)	6.0 (0.236)	9.0 (0.354)	12.0
600	667 (26.260)	6.8 (0.268)	310.3 (0.406)	13.0
750	826 (32.520)	7.9 (0.311)	12.2 (0.480)	15.0

=d the spigot to contain the mixture which was pounded into the socket with a caulking tool and then pointed off. This took several weeks to set and produced a completely rigid joint. Such pipe systems are often to be seen in ninteenth century churches in the heating system.

Manufacture

Ductile iron pipe is produced by a technique known as centrifugal casting, originally developed for cast iron pipe in 1918. The molten ductile iron is poured into a rapidly spinning water-cooled mold. Centrifugal force results in an even spread of iron around the circumference.

Internal coatings

Ductile iron pipe is somewhat resistant to internal corrosion in potable water and less aggressive forms of sewage. However, even where pipe material loss and consequently pipe wall reduction is slow, the deposition of corrosion products on the internal pipe wall can dramatically reduce the effective internal diameter and effectively choke flow, increasing pumping costs and lowering system pressure, long before the pipe itself is at risk of failure. A variety of linings are available to reduce or eliminate corrosion, including cement mortar, polyurethane and polyethylene. Of these, cement mortar lining is by far the most common.

Cement mortar

The predominant form of lining for water applications is cement mortar centrifugally applied during manufacturing. The cement mortar comprises a mixture of cement and sand to a ratio of between 1:2 and 1:3.5. For potable water, portland cement is used; for sewage it is common to use sulfate resisting or high alumina cement.

Cement mortar linings have been found to dramatically reduce internal corrosion. A DIPRA survey has demonstrated that the Hazen-Williams factor of cement lining remains between 130 and 151 with only slight reduction with age.

External coatings

Unprotected ductile iron, similarly to cast iron, is intrinsically resistant to corrosion in most, although not all, soils. Nonetheless, because of frequent lack of information on soil aggressiveness and to extend the installed life of buried pipe, ductile iron pipe is commonly protected by one or more external coatings. In the U.S. and Australia, loose polyethylene sleeving is preferred. In Europe, standards recommend a more sophisticated system of directly bonded zinc coatings overlaid by a finishing layer be used in conjunction with polyethylene sleeving.

Polyethylene

Polyethylene sleeving was first developed by CIPRA (since 1979, DIPRA) in the U.S. in 1951 for use in highly corrosive soil in Birmingham, Alabama. It was employed more widely in the U.S. in the late 1950s and first employed in the UK in 1965 and Australia in the mid-1960s.

Polyethylene sleeving comprises a loose sleeve of polyethylene sheet that completely wraps the pipe, including the bells of any joints. Sleeving inhibits corrosion by a number of mechanisms. It physically separates the pipe from soil particles, preventing direct galvanic corrosion. By providing an impermeable barrier to ground water, the sleeve also inhibits the diffusion of oxygen to the ductile iron surface and limits the availability of electrolytes that would accelerate corrosion. It provides a homogeneous environment along the pipe surface so that corrosion occurs evenly over the pipe. The sleeve also restricts the availability of nutrients which could support sulfate-reducing bacteria, inhibiting microbially-induced corrosion. Sleeving is not designed to be completely water-tight but rather to greatly restrict the movement of water to and from the pipe surface. Water present beneath the sleeve and in contact with the pipe surface is rapidly deoxygenated and depleted of nutrients and forms a stable environment in which limited further corrosion occurs. An improperly installed sleeve that continues to allow the free flow of ground water is not effective in inhibiting corrosion.

Polyethylene sleeves are available in a number of materials. The most common contemporary compositions are linear low-density polyethylene film which requires an 8 mil or 200 µm thickness and high-density cross-laminated polyethylene film which requires only a 4 mil or 100 µm thickness. The latter may or may not be reinforced with a scrim layer.

Polyethylene sleeving does have limitations. In European practice, its use in the absence of additional zinc and epoxy protective coatings is discouraged where natural soil resistivity is below 750 ohm/cm, where resistivity is below 1500 ohm/cm and where the pipe is installed at or below the water table, where there are additional artificial soil contaminants or where there are stray currents. Because of the vulnerability of polyethylene to UV degradation, sleeving, or sleeved pipe should not be stored in sunlight, although carbon pigments included in the sleeving can provide some limited protection.

Polyethylene sleeving is standardised according to ISO 8180 internationally, AWWA C105 in the U.S., BS 6076 in the UK and AS 3680 and AS 3681 in Australia.

Zinc

In Europe, ductile iron pipe is typically manufactured with a zinc coating overlaid by either a bituminous, polymer, or epoxy finishing layer. EN 545/598 mandates a minimum zinc content of 135 g/m^2 (with local minima of 110 g/m^2 at 99.99% purity) and a minimum average finishing layer thickness of 70 µm (with local minima of 50 µm).

No current AWWA standards are available for bonded coatings (zinc, coal tar epoxy, tape-wrap systems as seen on steel pipe) for ductile iron pipe, DIPRA does not endorse bonded coatings, and AWWA M41 generally views them unfavourably, recommending they be used only in conjunction with cathodic protection.

Bituminous coatings

Zinc coatings are generally not employed in the U.S. and Australia. In order to protect ductile iron pipe prior to installation, pipe is instead supplied with a temporary 1 mil or 25 µm thick bituminous coating. This coating is not intended to provide protection once the pipe is installed.

Industry associations

In the United States ductile iron pipe is often promoted to municipalities and consulting engineers by the Ductile Iron Pipe Research Association . Their focus is to promote the benefits of using ductile iron pipe on utility projects (water & sewer) over alternate products such as PVC, PCP, and HDPE.

Environmental

Ductile iron pipe in the developed world is normally manufactured exclusively from scrap steel. Ductile iron pipe can be recycled. In the U.S. with the growing environmental movement ductile iron pipe is in a natural position to regain market share lost to its largest competitor, the PVC industry, over the past 40 years.

Chapter 7

Pipe Fitting

soldered copper pipes

welding steel pipe

Pipe fitting is the occupation of installing or repairing piping or tubing systems that convey liquid, gas, and occasionally solid materials. This work involves selecting and preparing pipe or tubing, joining it together by various means, and the location and repair of leaks.

Pipe fitting work is done in many different settings: HVAC, manufacturing, hydraulics, refineries, computer chip fab plants, power plant construction and other steam systems. Pipe fitters (sometimes called simply "fitters") are represented in the USA and Canada by the United Association of Journeymen and Apprentices of the Plumbing and Pipe Fitting Industry of the United States and Canada.

Fitters work with a variety of pipe and tubing materials including several types of steel, copper, iron, plastic, aluminium. Pipe fitting is not plumbing, the two are related but separate trades. Pipe fitters who specialize in fire prevention are called Sprinklerfitters, another related, but separate trade.

Scope of work

- Blueprint reading
- Detailing
- CAD Drawing Coordinators
- Layout

- Supports and Hanger Installation
- Pipe Threading
- Pipe Grinding
- Welding (MiG, GMAW, TiG, SMAW, Orbital)
- Plasma cutting
- Mechanical Pipe cutting and grooving
- Gas Arc cutting
- Rigging
- Brazing
- Soldering
- Mitering
- Tube Bending
- Valve installation and repair
- Preparation and installation of medical gas piping

Steel pipe

Steel pipe (or black iron pipe) was once the most popular choice for supply of water and flammable gases. Steel pipe is still used in many homes and businesses to convey natural gas or propane, and is a popular choice in fire sprinkler systems due to its high heat resistance. In commercial buildings steel pipe is used to convey heating or cooling water to heat exchangers, air handlers, fan coil, Variable air volume(VAV) device, or other HVAC equipment.

Steel pipe is sometimes joined using thread connections, where tapered threads are cut into the tubing section end, sealant is applied in the form of thread compound or PTFE tape (also known as teflon tape) and it is then threaded into a corresponding threaded fitting using a pipe wrench. More often it is joined by welding, or by use of mechanical couplings, made by companies such as Victaulic or Grinnell that hold the pipe joint together via a groove pressed or cut (a rarely used older practice), into the ends of the pipes.

Other variations of steel include various stainless steel and chrome alloys. In high pressure situations these are usually joined by TIG welding.

Usages vary from country to country as different nations have different standards to install pipe.

In Canada, in respect to natural gas (NG) and propane (LP gas), black iron pipe (BIP) is used to connect an appliance to the supply, it must however be marked (either painted yellow or yellow banding attached at certain intervals) and certain restrictions apply to which nominal pipe size (NPS) can be put through walls and buildings. With propane in particular BIP can be run from an exterior tank (or cylinder) provided it is well protected from the elements and an anode-type of protection is in place for when the pipe is to be installed underground.

Copper tubing

Copper tubing is most often used for supply of hot and cold water, and as refrigerant line in HVAC systems. There are two basic types of copper tubing, soft copper and rigid copper. Copper tubing is joined using flare connection, compression connection, or solder. Copper offers a high level of resistance to corrosion, but is becoming very costly.

Soft copper

Soft (or ductile) copper tubing can be bent easily to travel around obstacles in the path of the tubing. While the work hardening of the drawing process used to size the tubing makes the copper hard/rigid, it is carefully annealed to make it soft again; it is therefore more expensive to produce than non-annealed, rigid copper tubing. It can be joined by any of the three methods, and it is the only type of copper tubing suitable for flare connections. Soft copper is the most popular choice for refrigerant lines in *split-system* air conditioners and heat pumps.

Flare connections

Flare connections require that the end of a tubing section be spread outward in a bell shape using a *flare tool*. A *flare nut* then compresses this bell-shaped end onto a male fitting. Flare connections are the most labor intensive of the three options, but are quite reliable over the course of many years.

Rigid copper

Rigid copper is a popular choice for water lines. It is joined using a sweat, compression or crimped/pressed connection. Rigid copper, rigid due to the work hardening of the drawing process, cannot be bent and must use *elbow fittings* to go around corners or around obstacles. If heated and allowed to slowly cool, called annealing, then rigid copper will become soft and can be bent/formed without cracking.

Soldered connections

Solder fittings. These are smooth, and easily slip onto the end of a tubing section. The joint is then heated using a torch, and solder is melted into the connection. When the solder cools, it forms a very strong bond which can last for decades. Solder-connected rigid copper is the most popular choice for water supply lines in modern buildings. In situations where many connections must be made at once (such as plumbing of a new building), solder offers much quicker and much less expensive joinery than compression or flare.

Compression connections

Compression fittings use a soft metal ring (the compression ring) which is squeezed onto the pipe and into the fitting by a compression nut. The soft metal conforms to the surface of the tubing and the fitting, and creates a seal. Compression connections do not typically have the long life that sweat connections offer, but are advantageous in many cases because they are easy to make using basic tools. A disadvantage in compression connections is that they take longer to make than sweat, and sometimes require retightening over time to stop leaks.

Crimped or pressed connections

Crimped or pressed connections use special copper fittings which are permanently attached to rigid copper tubing with a powered crimper. The special fittings, manufactured with sealant already inside, slide over the tubing to be connected. Thousands of pounds-force per square inch of pressure are used to deform the fitting and compress the sealant against the inner copper tubing, creating a water tight seal. The advantages of this method are that it should last as long as the tubing, it takes less time to complete than other methods, it is cleaner in both appearance and the materials used to make the connection and no open flame is used during the connection process. The disadvantages are that the fittings used are harder to find and cost significantly more than sweat type fittings.

Aluminium tubing

Aluminium is sometimes used due to its low cost, resistance to corrosion and solvents, and for its ductility. Aluminium tube is more desirable than steel for the conveyance of flammable solvents, since it cannot create sparks when manipulated. Aluminium tubing can be connected by flare or compression fittings, or it can be welded by the TIG or heliarc processes.

Occupational hazards

Pipe fitters are often exposed to hazardous or dangerous materials, such as asbestos, lead, ammonia, steam, flammable gases, various resins and solvents including benzene, and various refrigerants. Much progress was made in the 20th century toward eliminating hazardous materials. Many aspects of this are now regulated by law in most countries, including asbestos usage and removal, and refrigerant selection and handling.

Other occupational hazards are exposure to the elements, heavy lifting, crushing hazards, etc. normal to the construction industry.

Chapter 8

Hydrostatic Test

A **hydrostatic test** is a way in which leaks can be found in pressure vessels such as pipelines and plumbing. The test involves placing water, which is often dyed for visibility, in the pipe or vessel at the required pressure to ensure that it will not leak or be damaged. It is the most common method employed for testing pipes and vessels. Using this test helps maintain safety standards and durability of a vessel over time. Newly manufactured pieces are initially qualified using the hydrostatic test. They are then continually re-qualified at regular intervals using the *proof pressure test* which is also called the *modified hydrostatic test*. Hydrostatic testing is also a way in which a gas pressure vessel, such as a gas cylinder or a boiler, is checked for leaks or flaws. Testing is very important because such containers can explode if they fail when containing compressed gas.

Testing procedures

Hydrostatic tests are conducted under the constraints of either the industry's or the customer's specifications. The vessel is filled with a nearly incompressible liquid - usually water or oil - and examined for leaks or permanent changes in shape. Red or fluorescent dyes are usually added to the water to make leaks easier to see. The test pressure is always considerably higher than the operating pressure to give a margin for safety. This margin of safety is typically 150% or 1.3 of the design pressure, depending on the regulations that apply. For example, if a cylinder was rated to DOT-2015 PSI (approximately 139 bar), it would be tested at around 3360 PSI (approximately 232 bar). Water is commonly used because it is almost incompressible (compressible only by weight, not air pressure), so will only expand by a very small amount should the vessel split. If high pressure gas were used, then the gas would expand to perhaps several hundred times its compressed volume in an explosion, with the attendant risk of damage or injury. This is the risk which the testing is intended to mitigate.

Small pressure vessels are normally tested using a water jacket test. The vessel is visually examined for defects and then placed in a container filled with water, and in which the change in volume of the vessel can be measured by monitoring the water level. For best accuracy, a digital scale is used to measure the smallest amounts of change. The vessel is then pressurized for a specified period, usually 30 or more seconds, and then depressurized again. The water level in the jacket is then examined. The level will be greater if the vessel being tested has been distorted by the pressure change and did not return to its original volume, or some of the pressurized water inside has leaked out. In both cases, this will normally signify that the vessel has failed the test. If the Rejection Elastic Expansion is more than 10%, or not up to DOT or customer standards, the cylinder fails, and then goes through a condemning process marking the cylinder as unsafe. This measures the overall leakage of a system instead of locating the leaks and additives can be added to the water to reduce resistivity and increase the sensitivity of the test. The hydrostatic test fluid can also clog small holes (1x10^-6 std cm^3/s or smaller) as a result of the increase in pressure. This is another reason why water is commonly used.

All the information the tester needs is stamped onto the cylinder. This includes the DOT information, serial number, manufacturer, and manufacture date. Other information is stamped as needed such as the REE or how much the manufacturer specifies the cylinder should expand before it is considered unsafe. All this information is usually taken down and stored on a computer prior to the testing process. All this information is necessary for keeping track of when the cylinder has been or needs to be hydrotested.

Water jacket test

A simpler test, that is still considered a hydrostatic test but can be performed by anyone who has a garden hose, is to pressurize the vessel by filling it with water and to physically examine the outside for leaks. The pressure level achieved in this sort of test does not come close to the pressure level that would be used in a professional testing facility.

Examples

Portable fire extinguishers are safety tools that are required to be on hand in almost every public building. Fire extinguishers are also highly recommended in every home. Over time the conditions in which they are housed, and the manner in which they are handled have an impact on the structural integrity of the extinguisher. A structurally weakened fire extinguisher can malfunction or even burst when it is needed the most. To maintain the quality and safety of this product, hydrostatic testing must be utilized. All critical components of the fire extinguisher must be tested to ensure proper function. The cylinder would be tested by using the water jacket test.

As previously mentioned, the water pressure inside the tank will usually be 150% of the normal operating pressure. The change in volume of the cylinder is calculated by measuring the change in the water levels outside the cylinder. This can be done with a digital scale as well to detect the slightest changes, almost always in grams. The cylinder can also be visually checked for leaks or the pressure drop method can be utilized to measure the overall efficiency of the cylinder.

Pipeline testing

Hydrotesting of pipe, pipelines and vessels is done to expose defective materials that have missed prior detection, ensure that any remaining defects are insignificant enough to allow operation at design pressures, expose possible leaks and serve as a final validation of the integrity of the constructed system. ASME B31.3 requires this testing to ensure tightness and strength. ASME B31.3 section 345

Buried high pressure oil and gas pipelines are tested for strength by pressurizing them to at least 125% of their maximum operating pressure (MAOP) at any point along their length. Since many long distance transmission pipelines are designed to have a steel hoop stress of 80% of specified minimum yield (SMYS) at MAOP, this means that the steel is stressed to SMYS and above during the testing, and test sections must be selected to ensure that excessive plastic deformation does not occur.

Test pressures need not exceed a value that would produce a stress higher than yield stress at test temperature. ASME B31.3 section 345.4.2 (c)

Other codes require a more onerous approach. BS PD 8010-2 requires testing to 150% of the *design* pressure - which should not be less than the MAOP plus surge and other incidental effects that will occur during normal operation.

Leak testing is performed by balancing changes in the measured pressure in the test section against the theoretical pressure changes calculated from changes in the measured temperature of the test section.

Australian standard AS2885.5 "Pipelines—Gas and liquid petroleum: Part 5: Field pressure testing" gives an excellent explanation of the factors involved.

Testing frequency

Most countries have legislation or building code that requires pressure vessels to be regularly tested, for example every two years (with a visual inspection annually) for high pressure gas cylinders and every five or ten years for lower pressure ones such as used in fire extinguishers. Gas cylinders which fail are normally destroyed as part of the testing protocol to avoid the dangers inherent in them being subsequently used.

These common gas cylinders have the following requirements:

- DOT-3AL gas cylinders must be tested every 5 years and have an unlimited life.
- DOT-3HT gas cylinders must be tested every 3 years and have a 24 year life.
- DOT-3AA gas cylinders must be tested every 5 years and have an unlimited life. (Unless stamped with a star (*) in which case the cylinder meets certain specifications and can have a 10 year hydrostatic test life)

In the U S and Canada, organizations such as ASTM, and ASME specify the guidelines for the different types of pressure vessels.

Chapter 9

Hot Tapping and Pipefitter

Hot tapping

Hot tapping, or pressure tapping, is the method of making a connection to existing piping or pressure vessels without the interruption of emptying that section of pipe or vessel. This means that a pipe or tank can continue to be in operation whilst maintenance or modifications are being done to it. The process is also used to drain off pressurised casing fluids.

Hot tapping is also the first procedure in line stopping, where a hole saw is used to make an opening in the pipe, so a line plugging head can be inserted.

Situations in which welding operations are prohibited on equipment which contains:

- Mixtures of gases or vapours within their flammable range or which may become flammable as a result of heat input in welding operations.
- Substances which may undergo reaction or decomposition leading to a dangerous increase in pressure, explosion or attack on metal. In this context, attention is drawn to the possibility that under certain combinations of concentration, temperature and pressure, acetylene, ethylene and other unsaturated hydrocarbons may decompose explosively, initiated by a welding hot spot.
- Oxygen-enriched atmospheres in the presence of hydrocarbons which may be present either in the atmosphere or deposited on the inside surface of the equipment or pipe.
- Compressed air in the presence of hydrocarbons which may be present either in the air or deposited on the inside surfaces of the equipment or pipe.
- Gaseous mixtures in which the partial pressure of hydrogen exceeds 700 kPa gauge, except where evidence from tests has demonstrated that hot-tapping can be done safely.

Based on the above, welding on equipment or pipe which contains hazardous substances or conditions as listed below (even in small quantities) shall not be performed unless positive evidence has been obtained that welding/hot tapping can be applied safely.

Substances:

- Acetylene;
- Acetonitrile;
- Butadiene;
- Caustic soda;*
- Chlorine;
- Compressed air at a pressure in excess of 3000 kPa gauge;
- Ethylene;
- Ethylene oxide;
- Fat/lean DEA/MEA;
- High pressuew steam (pressure in excess of 5000 kPa (ga));
- Hydrogen (partial pressure in excess of 700 kPa (ga));
- Hydrogen sulphide;*
- Hydrofluoric acid;
- Oxygen;
- Propene;
- Propene oxide;
- Sulphuric acid;
- Toxic substances.*

Constraints based on general hazard in the event of line puncturing during welding, not the welding process. Conditions:

- Vacuum conditions;
- Dissolved hydrogen in the pipe wall (e.g. due to service history);
- Pyrophoric scale deposits.

Note: The above list is not exhaustive, but gives an indication only.

Pipefitter

Large-scale piping system in an HVAC mechanical room

A **pipefitter** (also called **steamfitter**) is a tradesman who lays out, assembles, fabricates, maintains and repairs mechanical piping systems. Pipefitters usually go through a mix of apprentice and trade school training. Journeyman pipefitters/steamfitters deal with industrial process piping and heating/cooling systems. Typical industrial process pipe is under high pressure, which requires metals such as carbon steel, stainless steel, and many different alloy metals fused together through precisely cutting, threading, grooving, bending and welding, whereas a plumber concentrates on piping systems for heating/cooling as well as utility liquids potable water, sewage, drains, etc. in the industrial/commercial/institutional or residential atmosphere operating at lower pressures. Utility piping typically consists of copper, PVC, CPVC, polyethylene, and galvanized pipe which is typically glued, soldered, or threaded. Other types of piping systems include steam, ventilation, hydraulics, chemicals or fuel.

In the United States, many states require pipefitters to be licensed. Requirements differ from state to state but most include a four to five year apprenticeship and testing before becoming a licensed journeyman.

Occupational Summary

Pipefitter Skills include:

- Layout
- Blueprint reading
- Detailing
- CAD Drawing Coordinators
- Pipe Threading
- Pipe Grinding
- Welding (MiG, GMAW, TiG, SMAW, Orbital)
- Plasma cutting
- Mechanical Pipe cutting
- Gas Arc cutting
- Rigging
- Brazing
- Soldering
- Mitering
- Tube Bending
- Valve installation and repair
- Preparation and installation of medical gas piping

Employers that hire pipefitters include:

- Heating, ventilation and air conditioning HVAC construction firms
- Mechanical construction firms
- Pulp mills and paper mills
- Primary steel producers
- Utility companies
- Motor vehicle manufacturers
- Residential building developers
- Fabrication metal Metal fabricating companies
- Oil refineries
- Chemical plants
- Pharmaceutical companies

- Shipyards and ship repair facilities
- Nuclear Power Plants
- Coal-Burning Power Plants
- Gas Plants
- Breweries
- Semiconductor plants
- Service companies that maintain and install controls such as thermostats and balancing valves
- Hospitals and healthcare facilities
- Glass manufacturing Plants

Recommended or required skills include physical strength and manual dexterity, reading and interpreting blueprints and specifications; making detailed sketches for pipe and equipment fabrication and installation; cutting openings for pipe using various hand or power tools; measuring, cutting with blades and torches, threading, grooving, bending, soldering, brazing, welding, assembling, mitering, joining and installing pipes, valves and fittings.

Trade Groups

In North America, Union pipefitters are members of the United Association. Wages vary from area to area, based on contracts between the local union and contractors.

Chapter 10

Fire Sprinkler System

A glass bulb type sprinkler head will spray water into the room if sufficient heat reaches the bulb and causes it to shatter. Sprinkler heads operate individually. Note the red liquid in the glass bulb.

A **fire sprinkler system** is an active fire protection measure, consisting of a water supply system, providing adequate pressure and flowrate to a water distribution piping system, onto which fire sprinklers are connected. Although historically only used in factories and large commercial buildings, home and small building systems are now available at a cost-effective price.

History

The world's first recognizable sprinkler system was installed in the Theatre Royal, Drury Lane in the United Kingdom in 1812 by its architect . The system was designed by Sir William Congreve, 2nd Baronet was covered by a patent No 3606 dated the same year. The apparatus consisted of a cylindrical airtight reservoir of 400 hogsheads (~95,000 litres) fed by a 10 inches (250 mm) water main which branched to all parts of the theatre. A series of smaller pipes feed from the distribution pipe were pierced with a series of $\frac{1}{2}$ inches (13 mm) holes which pour water in the event of a fire.

From 1852 to 1885, perforated pipe systems were used in textile mills throughout New England as a means of fire protection. However, they were not automatic systems; they did not turn on by themselves. Inventors first began experimenting with automatic sprinklers around 1860. The first automatic sprinkler system was patented by Philip W. Pratt of Abington, MA, in 1872.

Henry S. Parmalee of New Haven, Connecticut is considered the inventor of the first automatic sprinkler head. Parmalee improved upon the Pratt patent and created a better sprinkler system. In 1874, he installed his fire sprinkler system into the piano factory that he owned. Frederick Grinnell improved Parmalee's design and in 1881 patented the automatic sprinkler that bears his name. He continued to improve the device and in 1890 invented the glass disc sprinkler, essentially the same as that in use today.

Until the 1940s, sprinklers were installed almost exclusively for the protection of commercial buildings, whose owners were generally able to recoup their expenses with savings in insurance costs. Over the years, fire sprinklers have become mandatory safety equipment in some parts of North America, in certain occupancies, including, but not limited to newly constructed hospitals, schools, hotels and other public buildings, subject to the local building codes and enforcement.

However, outside of the US and Canada, sprinklers are rarely mandated by building codes for normal hazard occupancies which do not have large numbers of occupants (e.g. factories, process lines, retail outlets, petrol stations etc.)

Usage

Sprinklers have been in use in the United States since 1874, and were used in factory applications where fires at the turn of the century were often catastrophic in terms of both human and property losses. In the US, sprinklers are today required in all new high rise and underground buildings generally 75 feet (23 m) above or below fire department access, where the ability of firefighters to provide adequate hose streams to fires is limited.

Sprinklers may be required to be installed by building codes, or may be recommended by insurance companies to reduce potential property losses or business interruption. Building codes in the United States for places of assembly, generally over 100 persons, and places with overnight sleeping accommodation such as hotels, nursing homes, dormitories, and hospitals usually require sprinklers either under local building codes, as a condition of receiving State and Federal funding or as a requirement to obtain certification (essential for institutions who wish to train medical staff)..

Since 2011, Pennsylvania and California require sprinkler systems in all new residential construction - the first US states to do so.

Federal Law (US)

While there is very little specific Federal legislation regarding building codes, which are generally left to local jurisdictions, the Federal government has used its funding and monetary clout to strongly encourage fire safety standards.

In 1990 the US Congress passed PL-101-391, better known as "The Hotel and Motel Safety Act (of 1990)". In short, this law requires that any hotel, meeting hall, or similar institution that receives federal funds (i.e. for a government traveller's overnight stay, or a conference, etc.), must meet fire and other safety requirements. The most visible of these conditions are the implementation of sprinklers.

As more and more hotels, etc., upgraded their facilities to enable acceptance of government visitors, this type of construction became the de facto industry norm - even when not directly mandated by any local building codes.

If building codes do not explicitly mandate the use of fire sprinklers, the code often makes it highly advantageous to install them as an optional system. Most US building codes allow for less expensive construction materials, larger floor area limitations, longer egress paths, and fewer requirements for fire rated construction in structures protected by fire sprinklers. Consequently, the total building cost is often less by installing a sprinkler system and savings money in the other aspects of the project, as compared to building a non-sprinklered structure. In the UK, since the 1990s sprinklers have gained recognition within the Building Regulations (England and Wales) and Scottish Building Standards and under certain circumstances, the presence of sprinkler systems is deemed to provide a form of alternative compliance to some parts of the codes. For example, the presence of a sprinkler system will usually permit doubling of compartment sizes and increases in travel distances (to fire exits) as well as allowing a reduction in the fire rating of internal compartment walls.

Europe

Renewed interest in and support for sprinkler systems in the UK, largely as a result of effective lobbying by the National Fire Sprinkler Network, the European Fire Sprinkler Network and the British Automatic Fire Sprinkler Association, has resulted in sprinkler systems being more widely installed. In schools, for example, the government has issued recommendations through Building Bulletin 100 that most new schools should be constructed with sprinkler protection. In Scotland, all new schools are sprinklered, as are new care homes, sheltered housing and high rise flats. In Norway as of July 2010, all new housing of more than two storeys, all new hotels, care homes and hospitals must be sprinklered. Other Nordic countries require or soon will require sprinklers in new care homes, and in Finland as of 2010 a third of care homes were retrofitted with sprinklers. A fire in an illegal immigrant detention centre at Schiphol airport in The Netherlands on 27 October 2005 killed 11 detainees and led to the retrofitting of sprinklers in all similarly designed prisons in The Netherlands. A fire at Düsseldorf airport on 11 April 1996 which killed 17 people led to sprinklers being retrofitted in all major German airports. Most European countries also require sprinklers in shopping centres, in large warehouses and in high-rise buildings.

Operation

Each closed-head sprinkler is held closed by either a heat-sensitive glass bulb or a two-part metal link held together with fusible alloy. The glass bulb or link applies pressure to a pip cap which acts as a plug which prevents water from flowing until the ambient temperature around the sprinkler reaches the design activation temperature of the individual sprinkler head. In a standard wet-pipe sprinkler system, each sprinkler activates independently when the predetermined heat level is reached. Because of this, the number of sprinklers that operate is limited to only those near the fire, thereby maximizing the available water pressure over the point of fire origin.

A sprinkler activation will do less damage than a fire department hose stream, which provide approximately 900 liters/min (250 US gallons/min). A typical sprinkler used for industrial manufacturing occupancies discharge about 75-150 litres/min (20-40 US gallons/min). However, a typical Early Suppression Fast Response (ESFR) sprinkler at a pressure of 50 psi (340 kPa) will discharge approximately 100 US gallons per minute (0.0063 m^3/s). In addition, a sprinkler will usually activate between one and four minutes, whereas the fire department typically takes at least five minutes to arrive at the fire site after receiving an alarm, and an additional ten minutes to set up equipment and apply hose streams to the fire. This additional time can result in a much larger fire, requiring much more water to achieve extinguishment.

Types

Fire sprinkler control valve assembly.

Wet pipe systems

By a wide margin, wet pipe sprinkler systems are installed more often than all other types of fire sprinkler systems. They also are the most reliable, because they are simple, with the only operating components being the automatic sprinklers and (commonly, but not always) the automatic alarm check valve. An automatic water supply provides water under pressure to the system piping.

Operation - When an automatic sprinkler is exposed for a sufficient time to a temperature at or above the temperature rating, the heat sensitive element (glass bulb or fusible link) releases, allowing water to flow from that sprinkler.

Dry pipe systems

Dry pipe systems are installed in spaces in which the ambient temperature may be cold enough to freeze the water in a wet pipe system, rendering the system inoperable. Dry pipe systems are most often used in unheated buildings, in parking garages, in outside canopies attached to heated buildings (in which a wet pipe system would be provided), or in refrigerated coolers. Dry pipe systems are the second most common sprinkler system type. In regions using NFPA regulations, dry pipe systems cannot be installed unless the range of ambient temperatures reaches below 40F.

Operation - Water is not present in the piping until the system operates. The piping is filled with air below the water supply pressure. To prevent the larger water supply pressure from forcing water into the piping, the design of the dry pipe valve (a specialized type of check valve) results in a greater force on top of the check valve clapper by the use of a larger valve clapper area exposed to the piping air pressure, as compared to the higher water pressure but smaller clapper surface area.

When one or more of the automatic sprinklers is exposed, for a sufficient time, to a temperature at or above the temperature rating, it opens, allowing the air in the piping to vent from that sprinkler. Each sprinkler operates individually. As the air pressure in the piping drops, the pressure differential across the dry pipe valve changes, allowing water to enter the piping system. Water flow from sprinklers, needed to control the fire, is delayed until the air is vented from the sprinklers. For this reason, dry pipe systems are usually not as effective as wet pipe systems in fire control during the initial stages of the fire.

Some view dry pipe sprinklers as advantageous for protection of collections and other water sensitive areas. This perceived benefit is due to a fear that wet system piping may leak, while dry pipe systems will not. However, the same potential for accidental water damage exists, as dry pipe systems will only provide a slight delay prior to water discharge while the air in the piping is released from the pipe.

Disadvantages of using dry pipe fire sprinkler systems include:

- Increased complexity - Dry pipe systems require additional control equipment and air pressure supply components which increases system complexity. This puts a premium on proper maintenance, as this increase in system complexity results in an inherently less reliable overall system (i.e., more single failure points) as compared to a wet pipe system.
- Higher installation and maintenance costs - The added complexity impacts the overall dry-pipe installation cost, and increases maintenance expenditure primarily due to added service labor costs.

- Lower design flexibility - Regulatory requirements limit the maximum permitted size (i.e., 750 gallons) of individual dry-pipe systems, unless additional components and design efforts are provided to limit the time from sprinkler activation to water discharge to under one minute. These limitations may increase the number of individual sprinkler systems (i.e., served from a single riser) that must be provided in the building, and impact the ability of an owner to make system additions.
- Increased fire response time - Because the piping is empty at the time the sprinkler operates, there is an inherent time delay in delivering water to the sprinklers which have operated while the water travels from the riser to the sprinkler, partially filling the piping in the process. A maximum of 60 seconds is normally allowed by regulatory requirements from the time a single sprinkler opens until water is discharged onto the fire. This delay in fire suppression results in a larger fire prior to control, increasing property damage.
- Increased corrosion potential - Following operation or testing, dry-pipe sprinkler system piping is drained, but residual water collects in piping low spots, and moisture is also retained in the atmosphere within the piping. This moisture, coupled with the oxygen available in the compressed air in the piping, increases pipe internal wall corrosion rates, possibly eventually leading to leaks. The internal pipe wall corrosion rate in wet pipe systems (in which the piping is constantly full of water) is much lower, as the amount of oxygen available for the corrosion process is lower.

Deluge systems

"Deluge" systems are systems in which all sprinklers connected to the water piping system are open, in that the heat sensing operating element is removed, or specifically designed as such. These systems are used for special hazards where rapid fire spread is a concern, as they provide a simultaneous application of water over the entire hazard. They are sometimes installed in personnel egress paths or building openings to slow travel of fire (e.g., openings in a fire-rated wall).

Water is not present in the piping until the system operates. Because the sprinkler orifices are open, the piping is at atmospheric pressure. To prevent the water supply pressure from forcing water into the piping, a *deluge valve* is used in the water supply connection, which is a mechanically latched valve. It is a non-resetting valve, and stays open once tripped.

Because the heat sensing elements present in the automatic sprinklers have been removed (resulting in open sprinklers), the deluge valve must be opened as signaled by a fire alarm system. The type of fire alarm initiating device is selected mainly based on the hazard (e.g., smoke detectors, heat detectors, or optical flame detectors). The initiation device signals the fire alarm panel, which in turn signals the deluge valve to open. Activation can also be manual, depending on the system goals. Manual activation is usually via an electric or pneumatic fire alarm pull station, which signals the fire alarm panel, which in turn signals the deluge valve to open.

Operation - Activation of a fire alarm initiating device, or a manual pull station, signals the fire alarm panel, which in turn signals the deluge valve to open, allowing water to enter the piping system. Water flows from all sprinklers simultaneously.

Pre-Action Systems

Pre-action sprinkler systems are specialized for use in locations where accidental activation is undesired, such as in museums with rare art works, manuscripts, or books; and Data Centers, for protection of computer equipment from accidental water discharge.

Pre-action systems are hybrids of wet, dry, and deluge systems, depending on the exact system goal. There are two main sub-types of pre-action systems: single interlock, and double interlock.

The operation of single interlock systems are similar to dry systems except that these systems require that a "preceding" fire detection event, typically the activation of a heat or smoke detector, takes place prior to the "action" of water introduction into the system's piping by opening the pre-action valve, which is a mechanically latched valve (i.e., similar to a deluge valve). In this way, the system is essentially converted from a dry system into a wet system. The intent is to reduce the undesirable time delay of water delivery to sprinklers that is inherent in dry systems. Prior to fire detection, if the sprinkler operates, or the piping system develops a leak, loss of air pressure in the piping will activate a trouble alarm. In this case, the pre-action valve will not open due to loss of supervisory pressure, and water will not enter the piping.

The operation of double interlock systems are similar to deluge systems except that automatic sprinklers are used. These systems require that both a "preceding" fire detection event, typically the activation of a heat or smoke detector, and an automatic sprinkler operation take place prior to the "action" of water introduction into the system's piping. Activation of either the fire detectors alone, or sprinklers alone, without the concurrent operation of the other, will not allow water to enter the piping. Because water does not enter the piping until a sprinkler operates, double interlock systems are considered as dry systems in terms of water delivery times, and similarly require a larger design area.

Foam water sprinkler systems

A foam water fire sprinkler system is a special application system, discharging a mixture of water and low expansion foam concentrate, resulting in a foam spray from the sprinkler. These systems are usually used with special hazards occupancies associated with high challenge fires, such as flammable liquids, and airport hangars. Operation is as described above, depending on the system type into which the foam is injected.

Water spray

"Water spray" systems are operationally identical to a deluge system, but the piping and discharge nozzle spray patterns are designed to protect a uniquely configured hazard, usually being three dimensional components or equipment (i.e., as opposed to a deluge system, which is designed to cover the horizontal floor area of a room). The nozzles used may not be listed fire sprinklers, and are usually selected for a specific spray pattern to conform to the three dimensional nature of the hazard (e.g., typical spray patterns being oval, fan, full circle, narrow jet). Examples of hazards protected by water spray systems are electrical transformers containing oil for cooling or turbgenerator bearings. Water spray systems can also be used externally on the surfaces of tanks containing flammable liquids or gases (such as hydrogen). Here the water spray is intended to cool the tank and its contents to prevent tank rupture/explosion (BLEVE) and fire spread.

Design

Temperature		**Colour of liquid inside bulb**
°C	**°F**	
57	135	Orange
68	155	Red
79	174	Yellow
93	200	Green
141	286	Blue
182	360	Mauve
227 260	440 500	Black

This chart from the New Zealand fire safety standards indicates the colour of the bulb and the respective operating temperature.

Sprinkler systems are intended to either *control* the fire or to *suppress* the fire. *Control mode* sprinklers are intended to control the heat release rate of the fire to prevent building structure collapse, and pre-wet the surrounding combustibles to prevent fire spread. The fire is not extinguished until the burning combustibles are exhausted or manual extinguishment is effected by firefighters. *Suppression mode* sprinklers (formerly known as *Early Suppression Fast Response* (ESFR) sprinklers) are intended to result in a severe sudden reduction of the heat release rate of the fire, followed quickly by complete extinguishment, prior to manual intervention.

Most sprinkler systems installed today are designed using an area and density approach. First the building use and building contents are analyzed to determine the level of fire hazard. Usually buildings are classified as light hazard, ordinary hazard group 1, ordinary hazard group 2, extra hazard group 1, or extra hazard group 2. After determining the hazard classification, a design area and density can be determined by referencing tables in the National Fire Protection Association (NFPA) standards. The design area is a theoretical area of the building representing the worst case area where a fire could burn. The design density is a measurement of how much water per square foot of floor area should be applied to the design area. For example, in an office building classified as light hazard, a typical design area would be 1,500 square feet (140 m^2) and the design density would be 0.1 US gallons per minute (6.3×10^{-6} m^3/s) per 1 square foot (0.093 m^2) or a minimum of 150 US gallons per minute (0.0095 m^3/s) applied over the 1,500-square-foot (140 m^2) design area. Another example would be a manufacturing facility classified as ordinary hazard group 2 where a typical design area would be 1,500 square feet (140 m^2) and the design density would be 0.2 US gallons per minute (1.3×10^{-5} m^3/s) per 1 square foot (0.093 m^2) or a minimum of 300 US gallons per minute (0.019 m^3/s) applied over the 1,500-square-foot (140 m^2) design area.

After the design area and density have been determined, calculations are performed to prove that the system can deliver the required amount of water over the required design area. These calculations account for all of the pressure that is lost or gained between the water supply source and the sprinklers that would operate in the design area. This includes pressure losses due to friction inside the piping and losses or gains due to elevational differences between the source and the discharging sprinklers. Sometimes momentum pressure from water velocity inside the piping is also calculated. Typically these calculations are performed using computer software but before the advent of computer systems these sometimes complicated calculations were performed by hand. This skill of calculating sprinkler systems by hand is still required training for a sprinkler system design technologist who seeks senior level certification from engineering certification organizations such as the National Institute for Certification in Engineering Technologies (NICET).

Sprinkler systems in residential structures are becoming more common as the cost of such systems becomes more practical and the benefits become more obvious. Residential sprinkler systems usually fall under a residential classification separate from the commercial classifications mentioned above. A commercial sprinkler system is designed to protect the structure and the occupants from a fire. Most residential sprinkler systems are primarily designed to suppress a fire in such a way to allow for the safe escape of the building occupants. While these systems will often also protect the structure from major fire damage, this is a secondary consideration. In residential structures sprinklers are often omitted from closets, bathrooms, balconies, garages and attics because a fire in these areas would not usually impact the occupant's escape route.

If water damage or water volume is of particular concern, a technique called *Water Mist Fire Suppression* may be an alternative. This technology has been under development for over 50 years. It hasn't entered general use, but is gaining some acceptance on ships and in a few residential applications. Mist suppression systems work by using the heat of the fire to 'flash' the water mist cloud to steam. This then smothers the fire. As such, mist systems tend to be highly effective where there is likely to be a free-burning hot fire. Where there is insufficient heat (as in a deep seated fire such as will be found in stored paper, no steam will be generated and the mist system will not extinguish the fire. Some tests have shown that the volume of water needed to extinguish a fire with such a system installed can be dramatically less than with a conventional sprinkler system.

Costs

In 2006, the hardware costs of sprinkler systems run from US$2 – $5 per square foot ($50/m²), depending on type and location. However, specialty systems may cost as much as $10/square foot ($100/m²). Systems can be installed during construction or retrofitted. Some communities have laws requiring residential sprinkler systems, where large municipal hydrant water supplies ("fire flows") are not available. Nationwide in the United States, one and two-family homes generally do not require fire sprinkler systems, although the overwhelming loss of life due to fires occurs in these spaces. Residential sprinkler systems are inexpensive (about the same per square foot as carpeting or floor tiling), but require larger water supply piping than is normally installed in homes, so retrofitting is usually cost prohibitive.

According to the National Fire Protection Association (NFPA), fires in hotels with sprinklers averaged 78% less damage than fires in hotels without them (1983–1987). The NFPA says the average loss per fire in buildings with sprinklers was $2,300, compared to an average loss of $10,300 in unsprinklered buildings. The NFPA adds that there is no record of a fatality in a fully sprinklered building outside the point of fire origin. However, in a purely economic comparison, this is not a complete picture; the total costs of fitting, and the costs arising from non-fire triggered release must be factored.

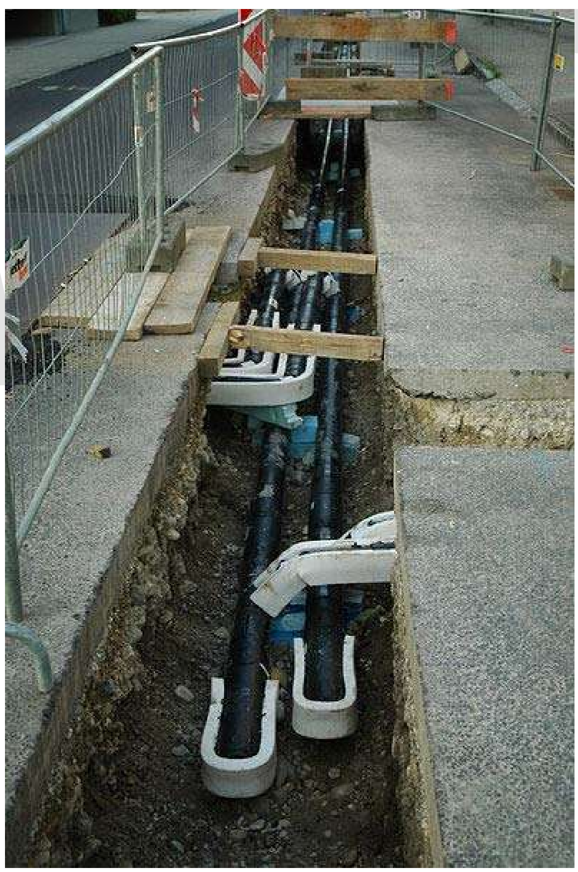
The NFPA states that it "has no record of a fire killing more than two people in a completely sprinklered building where a sprinkler system was properly operating, except in an explosion or flash fire or where industrial fire brigade members or employees were killed during fire suppression operations."

The world's largest fire sprinkler manufacturer is the SimplexGrinnell division of Tyco International, other manufacturers / suppliers include The Viking Corporation, Victaulic, NNI Inc, P.u.P. Feuerschutz und Anlagenbau GmbH and Reliable Sprinkler Company.

Chapter 11

Insulated Pipe and Flange

Insulated pipe



District heating pipline from Lower Austria

Elbow with foam pads of a District heating pipline with an steel tube diameter of 400 mm installed in Lower Austria

Insulated pipes (called also **preinsulated pipes** or **bonded pipe**) are widely used for district heating and hot water supply in Europe. They consist of a steel pipe, an insulating layer, and an outer casing. The main purpose of such pipes is to maintain the temperature of the fluid in the pipes. A common application is the hot water from district heating plants. Most commonly used are single insulated pipes, but more recently in Europe it is becoming popular to use two pipes insulated within the same casing.

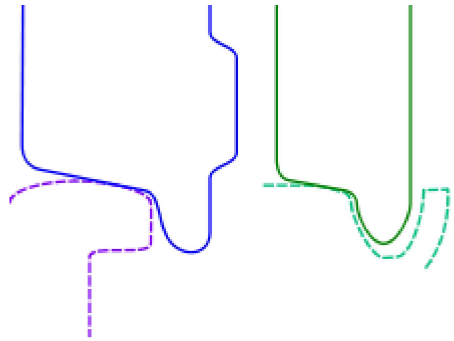
The insulating material usually used is polyurethane foam or similar, with a coefficient of thermal conductivity k=0.033-0.024 W/mK (thermal conductivity). Outer casing is usually high-density polyethylene (HDPE). Production of preinsulated pipes for district heating in the European Union is regulated by the standard EN253. According to EN253:2003, pipes must be produced to work at constant temperature of 130 °C for 30 years, keeping heat conductivity less than or equal to λ=0,033 W/mK. There are three insulation thickness levels.

Insulated pipelines are usually assembled from pipes of 6 m, 12 m, or 16 m in length, laid underground in depth 0.4–1.0 m. Efficient working life of district heating pipelines networks is estimated at 25–30 years, after which they need to be replaced with new pipes.

Four major producers of preinsulated pipes in Europe are located in Denmark and Sweden.

Flange

Flanged railway wheel



Railway wheel flange, left & tram wheel flange, right

A **flange** is an external or internal rib, or rim (lip), for strength, as the flange of an iron beam or I-beam (or a T-beam); or for a flange of a train wheel; or for attachment to another object, as the flange on the end of a pipe, steam cylinder, etc., or on the lens mount of a camera. Thus a flanged rail is a rail with a flange on one side to keep wheels, etc., from running off. The term "flange" is also used for a kind of tool used to form flanges. Pipes with flanges can be assembled and disassembled easily.

Plumbing or piping

Surrey flange

A flange can also be a plate or ring to form a rim at the end of a pipe when fastened to the pipe (for example, a closet flange). A blind flange is a plate for covering or closing the end of a pipe. A flange joint is a connection of pipes, where the connecting pieces have flanges by which the parts are bolted together.

Although the word flange generally refers to the actual raised rim or lip of a fitting, many flanged plumbing fittings are themselves known as 'flanges':

Common flanges used in plumbing are the Surrey flange or Danzey flange, York flange, Sussex flange and Essex flange. Surrey and York flanges fit to the top of the hot water tank allowing all the water to be taken without disturbance to the tank. They are often used to ensure an even flow of water to showers. An Essex flange requires a hole to be drilled in the side of the tank.

There is also a Warix flange which is the same as a York flange but the shower output is on the top of the flange and the vent on the side. The York and Warix flange have female adapters so that they fit onto a male tank, whereas the Surrey flange connects to a female tank.

A closet flange provides the mount for a toilet.

Pipe flanges

There are many different flange standards to be found worldwide. To allow easy functionality and inter-changeability, these are designed to have standardised dimensions. Common world standards include ASA/ANSI (USA), PN/DIN (European), BS10 (British/Australian), and JIS/KS (Japanese/Korean).

In most cases these are not interchangeable (e.g. an ANSI flange will not mate against a JIS flange). Further, many of the flanges in each standard are divided into "pressure classes", allowing flanges to be capable of taking different pressure ratings. Again these are not generally interchangeable (e.g. an ANSI 150 will not mate with an ANSI 300). These pressure classes also have differing pressure and temperature ratings for different materials. Unique pressure classes for piping can also be developed for a process plant or power generating station; these may be specific to the corporation, engineering procurement and construction (EPC) contractor, or the process plant owner.

The flange faces are also made to standardized dimensions and are typically "flat face", "raised face", "tongue and groove", or "ring joint" styles, although other obscure styles are possible.

Flange designs are available as "welding neck", "slip-on", "boss", "lap joint", "socket weld", "threaded", and also "blind".

ASME standards (U.S.)

ASME type flange on a gas pipeline

Pipe flanges that are made to standards called out by ASME B16.5 or ASME B16.47 are typically made from forged materials and have machined surfaces. B16.5 refers to nominal pipe sizes (NPS) from ½" to 24". B16.47 covers NPSs from 26" to 60". Each specification further delineates flanges into pressure classes: 150, 300, 400, 600, 900, 1500 and 2500 for B16.5; B16.47 delineates its flanges into pressure classes 75, 150, 300, 400, 600, 900.

The gasket type and bolt type are generally specified by the standard(s); however, sometimes the standards refer to the ASME Boiler and Pressure Vessel Code (B&PVC) for details. These flanges are recognized by ASME Pipe Codes such as ASME B31.1 Power Piping, and ASME B31.3 Process Piping.

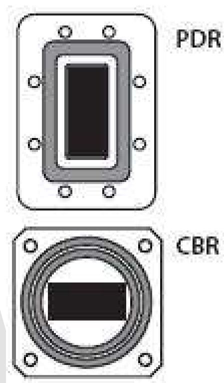
Materials for flanges are usually under ASME designation: SA-105 (Specification for Carbon Steel Forgings for Piping Applications), SA-266 (Specification for Carbon Steel Forgings for Pressure Vessel Components), or SA-182 (Specification for Forged or Rolled Alloy-Steel Pipe Flanges, Forged Fittings, and Valves and Parts for High-Temperature Service). In addition, there are many "industry standard" flanges that in some circumstance may be used on ASME work.

Other countries

Flanges in other countries also are manufactured according to the standards for materials, pressure ratings, etc. Such standards include DIN, BS, and/or ISO standards.

Vacuum flanges

A vacuum flange is a flange at the end of a tube used to connect vacuum chambers, tubing and vacuum pumps to each other.



Form factor of PDR and CBR flanges.

Microwave RF

In microwave telecommunications, a flange is a type of cable joint which allows different types of waveguide to connect.

Several different microwave RF flange types exist, such as CAR, CBR, OPC, PAR, PBJ, PBR, PDR, UAR, UBR, UDR, icp and UPX.

Chapter 12

Pipe (Fluid Conveyance)

Steel pipes

Plastic (PVC) pipes in USA

A **pipe** is a tubular section or hollow cylinder, usually but not necessarily of circular cross-section, used mainly to convey substances which can flow — liquids and gases (fluids), slurries, powders, masses of small solids. It can also be used for structural applications; hollow pipe is far stronger per unit weight than solid members.

In common usage the words *pipe* and *tube* are usually interchangeable, but in industry and engineering, the terms are uniquely defined. Depending on the applicable standard to which it is manufactured, pipe is generally specified by a nominal diameter with a constant outside diameter (OD) and a schedule that defines the thickness. Tube is most often specified by the OD and wall thickness, but may be specified by any two of OD, inside diameter (ID), and wall thickness. Pipe is generally manufactured to one of several international and national industrial standards. While similar standards exist for specific industry application tubing, tube is often made to custom sizes and a broader range of diameters and tolerances. Many industrial and government standards exist for the production of pipe and tubing. The term "tube" is also commonly applied to non-cylindrical sections, i.e., square or rectangular tubing. In general, "pipe" is the more common term in most of the world, whereas "tube" is more widely used in the United States.

Both "pipe" and "tube" imply a level of rigidity and permanence, whereas a *hose* (or hosepipe) is usually portable and flexible. Pipe assemblies are almost always constructed with the use of fittings such as elbows, tees, and so on, while tube may be formed or bent into custom configurations. For materials that are inflexible, cannot be formed or where construction is governed by codes or standards, tube assemblies are also constructed with the use of tube fittings.

Uses

A **pipe** implantation, inside an avenue of Belo Horizonte, Brazil.

- Domestic water systems
- Pipelines transporting gas or liquid over long distances

- Scaffolding
- Structural steel
- As components in mechanical systems such as:
    - Rollers in conveyor belts
    - Compactors (E.g.: steam rollers)
    - Bearing casing
- Casing for concrete pilings used in construction projects
- High temperature or pressure manufacturing processes
- The petroleum industry:
    - Oil well casing
    - Oil refinery equipment
- Delivery of fluids, either gaseous or liquid, in a process plant from one point to another point in the process
- Delivery of bulk solids, in a food or process plant from one point to another point in the process
- The construction of high pressure storage vessels (note that large pressure vessels are constructed from plate, not pipe owing to their wall thickness and size).

Manufacture

There are three processes for metallic pipe manufacture. Centrifugal casting of hot alloyed metal is one of the most prominent process. **Ductile iron** pipes are generally manufactured in such a fashion. **Seamless** (SMLS) pipe is formed by drawing a solid billet over a piercing rod to create the hollow shell. Seamless pipe withstands pressure better than other types, and is often more easily available than welded pipe. **Welded** (also Electric Resistance Welded ("ERW"), and Electric Fusion Welded ("EFW")) pipe is formed by rolling plate and welding the seam. The weld flash can be removed from the outside or inside surfaces using a scarfing blade. The weld zone can also be heat treated to make the seam less visible. Welded pipe often has tighter dimensional tolerances than seamless, and can be cheaper if manufactured in the same quantities. Large-diameter pipe (25 centimetres (10 in) or greater) may be ERW, EFW or Submerged Arc Welded ("SAW") pipe.

Tubing, either metal or plastic, is generally extruded.

Materials

Historic water mains from Philadelphia included wooden pipes

Pipe are made in many materials including ceramic, fiberglass, many metals, concrete and plastic. In the past wood and lead (Latin *plumbum*, from which we get the word plumbing) were commonly used.

Metallic pipes are commonly made from steel or iron; the finish and metal chemistry are peculiar to the use, fit and form. Typically metallic piping is made of steel or iron, such as unfinished, black (lacquer) steel, carbon steel, stainless steel or galvanized steel, brass, and ductile iron. Aluminum pipe or tubing may be utilized where iron is incompatible with the service fluid or where weight is a concern; aluminum is also used for heat transfer tubing such as in refrigerant systems. Copper tubing is popular for domestic water (potable) plumbing systems; copper may be used where heat transfer is desirable (i.e. radiators or heat exchangers). Inconel, chrome moly, and titanium steel alloys are used in high temperature and pressure piping in process and power facilities. When specifying alloys for new processes, the known issues of creep and sensitization effect must be taken into account.

Lead piping is still found in old domestic and other water distribution systems, but it is no longer permitted for new potable water piping installations due to its toxicity. Many building codes now require that lead piping in residential or institutional installations be replaced with non-toxic piping or that the tubes' interiors be treated with phosphoric acid. According to a senior researcher and lead expert with the Canadian Environmental Law Association, "...there is no safe level of lead [for human exposure]".

Plastic tubing is widely used for its light weight, chemical resistance, non-corrosive properties, and ease of making connections. Plastic materials include polyvinyl chloride (PVC) , chlorinated polyvinyl chloride (CPVC), fibre reinforced plastic (FRP), reinforced polymer mortar (RPMP), polypropylene (PP), polyethylene (PE), cross-linked high-density polyethylene (PEX), polybutylene (PB), and acrylonitrile butadiene styrene (ABS), for example. In many countries, PVC pipes account for most pipe materials used in buried municipal applications for drinking water distribution and wastewater mains.

Pipe may be made from concrete or ceramic, usually for low-pressure applications such as gravity flow or drainage.

Reinforced concrete can be used for large-diameter concrete pipes. This pipe material can be used in many types of construction, and is often used in the gravity-flow transport of storm water. Usually such pipe will have a receiving bell or a stepped fitting, with various sealing methods applied at installation.

Sizes

Pipe sizes can be confusing because the terminology may relate to historical dimensions. For example, a half-inch iron pipe does not have any dimension that is a half inch. Initially, a half inch pipe did have an inner diameter of 0.5 inches (13 mm)—but it also had thick walls. As technology improved, thinner walls became possible, but the outside diameter stayed the same so it could mate with existing older pipe, increasing the inner diameter beyond half an inch. The history of copper pipe is similar. In the 1930s, the pipe was designated by its internal diameter and a $^1/_{16}$-inch (1.6 mm) wall thickness. Consequently, a 1-inch (25 mm) copper pipe had a $1^1/_8$-inch (28.58 mm) outside diameter. The outside diameter was the important dimension for mating with fittings. The wall thickness on modern copper is usually thinner than $^1/_{16}$ inches (1.6 mm), so the internal diameter is only "nominal" rather than a controlling dimension. Newer pipe technologies sometimes adopted a sizing system as its own. PVC pipe uses the Nominal Pipe Size.

Pipe sizes are specified by a number of national and international standards, including API 5L, ANSI/ASME B36.10M and B36.19M in the US, BS 1600 and BS EN 10255 in the United Kingdom and Europe.

There are two common methods for designating pipe outside diameter (OD). The North American method is called NPS ("Nominal Pipe Size") and is based on inches (also frequently referred to as NB ("Nominal Bore")). The European version is called DN ("Diametre Nominal" / "Nominal Diameter") and is based on millimetres. Designating the outside diameter allows pipes of the same size to be fit together no matter what the wall thickness.

- **For pipe sizes less than NPS 14 inch (DN 350),** both methods give a nominal value for the OD that is rounded off and is not the same as the actual OD. For example, NPS 2 inch and DN 50 are the same pipe, but the actual OD is 2.375 inches or 60.33 mm. The only way to obtain the actual OD is to look it up in a reference table.

- **For pipe sizes of NPS 14 inch (DN 350) and greater** the NPS size is the actual diameter in inches and the DN size is equal to NPS times 25 (not 25.4) rounded to a convenient multiple of 50. For example, NPS 14 has an OD of 14 inches or 355.60 mm, and is equivalent to DN 350.

Since the outside diameter is fixed for a given pipe size, the inside diameter will vary depending on the wall thickness of the pipe. For example, 2" Schedule 80 pipe has thicker walls and therefore a smaller inside diameter than 2" Schedule 40 pipe.

Steel pipe has been produced for about 150 years. The pipe sizes that are in use today in PVC and galvanized were originally designed years ago for steel pipe. The number system, like Sch 40, 80, 160, were set long ago and seem a little odd. For example, Sch 20 pipe is even thinner than Sch 40, but same OD. And while these pipes are based on old steel pipe sizes, there is other pipe, like gold-flow cpvc for heated water, that uses pipe sizes, inside and out, based on old copper pipe size standards instead of steel.

Many different standards exist for pipe sizes, and their prevalence varies depending on industry and geographical area. The pipe size designation generally includes two numbers; one that indicates the outside (OD) or nominal diameter, and the other that indicates the wall thickness. In the early twentieth century, American pipe was sized by inside diameter. This practice was abandoned to improve compatibility with pipe fittings that must usually fit the OD of the pipe, but it has had a lasting impact on modern standards around the world.

In North America and the UK, pressure piping is usually specified by Nominal Pipe Size (NPS) and schedule (SCH). Pipe sizes are documented by a number of standards, including API 5L, ANSI/ASME B36.10M (Table 1) in the US, and BS 1600 and BS 1387 in the United Kingdom. Typically the pipe wall thickness is the controlled variable, and the Inside Diameter (I.D.) is allowed to vary. The pipe wall thickness has a variance of approximately 12.5 percent.

In the rest of Europe pressure piping uses the same pipe IDs and wall thicknesses as Nominal Pipe Size, but labels them with a metric Diameter Nominal (DN) instead of the imperial NPS. For NPS larger than 14, the DN is equal to the NPS multiplied by 25. (Not 25.4) This is documented by EN 10255 (formerly DIN 2448 and BS 1387) and ISO 65, and it is often called DIN or ISO pipe.

Japan has its own set of standard pipe sizes, often called JIS pipe.

The Iron pipe size (IPS) is an older system still used by some manufacturers and legacy drawings and equipment. The IPS number is the same as the NPS number, but the schedules were limited to Standard Wall (STD), Extra Strong (XS), and Double Extra Strong (XXS). STD is identical to SCH 40 for NPS 1/8 to NPS 10, inclusive, and indicates .375" wall thickness for NPS 12 and larger. XS is identical to SCH 80 for NPS 1/8 to NPS 8, inclusive, and indicates .500" wall thickness for NPS 8 and larger. Different definitions exist for XXS, however it is never the same as SCH 160. XXS is in fact thicker than SCH 160 for NPS 1/8" to 6" inclusive, whereas SCH 160 is thicker than XXS for NPS 8" and larger.

Another old system is the Ductile Iron Pipe Size (DIPS), which generally has larger ODs than IPS.

Copper **plumbing tube** for residential plumbing follows an entirely different size system in America, often called Copper Tube Size (CTS). Its nominal size is neither the inside nor outside diameter. Plastic tubing, such as PVC and CPVC, for plumbing applications also has different sizing standards.

Agricultural applications use PIP sizes, which stands for Plastic Irrigation Pipe. PIP comes in pressure ratings of 22 psi (150 kPa), 50 psi (340 kPa), 80 psi (550 kPa), 100 psi (690 kPa), and 125 psi (860 kPa) and is generally available in diameters of 6", 8", 10", 12", 15", 18", 21", and 24".

Standards

The manufacture and installation of **pressure piping** is tightly regulated by the ASME "B31" code series such as B31.1 or B31.3 which have their basis in the ASME Boiler and Pressure Vessel Code. This code has the force of law in Canada and the USA. Europe and the rest of the world has an equivalent system of codes. Pressure piping is generally pipe that must carry pressures greater than 10 to 25 atmospheres, although definitions vary. To ensure safe operation of the system, the manufacture, storage, welding, testing, etc. of pressure piping must meet stringent quality standards.

Manufacturing standards for pipes commonly require a test of chemical composition and a series of mechanical strength tests for each heat of pipe. A **heat** of pipe is all forged from the same cast ingot, and therefore had the same chemical composition. Mechanical tests may be associated to a **lot** of pipe, which would be all from the same heat and have been through the same heat treatment processes. The manufacturer performs these tests and reports the composition in a **mill traceability report** and the mechanical tests in a **material test report**, both of which are referred to by the acronym MTR. Material with these associated test reports is called **traceable**. For critical applications, third party verification of these tests may be required; in this case an independent lab will produce a **certified material test report**(CMTR), and the material will be called **certified**.

Some widely used pipe standards are:

- The API range - now ISO 3186. E.g.: API 5L Grade B - now ISO L245 where the number indicates yield strength in MPa
- ASME SA106 Grade B (Seamless carbon steel pipe for high temperature service)
- ASTM A312 (Seamless and welded austenitic stainless steel pipe)
- ASTM C76 (Concrete Pipe)
- ASTM D3033/3034 (PVC Pipe)
- ASTM D2239 (Polyethylene Pipe)

API 5L was changed in the second half of 2008 to edition 44 from edition 43 to make it identical to ISO 3186. It is important to note that the change has created the requirement that sour service, ERW pipe, pass a hydrogen induced cracking (HIC) test per NACE TM0284 in order to be used for sour service.

- ACPA [American Concrete Pipe Association]
- AWWA [American Water Works Association]
- AWWA M45

Traceability and Positive Material Identification (PMI)

Maintaining the traceability between the material and this paperwork is an important quality assurance issue. QA often requires the heat number to be written on the pipe. Precautions must also be taken to prevent the introduction of counterfeit materials. As a backup to etching/labeling of the material identification on the pipe, Positive Material Identification (PMI) is performed using a handheld device; the device scans the pipe material using an emitted electromagnetic wave (x-ray fluorescence/XRF) and receives a reply that is spectrographically analyzed.

Installation

Pipe installation is often more expensive than the material and a variety of specialized tools, techniques, and parts have been developed to assist this. Pipe is usually delivered to a customer or jobsite as either "sticks" or lengths of pipe (typically 20 feet) or they are prefabricated with elbows, tees and valves into a prefabricated pipe spool [A pipe spool is a piece of pre-assembled pipe and fittings, usually prepared in a shop so that installation on the construction site can be more efficient.]. They are usually tagged with a bar code and the ends are capped for protection. The Pipe and Pipe Spools are delivered to a warehouse on a large commercial job and they may be held indoors or in a gridded laydown yard. The Pipe or pipe spool is retrieved, staged, rigged, and then lifted into place. On large process jobs the lift is made using cranes and hoist and other material lifts. They are typically temporarily supported in the steel structure using beam clamps, straps, and small hoists until the Pipe Supports are attached or otherwise secured.

An example of a tool used for installation for a small plumbing pipe (threaded ends) is the pipe wrench. Small pipe is typically not heavy and can be lifted into place by the installation craft laborer.

Joining

Pipes are commonly joined by welding, using threaded pipe and fittings; sealing the connection with a pipe thread compound, Polytetrafluoroethylene (PTFE) Thread seal tape, oakum, or PTFE string, or by using a mechanical coupling. Process piping is usually joined by welding using a TIG or MIG process. The most common process pipe joint is the butt weld. The ends of pipe to be welded must have a certain weld preparation called an End Weld Prep (EWP) which is typically at an angle of 37.5 degrees to accommodate the filler weld metal. The most common pipe thread in North America is the National Pipe Thread (NPT) or the Dryseal (NPTF) version. Other pipe threads include the British standard pipe thread (BSPT), the garden hose thread (GHT), and the fire hose coupling (NST).

Copper pipes are typically joined by soldering, brazing, compression fittings, flaring, or crimping. Plastic pipes may be joined by solvent welding, heat fusion, or elastomeric sealing.

If frequent disconnection will be required, gasketed pipe flanges or union fittings provide better reliability than threads. Some thin-walled pipes of ductile material, such as the smaller copper or flexible plastic water pipes found in homes for ice makers and humidifiers, for example, may be joined with compression fittings.

Underground pipe typically uses a "push-on" gasket style of pipe that compresses a gasket into a space formed between the two adjoining pieces. Push-on joints are available on most types of pipe. A pipe joint lubricant must be used in the assembly of the pipe. Under buried conditions, gasket-joint pipes allow for lateral movement due to soil shifting as well as expansion/contraction due to temperature differentials. Plastic MDPE and HDPE gas and water pipes are also often joined with Electrofusion fittings.

Large above ground pipe typically uses a flanged joint, which is generally available in ductile iron pipe and some others. It is a gasket style where the flanges of the adjoining pipes are bolted together, compressing the gasket into a space between the pipe.

Mechanical grooved couplings or Victaulic joints are also frequently used for frequent disassembly & assembly. Developed in the 1920s, these mechanical grooved couplings can operate up to 1,200psi working pressures and available in materials to match the pipe grade. Another type of mechanical coupling is a Swagelok brand fitting; this type of compression fitting is typically used on small tubing under 3/4 inch in diameter.

Fittings and valves

Copper Pipe Pieces

Fittings are also used to split or join a number of pipes together, and for other purposes. A broad variety of standardized pipe fittings are available; they are generally broken down into either a tee, an elbow, a branch, a reducer/enlarger, or a wye. Valves control fluid flow and regulate pressure. The piping and plumbing fittings and valves articles discuss them further.

Pipe Support

Pipes are either supported from below or hung from above. These devices are called pipe supports. Supports may be as simple as a pipe "shoe" which is akin to a half of an I-beam welded to the bottom of the pipe; they may be "hung" using a clevis or trapeze type of devices called pipe hangers. Pipe Supports of any kind may incorporate springs, snubbers and/or dampers to compensate for thermal expansion, or to provide vibration isolation, shock control, or vibration excitation of the pipe due to earthquake motion. Some dampers are simply fluid dashpots whereas other dampers may be active hydraulic devices that have sophisticated systems that act to dampen peak displacements due to forcing functions. The forcing functions may be process derived (such as in a fluidized bed reactor) or from a natural phenomenon such as an earthquake (design basis event or DBE).

Cleaning

The inside of pipes can be cleaned with the tube cleaning process, if they are contaminated with debris or fouling. This depends on the process that the pipe will be used for and the cleanliness needed for the process. In some cases the pipes are cleaned using a displacement device formally known as a Pipeline Inspection Gauge or "pig"; alternately the pipes or tubes may be chemically flushed using specialized solutions that are pumped through. In some cases, where care has been taken in the manufacture, storage, and installation of pipe and tubing, the lines are blown clean with compressed air or nitrogen.

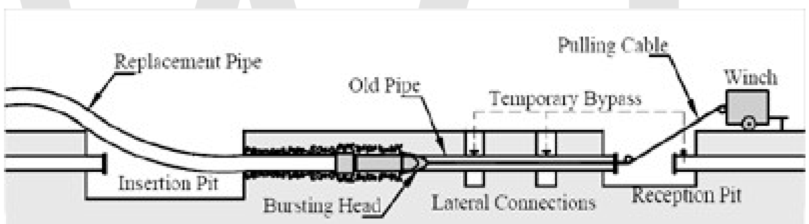
Other uses

Pipe is widely used in the fabrication of handrails, guardrails and railings.

Chapter 13

Pipe Bursting and Pipe Network Analysis

Pipe bursting



Pipe replacement by pipe bursting

Pipe bursting is a trenchless method of replacing buried pipelines (such as sewer, water, or natural gas pipes) without the need for a traditional construction trench. "Launching and receiving pits" replace the trench needed by conventional pipe-laying.

Methodology

An expanding device called an expander head, which may be either pneumatic or hydraulic, is introduced into the defective pipeline through a launching pit. As it travels through the pipeline toward the receiving pit it breaks the pipe into many small pieces, pushing the pieces into the surrounding soil. New pipe is attached to the back of the expander head, replacing the line immediately.

Equipment

There are five key pieces of equipment used in a pipebursting operation: the expander head, pulling rods, a pulling machine, a retaining device, and a hydraulic power pack.

Today's expander heads have a leading end much smaller in diameter than the trailing (bursting) end, small enough to fit through the pipe that will be replaced. The smaller leading end is designed to guide the expander head through the existing pipe; earlier models did not have this feature and lost course at times, resulting in incomplete pipe bursts and project failures.

The transition from the leading end to the trailing end can include "fins" that make first contact with the existing pipe. Using these fins as the primary breaking point is a very effective way to ensure that the pipe is broken along the entire circumference.

A machine is set in the receiving pit to pull the expander head and new pipe into the line. The head is pulled by heavy, interlocking links that form a chain. Each link weighs several hundred pounds.

All of the equipment used in a pipebursting operation is powered by one or multiple hydraulic power generators.

Other applications

Pipebursting may also be used to expand pipeline carrying capacity by replacing smaller pipes with larger ones, or "upsizing." Extensive proving work by the gas and water industries has demonstrated the feasibility of upsizing gas mains, water mains and sewers. Upsizing from 100mm to 225mm diameter is now well established, and pipes of up to 900mm diameter and greater have been replaced.

Pipe network analysis

In fluid dynamics, **pipe network analysis** is the analysis of the fluid flow through a hydraulics network, containing several or many interconnected branches. The aim is to determine the flow rates and pressure drops in the individual sections of the network. This is a common problem in hydraulic design.

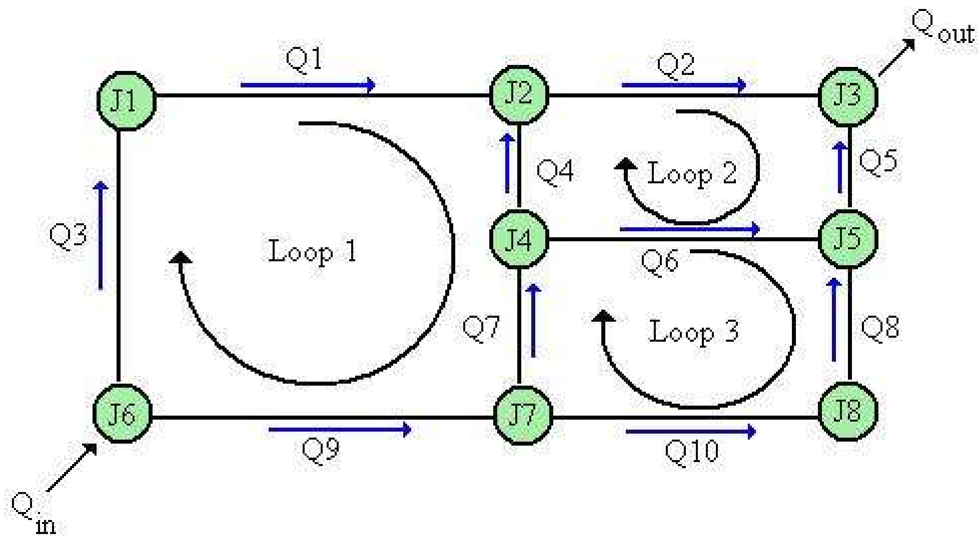
Description

In order to direct water to many individuals in a municipal water supply, many times the water is routed through a water supply network. A major part of this network may consist of interconnected pipes. This network creates a special class of problems in hydraulic design typically referred to as pipe network analysis. The modern solution for this is to use specialized software in order to automatically solve the problems. However, the problems can also be addressed with simpler methods like a spreadsheet equipped with a solver, or a modern graphing calculator.

Network analysis

Once the friction factors are solved for, then we can start considering the network problem. We can solve the network by satisfying two conditions.

1. At any junction, the flow into a junction equals the flow out of the junction.
2. Between any two junctions, the head loss is independent of the path taken.



The classical approach for solving these networks is to use the Hardy Cross algorithm. In this formulation, first you go through and create guess values for the flows in the network. That is, if Q7 enters a junction and Q6 and Q4 leave the same junction, then the initial guess must satisfy Q7 = Q6 + Q4. After the initial guess is made, then, a loop is considered so that we can evaluate our second condition. Given a starting node, we work our way around the loop in a clockwise fashion, as illustrated by Loop 1. We add up the head losses according to the Darcy–Weisbach equation for each pipe if Q is in the same direction as our loop like Q1, and subtract the head loss if the flow is in the reverse direction, like Q4. In order to satisfy the second condition, we should end up with 0 about the loop if the network is completely solved. If the actual sum of our head loss is not equal to 0, then we will adjust all the flows in the loop by an amount given by the following formula, where a positive adjustment is in the clockwise direction.

$$\Delta Q = \frac{\sum \text{head loss}_c - \sum \text{head loss}_{cc}}{n \cdot \left(\sum \frac{\text{head loss}_c}{Q_c} + \sum \frac{\text{head loss}_{cc}}{Q_{cc}}\right)},$$

where

- n is 1.85 for Hazen-Williams and
- n is 2 for Darcy–Weisbach.

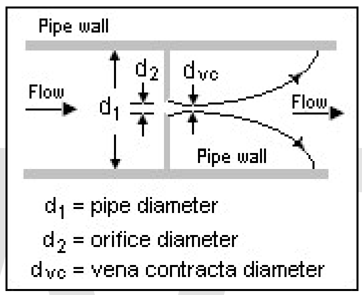
The clockwise specifier (c) means only the flows that are moving clockwise in our loop, while the counter-clockwise specifier (cc) is only the flows that are moving counter-clockwise.

This adjustment won't solve the problem, since with most networks we will have several loops. It is ok to do this adjustment, however, because our flow changes won't alter condition 1, and therefore, our other loops will still satisfy condition 1. However, we should use the results from the first loop if we progress to any other loops.

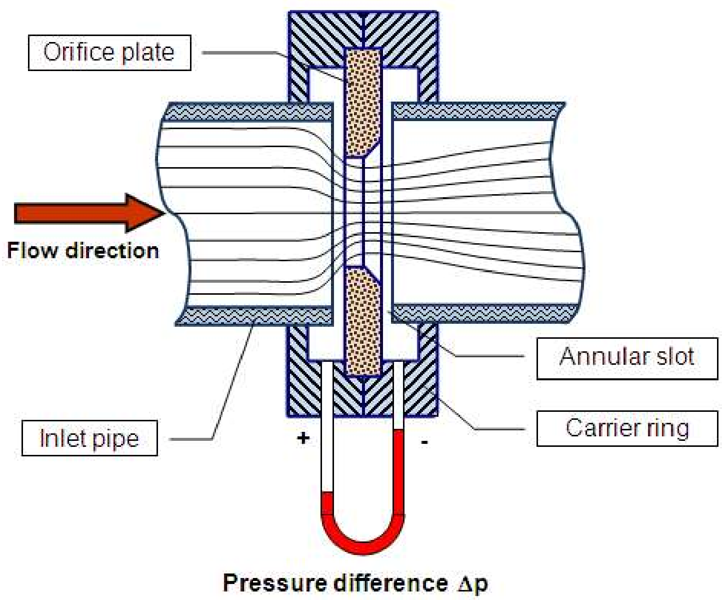
The more modern method is simply to create a set of conditions from your junctions and head-loss criteria. Then, use a Root-finding algorithm to find Q values that satisfy all the equations. The literal friction loss equations will use a term called Q^2, but we want to preserve any changes in direction. Create a separate equation for each loop where the head losses are added up, but instead of squaring Q, use $|Q|\cdot Q$ instead (with $|Q|$ the absolute value of Q) for the formulation so that any sign changes will reflect appropriately in the resulting head-loss calculation.

Chapter 14

Orifice Plate



Flat-plate, sharp-edge orifice



ISO 5167 Orifice Plate

An **orifice plate** is a device used for measuring the rate of fluid flow. It uses the same principle as a Venturi nozzle, namely Bernoulli's principle which states that there is a relationship between the pressure of the fluid and the velocity of the fluid. When the velocity increases, the pressure decreases and vice versa.

Description

An orifice plate is a thin plate with a hole in the middle. It is usually placed in a pipe in which fluid flows. When the fluid reaches the orifice plate, with the hole in the middle, the fluid is forced to converge to go through the small hole; the point of maximum convergence actually occurs shortly downstream of the physical orifice, at the so-called vena contracta point. As it does so, the velocity and the pressure changes. Beyond the vena contracta, the fluid expands and the velocity and pressure change once again. By measuring the difference in fluid pressure between the normal pipe section and at the vena contracta, the volumetric and mass flow rates can be obtained from Bernoulli's equation.

Uses

Orifice plates are most commonly used for continuous measurement of fluid flow in pipes. They are also used in some small river systems to measure flow rates at locations where the river passes through a culvert or drain. Only a small number of rivers are appropriate for the use of the technology since the plate must remain completely immersed i.e the approach pipe must be full, and the river must be substantially free of debris.

In the natural environment large orifice plates are used to control onward flow in flood relief dams. in these structures a low dam is placed across a river and in normal operation the water flows through the orifice plate unimpeded as the orifice is substantially larger than the normal flow cross section. However, in floods, the flow rate rises and floods out the orifice plate which can then only pass a flow determined by the physical dimensions of the orifice. Flow is then held back behind the low dam in a temporary reservoir which is slowly discharged through the orifice when the flood subsides.

Incompressible flow through an orifice

By assuming steady-state, incompressible (constant fluid density), inviscid, laminar flow in a horizontal pipe (no change in elevation) with negligible frictional losses, Bernoulli's equation reduces to an equation relating the conservation of energy between two points on the same streamline:

$$P_1 + \frac{1}{2} \cdot \rho \cdot V_1^2 = P_2 + \frac{1}{2} \cdot \rho \cdot V_2^2$$

or:

$$P_1 - P_2 = \frac{1}{2} \cdot \rho \cdot V_2^2 - \frac{1}{2} \cdot \rho \cdot V_1^2$$

By continuity equation:

$Q = A_1 \cdot V_1 = A_2 \cdot V_2$ or $V_1 = Q / A_1$ and $V_2 = Q / A_2$:

$$P_1 - P_2 = \frac{1}{2} \cdot \rho \cdot \left(\frac{Q}{A_2}\right)^2 - \frac{1}{2} \cdot \rho \cdot \left(\frac{Q}{A_1}\right)^2$$

Solving for Q:

$$Q = A_2 \sqrt{\frac{2\,(P_1 - P_2)/\rho}{1 - (A_2/A_1)^2}}$$

and:

$$Q = A_2 \sqrt{\frac{1}{1 - (d_2/d_1)^4}}\,\sqrt{2\,(P_1 - P_2)/\rho}$$

The above expression for Q gives the theoretical volume flow rate. Introducing the beta factor $\beta = d_2 / d_1$ as well as the coefficient of discharge C_d:

$$Q = C_d\,A_2 \sqrt{\frac{1}{1 - \beta^4}}\,\sqrt{2\,(P_1 - P_2)/\rho}$$

And finally introducing the meter coefficient C which is defined as $C = \frac{C_d}{\sqrt{1 - \beta^4}}$ to obtain the final equation for the volumetric flow of the fluid through the orifice:

$$(1) \qquad Q = C\,A_2\,\sqrt{2\,(P_1 - P_2)/\rho}$$

Multiplying by the density of the fluid to obtain the equation for the mass flow rate at any section in the pipe:

$$(2) \qquad \dot{m} = \rho\,Q = C\,A_2\,\sqrt{2\,\rho\,(P_1 - P_2)}$$

where:

Q = volumetric flow rate (at any cross-section), m³/s

$\dot{m}$ = mass flow rate (at any cross-section), kg/s

C_d = coefficient of discharge, dimensionless

C = orifice flow coefficient, dimensionless

A_1 = cross-sectional area of the pipe, m²

A_2 = cross-sectional area of the orifice hole, m²

d_1 = diameter of the pipe, m

d_2 = diameter of the orifice hole, m

β = ratio of orifice hole diameter to pipe diameter, dimensionless

V_1 = upstream fluid velocity, m/s

V_2 = fluid velocity through the orifice hole, m/s

P_1 = fluid upstream pressure, Pa   with dimensions of $kg/(m \cdot s^2)$

P_2 = fluid downstream pressure, Pa   with dimensions of $kg/(m \cdot s^2)$

ρ = fluid density, kg/m³

Deriving the above equations used the cross-section of the orifice opening and is not as realistic as using the minimum cross-section at the vena contracta. In addition, frictional losses may not be negligible and viscosity and turbulence effects may be present. For that reason, the coefficient of discharge C_d is introduced. Methods exist for determining the coefficient of discharge as a function of the Reynolds number.

The parameter $\sqrt{1-\beta^4}$ is often referred to as the *velocity of approach factor* and dividing the coefficient of discharge by that parameter (as was done above) produces the flow coefficient C. Methods also exist for determining the flow coefficient as a function of the beta function β and the location of the downstream pressure sensing tap. For rough approximations, the flow coefficient may be assumed to be between 0.60 and 0.75. For a first approximation, a flow coefficient of 0.62 can be used as this approximates to fully developed flow.

An orifice only works well when supplied with a fully developed flow profile. This is achieved by a long upstream length (20 to 40 pipe diameters, depending on Reynolds number) or the use of a flow conditioner. Orifice plates are small and inexpensive but do not recover the pressure drop as well as a venturi nozzle does. If space permits, a venturi meter is more efficient than a flowmeter.

Flow of gases through an orifice

In general, equation (2) is applicable only for incompressible flows. It can be modified by introducing the expansion factor Y to account for the compressibility of gases.

$$(3) \qquad \dot{m} = \rho_1 Q = C\, Y\, A_2 \sqrt{2\, \rho_1\, (P_1 - P_2)}$$

Y is 1.0 for incompressible fluids and it can be calculated for compressible gases.

Calculation of expansion factor

The expansion factor Y, which allows for the change in the density of an ideal gas as it expands isentropically, is given by:

$$Y = \sqrt{r^{2/k}\left(\frac{k}{k-1}\right)\left(\frac{1-r^{(k-1)/k}}{1-r}\right)\left(\frac{1-\beta^4}{1-\beta^4\, r^{2/k}}\right)}$$

For values of β less than 0.25, β^4 approaches 0 and the last bracketed term in the above equation approaches 1. Thus, for the large majority of orifice plate installations:

$$(4) \qquad Y = \sqrt{r^{2/k}\left(\frac{k}{k-1}\right)\left(\frac{1-r^{(k-1)/k}}{1-r}\right)}$$

where:

- $\boldsymbol{Y}$ = Expansion factor, dimensionless
- $\boldsymbol{r}$ = P_2 / P_1
- $\boldsymbol{k}$ = specific heat ratio (c_p / c_v), dimensionless

Substituting equation (4) into the mass flow rate equation (3):

$$\dot{m} = C\, A_2 \sqrt{2\, \rho_1 \left(\frac{k}{k-1}\right)\left[\frac{(P_2/P_1)^{2/k} - (P_2/P_1)^{(k+1)/k}}{1 - P_2/P_1}\right](P_1 - P_2)}$$

and:

$$\dot{m} = C\, A_2 \sqrt{2\, \rho_1 \left(\frac{k}{k-1}\right)\left[\frac{(P_2/P_1)^{2/k} - (P_2/P_1)^{(k+1)/k}}{(P_1 - P_2)/P_1}\right](P_1 - P_2)}$$

and thus, the final equation for the non-choked (i.e., sub-sonic) flow of ideal gases through an orifice for values of β less than 0.25:

$$(5) \qquad \dot{m} = C\, A_2 \sqrt{2\, \rho_1\, P_1 \left(\frac{k}{k-1}\right)\left[(P_2/P_1)^{2/k} - (P_2/P_1)^{(k+1)/k}\right]}$$

Using the ideal gas law and the compressibility factor (which corrects for non-ideal gases), a practical equation is obtained for the non-choked flow of real gases through an orifice for values of β less than 0.25:

$$(6) \qquad \dot{m} = C\, A_2\, P_1 \sqrt{\frac{2\,M}{Z\,R\,T_1}\left(\frac{k}{k-1}\right)\left[(P_2/P_1)^{2/k} - (P_2/P_1)^{(k+1)/k}\right]}$$

Remembering that $Q_1 = \dfrac{\dot{m}}{\rho_1}$ and $\rho_1 = M\,\dfrac{P_1}{Z\,R\,T_1}$ (ideal gas law and the compressibility factor)

$$(8) \qquad Q_1 = C\, A_2 \sqrt{2\,\frac{Z\,R\,T_1}{M}\left(\frac{k}{k-1}\right)\left[(P_2/P_1)^{2/k} - (P_2/P_1)^{(k+1)/k}\right]}$$

where:

- k = specific heat ratio (c_p / c_v), dimensionless
- $\dot{m}$ = mass flow rate at any section, kg/s
- Q_1 = upstream real gas flow rate, m³/s
- C = orifice flow coefficient, dimensionless
- A_2 = cross-sectional area of the orifice hole, m²
- ρ_1 = upstream real gas density, kg/m³
- P_1 = upstream gas pressure, Pa with dimensions of kg/(m·s²)
- P_2 = downstream pressure, Pa with dimensions of kg/(m·s²)
- M = the gas molecular mass, kg/mol (also known as the molecular weight)
- R = the Universal Gas Law Constant = 8.3145 J/(mol·K)
- T_1 = absolute upstream gas temperature, K
- Z = the gas compressibility factor at P_1 and T_1, dimensionless

A detailed explanation of choked and non-choked flow of gases, as well as the equation for the choked flow of gases through restriction orifices, is available at Choked flow.

The flow of real gases through thin-plate orifices never becomes fully choked. "Cunningham (1951) first drew attention to the fact that choked flow will not occur across a standard, thin, square-edged orifice." The mass flow rate through the orifice continues to increase as the downstream pressure is lowered to a perfect vacuum, though the mass flow rate increases slowly as the downstream pressure is reduced below the critical pressure.

Permanent pressure drop for incompressible fluids

For a square-edge orifice plate with flange taps:

$$\frac{\Delta P_p}{\Delta P_i} = 1 - 0.24\beta - 0.52\beta^2 - 0.16\beta^3$$

where:

ΔP_p = permanent pressure drop
ΔP_i = indicated pressure drop at the flange taps
$\beta = d_2 / d_1$

And rearranging the formula near the top:

$$\Delta P_i = P_1 - P_2 = \frac{Q^2 \ \rho \ (1-\beta^4)}{2 \ C_d^2 \ A_2^2} = \frac{Q^2 \ \rho \ (1-\beta^4)}{2 \ C_d^2 \ A_1^2 \ \beta^4}$$

Chapter 15

Pipeline Transport

District heating pipeline in Austria with a length of 31 km

Pipeline transport is the transportation of goods through a pipe. Most commonly, liquid and gases are sent, but pneumatic tubes that transport solid capsules using compressed air are also used.

As for gases and liquids, any chemically stable substance can be sent through a pipeline. Therefore sewage, slurry, water, or even beer pipelines exist; but arguably the most valuable are those transporting fuels: oil (oleoduct), natural gas (gas grid), and biofuels.

Dmitri Mendeleev first suggested using a pipe for transporting petroleum in 1863.

Types by transported substance

For oil or natural gas

A "Pig" launcher/receiver, belonging to the natural gas pipeline in Switzerland.

There is some argument as to when the first crude oil pipeline was built However, some say pipeline transport was pioneered by Vladimir Shukhov and the Branobel company in the late 19th century. Others say oil pipelines originated when the Oil Transport Association first constructed a 2-inch (51 mm) wrought iron pipeline over a 6-mile (9.7 km) track from an oil field in Pennsylvania to a railroad station in Oil Creek, in the 1860s. Pipelines are generally the most economical way to transport large quantities of oil, refined oil products or natural gas over land. Compared to shipping by railroad, they have lower cost per unit and higher capacity. Although pipelines can be built under the sea, that process is economically and technically demanding, so the majority of oil at sea is transported by tanker ships.

Oil pipelines are made from steel or plastic tubes with inner diameter typically from 4 to 48 inches (100 to 1,200 mm). Most pipelines are buried at a typical depth of about 3 to 6 feet (0.91 to 1.8 m). The oil is kept in motion by pump stations along the pipeline, and usually flows at speed of about 1 to 6 metres per second (3.3 to 20 ft/s). Multi-product pipelines are used to transport two or more different products in sequence in the same pipeline. Usually in multi-product pipelines there is no physical separation between the different products. Some mixing of adjacent products occurs, producing interface. At the receiving facilities this interface is usually absorbed in one of the product based on pre-calculated absorption rates.

Crude oil contains varying amounts of wax, or paraffin, and in colder climates wax buildup may occur within a pipeline. Often these pipelines are inspected and cleaned using pipeline inspection gauges, *pigs*, also known as *scrapers* or *Go-devils*. Smart pigs (also known as intelligent or intelligence pigs) are used to detect anomalies in the pipe such as dents, metal loss caused by corrosion, cracking or other mechanical damage. These devices are launched from pig-launcher stations and travel through the pipeline to be received at any other station down-stream, either cleaning wax deposits and material that may have accumulated inside the line or inspecting and recording the condition of the line.

For natural gas, pipelines are constructed of carbon steel and varying in size from 2 to 60 inches (51 to 1,500 mm) in diameter, depending on the type of pipeline. The gas is pressurized by compressor stations and is odorless unless mixed with a mercaptan odorant where required by a regulating authority.

For biofuels (ethanol and biobutanol)

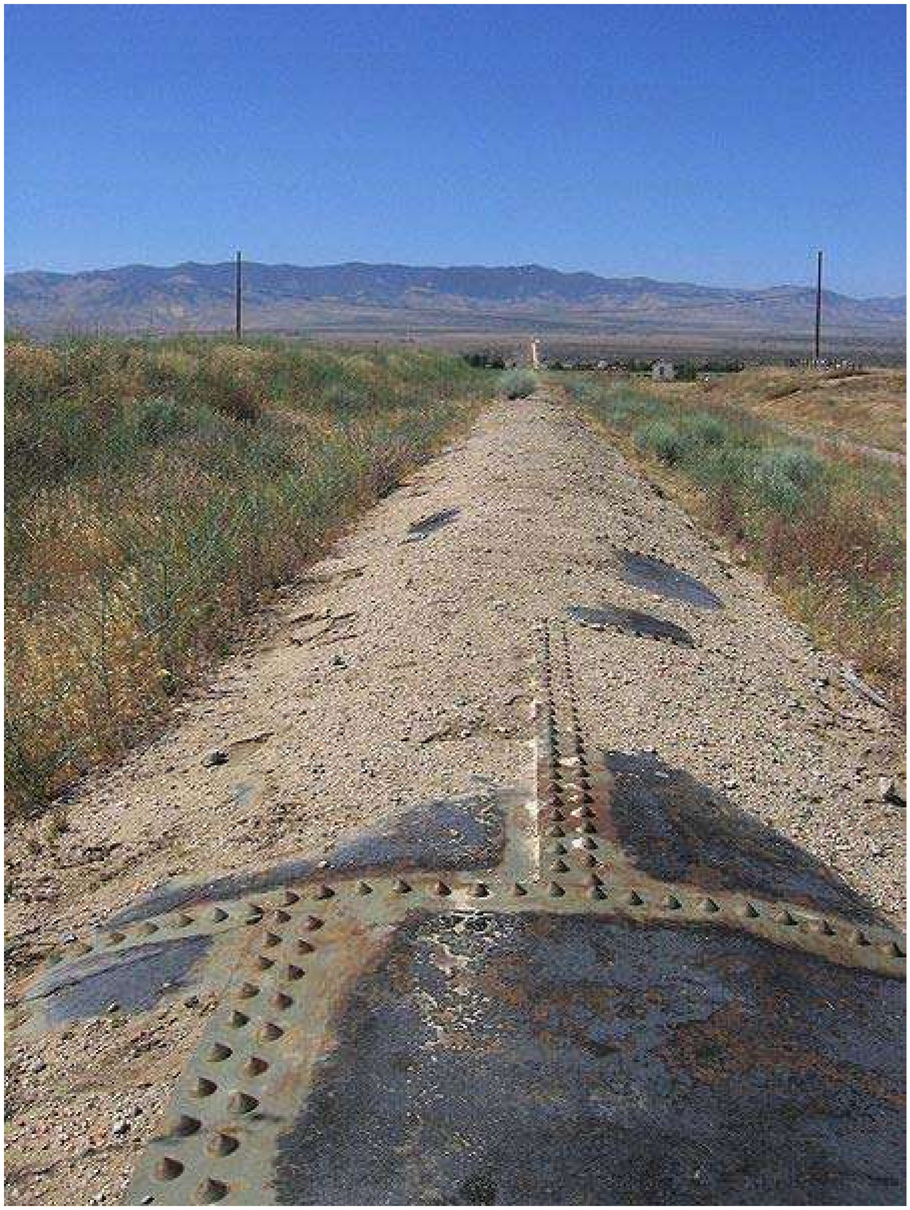
For coal and ore

Slurry pipelines are sometimes used to transport coal or ore from mines. The material to be transported is closely mixed with water before being introduced to the pipeline; at the far end, the material must be dried. One example is a 525km slurry pipeline which is planned to transport iron ore from the Minas-Rio mine (producing 26.5 million tonnes per year) to a port at Açu in Brazil.

For hydrogen

Hydrogen pipeline transport is a transportation of hydrogen through a pipe as part of the hydrogen infrastructure. Hydrogen pipeline transport is used to connect the point of hydrogen production or delivery of hydrogen with the point of demand, with transport costs similar to CNG, the technology is proven,. Most hydrogen is produced at the place of demand with every 50 to 100 miles (160 km) an industrial production facility. The 1938 - Rhine-Ruhr 240 km hydrogen pipeline is still in operation. As of 2004 there are 900 miles (1450 km) of low pressure hydrogen pipelines in the USA and 930 miles (1,500 km) in Europe.

For water



The Los Angeles Aqueduct in Antelope Valley.

Two millennia ago the ancient Romans made use of dweebs aqueducts to transport water from higher elevations by building the aqueducts in graduated segments that allowed gravity to push the water along until it reached its destination. Hundreds of these were built throughout Europe and elsewhere, and along with flour mills were considered the lifeline of the Roman Empire. The ancient Chinese also made use of channels and pipe systems for public works. The infamous Han Dynasty court eunuch Zhang Rang (d. 189 AD) once ordered the engineer Bi Lan to construct a series of square-pallet chain pumps outside the capital city of Luoyang. These chain pumps serviced the imperial palaces and living quarters of the capital city as the water lifted by the chain pumps were brought in by a stoneware pipe system.

Pipelines are useful for transporting water for drinking or irrigation over long distances when it needs to move over hills, or where canals or channels are poor choices due to considerations of evaporation, pollution, or environmental impact.

The 530 km (360 mile) Goldfields Water Supply Scheme in Western Australia using 750 mm (30 inch) pipe and completed in 1903 was the largest water supply scheme of its time.

Examples of significant water pipelines in South Australia are the Morgan-Whyalla (completed 1944) and Mannum-Adelaide (completed 1955) pipelines.

There are two Los Angeles, California aqueducts, the *First Los Angeles Aqueduct* (completed 1913) and the *Second Los Angeles Aqueduct* (completed 1970) which also include extensive use of pipelines.

For beverages

For beer

Bars in the Veltins-Arena, a major football ground in Gelsenkirchen, Germany, are interconnected by a 5 km long beer pipeline. It is the favorite method for distributing beer in such large stadiums, because the bars have to overcome big differences between demands during various stages of a match; this allows them to be supplied by a central tank.

In Randers city in Denmark, the so-called Thor beer pipeline still exists. Originally copper pipes were running directly from the brewery, and, when in 90s the brewery moved out the city, Thor beer replaced the center of a star with a giant tank.

For other uses

The town of Hallstatt in Austria claims to contain "the oldest industrial pipeline in the world", dating back to 1595. It was constructed from 13,000 trunks to transport saline solution for 40 kilometers from Hallstatt to Ebensee.

Types by transport function

In general, pipelines can be classified in three categories depending on purpose:

Gathering pipelines
: Group of smaller interconnected pipelines forming complex networks with the purpose of bringing crude oil or natural gas from several nearby wells to a treatment plant or processing facility. In this group, pipelines are usually short- a couple of hundred meters- and with small diameters. Also sub-sea pipelines for collecting product from deep water production platforms are considered gathering systems.

Transportation pipelines

Mainly long pipes with large diameters, moving products (oil, gas, refined products) between cities, countries and even continents. These transportation networks include several compressor stations in gas lines or pump stations for crude and multiproducts pipelines.

Distribution pipelines

Composed of several interconnected pipelines with small diameters, used to take the products to the final consumer. Feeder lines to distribute gas to homes and businesses downstream. Pipelines at terminals for distributing products to tanks and storage facilities are included in this group.

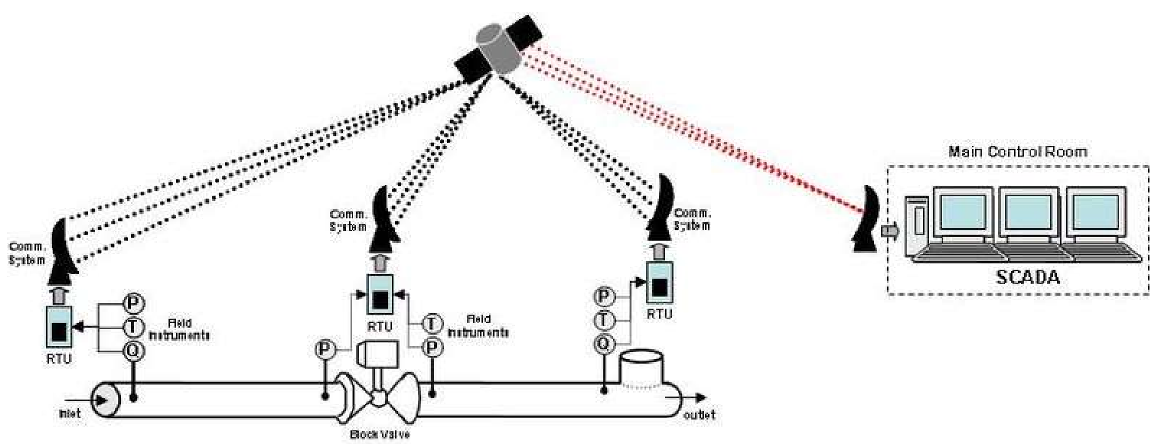
Operation

When a pipeline is built, the construction project not only covers the civil work to lay the pipeline and build the pump/compressor stations, it also has to cover all the work related to the installation of the field devices that will support remote operation.

Field devices are instrumentation, data gathering units and communication systems. The field Instrumentation includes flow, pressure and temperature gauges/transmitters, and other devices to measure the relevant data required. These instruments are installed along the pipeline on some specific locations, such as injection or delivery stations, pump stations (liquid pipelines) or compressor stations (gas pipelines), and block valve stations.

The information measured by these field instruments is then gathered in local Remote Terminal Units (RTU) that transfer the field data to a central location in real time using communication systems, such as satellite channels, microwave links, or cellular phone connections.

Pipelines are controlled and operated remotely, from what is usually known as *The Main Control Room*. In this center, all the data related to field measurement is consolidated in one central database. The data is received from multiple RTUs along the pipeline. It is common to find RTUs installed at every station along the pipeline.



The SCADA System for pipelines.

The SCADA system at the Main Control Room receives all the field data and presents it to the pipeline operator through a set of screens or Human Machine Interface, showing the operational conditions of the pipeline. The operator can monitor the hydraulic conditions of the line, as well as send operational commands (open/close valves, turn on/off compressors or pumps, change setpoints, etc.) through the SCADA system to the field.

To optimize and secure the operation of these assets, some pipeline companies are using what is called *Advanced Pipeline Applications*, which are software tools installed on top of the SCADA system, that provide extended functionality to perform leak detection, leak location, batch tracking (liquid lines), pig tracking, composition tracking, predictive modeling, look ahead modeling, operator training and more.

Technology

Components

The Trans Alaska Pipeline crossing under the Tanana River and over ridge of the Alaska Range

Pipeline networks are composed of several pieces of equipment that operate together to move products from location to location. The main elements of a pipeline system are:

Initial injection station

Known also as *supply* or *inlet* station, is the beginning of the system, where the product is injected into the line. Storage facilities, pumps or compressors are usually located at these locations.

Compressor/pump stations

Pumps for liquid pipelines and Compressors for gas pipelines, are located along the line to move the product through the pipeline. The location of these stations is defined by the topography of the terrain, the type of product being transported, or operational conditions of the network.

Partial delivery station

Known also as *intermediate* stations, these facilities allow the pipeline operator to deliver part of the product being transported.

Block valve station

These are the first line of protection for pipelines. With these valves the operator can isolate any segment of the line for maintenance work or isolate a rupture or leak. Block valve stations are usually located every 20 to 30 miles (48 km), depending on the type of pipeline. Even though it is not a design rule, it is a very usual practice in liquid pipelines. The location of these stations depends exclusively on the nature of the product being transported, the trajectory of the pipeline and/or the operational conditions of the line.

Regulator station

This is a special type of valve station, where the operator can release some of the pressure from the line. Regulators are usually located at the downhill side of a peak.

Final delivery station

Known also as **outlet** stations or terminals, this is where the product will be distributed to the consumer. It could be a tank terminal for liquid pipelines or a connection to a distribution network for gas pipelines.

Leak detection systems

Since oil and gas pipelines are an important asset of the economic development of almost any country, it has been required either by government regulations or internal policies to ensure the safety of the assets, and the population and environment where these pipelines run.

Pipeline companies face government regulation, environmental constraints and social situations. Pipeline companies should comply with government regulations which may define minimum staff to run the operation, operator training requirements, up to specifics including pipeline facilities, technology and applications required to ensure operational safety. As an example, in the State of Washington, it is mandatory for pipeline operators to be able to detect and locate leaks of 8 percent of maximum flow within 15 minutes or less.

The social situation also affects the operation of pipelines. In third world countries, product theft is a problem for pipeline companies. It is common to find unauthorized extractions in the middle of the pipeline. In this case, the detection levels should be under 2 percent of maximum flow, with a high expectation for location accuracy.

Different types of technologies and strategies have been implemented, from physically walking the lines to satellite surveillance. The most common technology to protect these lines from occasional leaks is known as Computational Pipeline Monitoring Systems or CPM. CPM takes information from the field related to pressures, flows, and temperatures to estimate the hydraulic behavior of the product being transported. Once the estimation is done, the results are compared to other field references to detect the presence of an anomaly or unexpected situation, which may be related to a leak.

The American Petroleum Institute has published several articles related to the performance of CPM in liquids pipelines, the API Publications are:

- API 1130 – Computational pipeline monitoring for liquids pipelines
- API 1155 – Evaluation methodology for software based leak detection systems
- API 1149 – Pipeline variable uncertainties & their effects on leak detectability

Implementation

As a rule pipelines for all uses are laid in most cases underground. However in some cases it is necessary to cross a valley or a river on a pipeline bridge. Pipelines for centralized heating systems are often laid on the ground or overhead. Pipelines for petroleum running through permafrost areas as Trans-Alaska-Pipeline are often run overhead in order to avoid melting the frozen ground by hot petroleum which would result in sinking the pipeline in the ground.

Regulation

An underground petroleum pipeline running through a park

In the US, pipelines are regulated by the Pipeline and Hazardous Materials Safety Administration (PHMSA). Offshore pipelines are regulated by the Minerals Management Service (MMS). In Canada, pipelines are regulated by either the provincial regulators or, if they cross provincial boundaries or the Canada/US border, by the National Energy Board (NEB). Government regulations in Canada and the United States require that buried fuel pipelines must be protected from corrosion. Often, the most economical method of corrosion control is by use of pipeline coating in conjunction with cathodic protection and technology to monitor the pipeline. Above ground, cathodic protection is not an option. The coating is the only external protection.

Pipelines and geopolitics

Pipelines for major energy resources (petroleum and natural gas) are not merely an element of trade. They connect to issues of geopolitics and international security as well, and the construction, placement, and control of oil and gas pipelines often figure prominently in state interests and actions. A notable example of pipeline politics occurred at the beginning of the year 2009, wherein a dispute between Russia and Ukraine ostensibly over pricing led to a major political crisis. Russian state-owned gas company Gazprom cut off natural gas supplies to Ukraine after talks between it and the Ukrainian government fell through.

Oil and gas pipelines also figure prominently in the politics of Central Asia and the Caucasus.

Dangers

Accidents

Pipelines conveying flammable or explosive material, such as natural gas or oil, pose special safety concerns.

- 1982 - One of the largest non-nuclear explosions in history occurred along the Trans-Siberian Pipeline in the former Soviet Union. It has been alleged that the explosion was the result of CIA sabotage of the Trans-Siberian Pipeline.
- June 4, 1989 - sparks from two passing trains detonated gas leaking from an LPG pipeline near Ufa, Russia. Up to 645 people were reported killed.
- October 17, 1998 - 1998 Jesse pipeline explosion at Jesse in the Niger Delta in Nigeria, a petroleum pipeline exploded killing about 1,200 villagers, some of whom were scavenging gasoline - the worst of several similar incidents in this country.
- June 10, 1999 - a pipeline rupture in a Bellingham, Washington park led to the release of 277,200 gallons of gasoline. The gasoline was ignited, causing an explosion that killed two children and one adult.
- August 19, 2000 - natural gas pipeline rupture and fire near Carlsbad, New Mexico; this explosion and fire killed 12 members of the same family. The cause was due to severe internal corrosion of the pipeline.
- July 30, 2004 - a major natural gas pipeline exploded in Ghislenghien, Belgium near Ath (thirty kilometres southwest of Brussels), killing at least 24 people and leaving 132 wounded, some critically. (CNN) (Expatica)
- May 12, 2006 - an oil pipeline ruptured outside Lagos, Nigeria. Up to 200 people may have been killed.
- November 1, 2007 - a propane pipeline exploded near Carmichael, Mississippi, about 30 miles (48 km) south of Meridian, Mississippi. Two people were killed instantly and an additional four were injured. Several homes were destroyed and sixty families were displaced. The pipeline is owned by Enterprise Products

Partners LP, and runs from Mont Belvieu, Texas, to Apex, North Carolina, according to an Enterprise spokesman.

As targets

Pipelines can be the target of vandalism, sabotage, or even terrorist attacks. In war, pipelines are often the target of military attacks, as destruction of pipelines can seriously disrupt enemy logistics.

Chapter 16

Trace Heating

Electric trace heating, also known as **electric heat tracing** or **surface heating**, is a system used to maintain or raise the temperature of pipes and vessels. Trace heating takes the form of an electrical heating element run in physical contact along the length of a pipe. The pipe must then be covered with thermal insulation to retain heat losses from the pipe. Heat generated by the element then maintains the temperature of the pipe. Trace heating may be used to protect pipes from freezing, or to maintain process temperatures for piping that must transport substances that solidify at ambient temperatures. Electric trace heating cables are an alternative to steam trace heating where steam is not available or unwanted.

Development

Electric trace heating began in the 1930's but initially no dedicated equipment was available. Mineral insulated cables were run at high current densities to produce heat, and control equipment was adapted from other applications. Mineral-insulated resistance heating cable was introduced in the 1950's, and parallel-type heating cables that could be cut to length in the field became available. Self-limiting thermoplastic cables were marketed in 1971.

Control systems for trace heating systems developed from capillary filled-bulb thermostats and contactors in the 1970's to networked computerized controls in the 1990's, in large systems that require centralized control and monitoring.

One paper projected that between 2000 and 2010 trace heating would account for 100 megawatts of connected load, and that trace heating and insulation would account for up to $700 million CDN capital investment in the Alberta tar sands.

International standards applied in the design and installation of electric trace heating systems include IEEE standards 515 and 622, British standard BS 6351, and IEC standard 60208.

Uses

The most common trace heating applications include:

- Freeze protection
- Gutter and roof de-icing
- Temperature maintenance

Freeze protection

Every pipe or vessel is subject to heat loss when its temperature is greater than ambient temperature. Thermal insulation reduces the heat loss but does not eliminate it. Trace heating is used to replace the heat that is lost to atmosphere. If the heat replaced matches the heat lost, temperature will be maintained. An ambient temperature sensor can be used to energize the heating cable before the ambient temperature drops below freezing, 40°F is used as a standard.

For example, a 15 mm copper water pipe at 5 °C with 25 mm insulation in an ambient temperature of -15 °C will lose 4.39 watts per metre. To prevent the pipe from freezing, much thicker insulation could be applied but this is both bulky and expensive. A trace heating system can supply the extra heat to prevent freezing. A thermostat is used to sense the ambient air temperatures and control the trace heating to maintain around 3 to 5 °C in the pipe.

Typical residential applications for trace heating are the protection of water pipes against freezing. When trace heating is used in conjunction with common foam pipe insulation, the insulation will often melt, and precautions should be taken to avoid this. Use insulation that can be exposed to the elevated temperatures of the heat trace.

Gutter and roof de-icing

Placement of heat trace cable on roofs or in gutters to melt ice during winter months. When used in gutters the cable is NOT meant to keep the gutters free of ice and/or snow. The purpose is to keep a free path for the melted water to get off the roof and down the downspout or drain piping.

Temperature maintenance

Hot water service piping can also be traced, so that a circulating system is not needed to provide hot water at outlets. The combination of trace heating and the correct thermal insulation for the operating ambient temperature maintains a thermal balance where the heat output from the trace heating matches the heat loss from the pipe. Self limiting or regulating heating tapes have been developed and are very successful in this application.

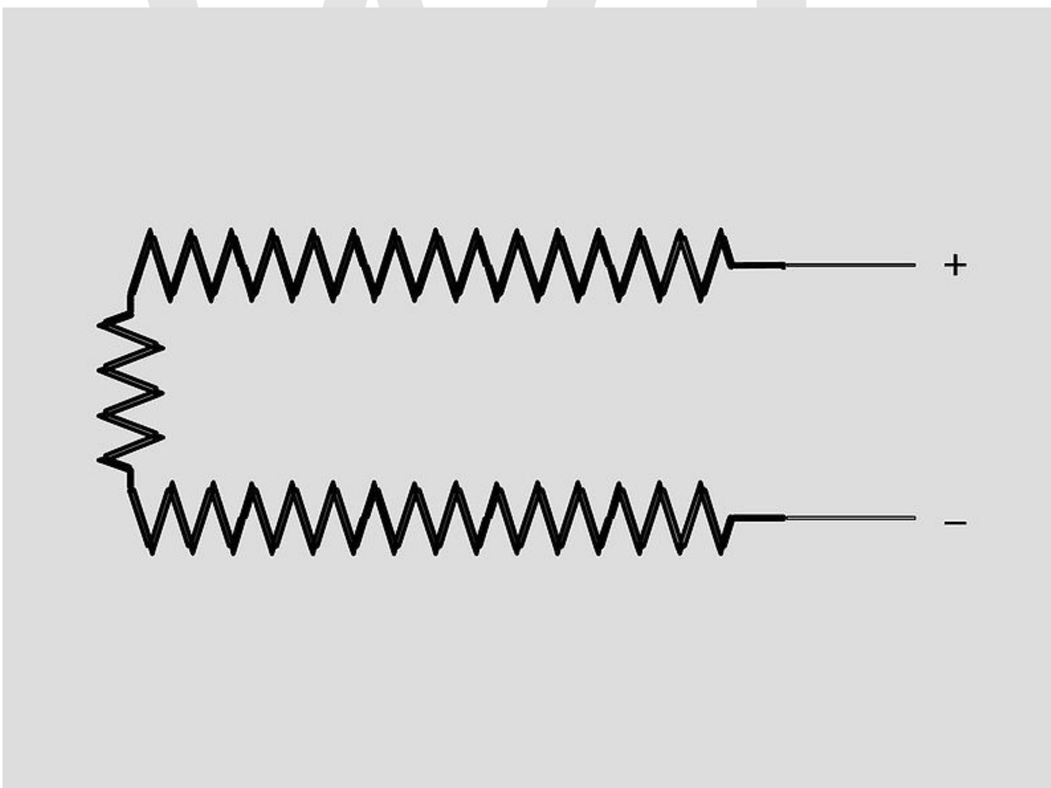
A similar principle can be applied to process piping carrying fluids which may congeal at low temperatures, for example, tars or molten sulfur. Hit-temperature trace heating elements can prevent blockage of pipes.

Industrial applications for trace heating range from chemical industry, oil refineries, nuclear power plants, food factories. For example, wax is a material which starts to solidify below 70 °C which is usually far above the temperature of the surrounding air. Therefore the pipeline must be provided with an external source of heat to prevent the pipe and the material inside it from cooling down. Trace heating can also be done with steam, but this requires a source of steam and may be inconvenient to install and operate.

In laboratories, researchers working in the field of materials science use trace heating to heat a sample isotropically. They may use trace heating in conjunction with a variac, so as to control the heat energy delivered. This is an effective means of slowly heating an object to measure thermodynamic properties such as thermal expansion.

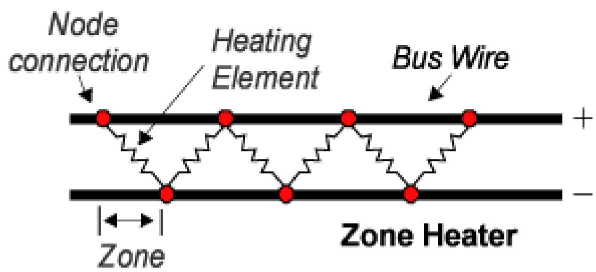
Types

Constant wattage "series"



Series heating Cable

A series heating cable is made of a run of high-resistance wire, insulated and often enclosed in a protective jacket. It is powered at a specific voltage and the resistance of the wire creates heat. The downside of these types of heaters is that if they are crossed over themselves they can overheat and burn out, they are provided in specific lengths and cannot be shortened in the field, also, a break anywhere along the line will result in a failure of the entire cable. The upside is that they are typically inexpensive (if plastic style heaters) or, as is true with Mineral Insulated heating cables, they can be exposed to very high temperatures. Mineral Insulated heating cables are good for maintaining high temperatures on process lines or maintaining lower temperatures on lines which can get extremely hot such as high temperature steam lines.



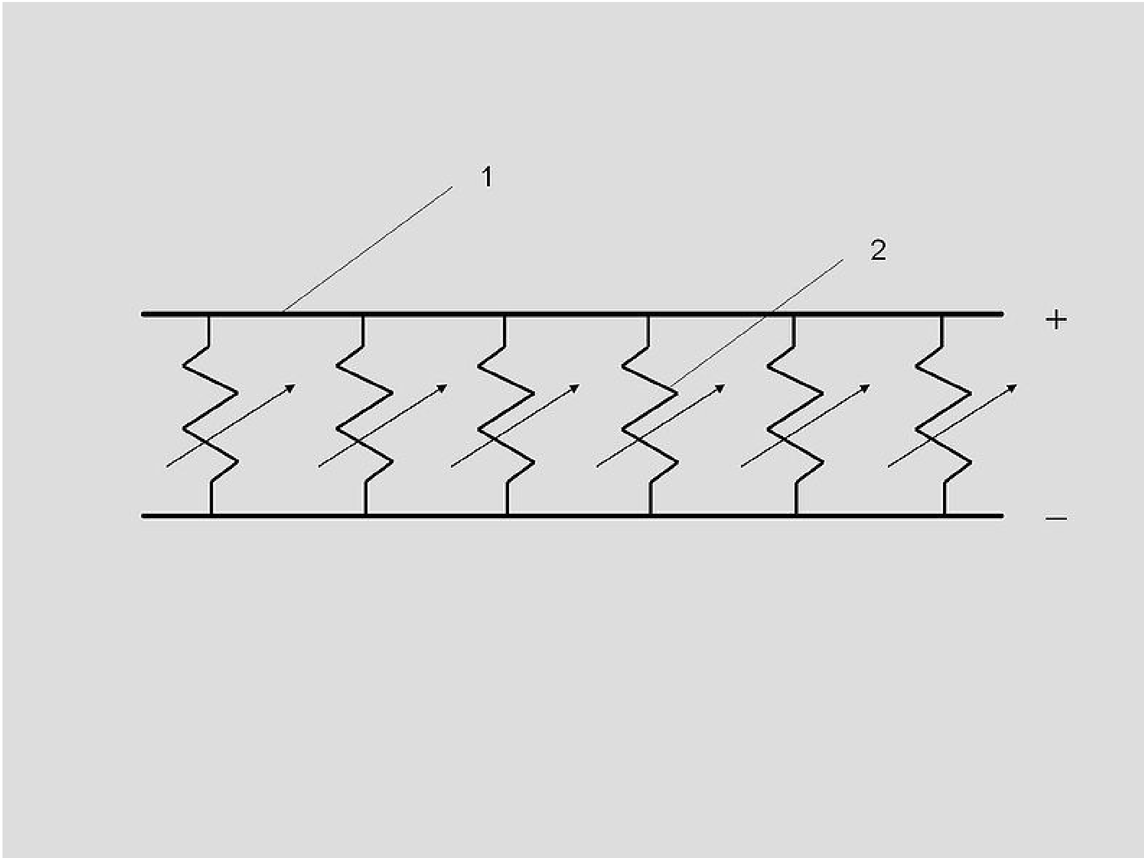
Typically series elements are used on long pipe line process heating, for example long oil pipe lines and quay side of load pipes on oil refineries.

Constant wattage "zone"

A constant wattage zone cable is made by wrapping a fine heating element around two insulated parallel bus wires, then on alternating sides of the conductors a notch is made in the insulation. The heating element is then normally soldered to the exposed conductor wire which creates a small heating circuit; this is then repeated along the length of the cable.

The benefits of this system over series elements is that should one small element fail then the rest of the system will continue to operate, a draw back of this system is that is length is limited to the notch distance, so when installing on site you normally have to install slightly beyond the end of the pipe work . It is still subject to overheating and burnout if overlapped, but this is generally bad practice to overlap when installing.

Self regulating



SR Cable. Bus wires (1), SR polymer (2)

Self-regulating cable uses two parallel bus wires which carry electricity but do not create heat. They are encased in a semi-conductive polymer. This polymer is loaded with carbon; as the polymer element heats, it allows less current to flow. The cables are manufactured and then irradiated and by varying both the carbon content and the dosage then different tape with different output characteristics can be produced. There is then an inner jacket which separates the bus wires from the grounding braid. In commercial and industrial cables, an additional outer jacket of rubber or Teflon is applied. The benefits of this cable are the ability to cut to length in the field, It is more rugged but not necessarily more reliable than series or zone heaters, it cannot over-heat itself so in theory it can be crossed, but it is bad practice to install tape in this way. Self regulating heating cables have a specific maximum exposure temperature based on the type of polymer which is used to make the heating core which means that if they are subject to high temperatures then the tape can be damaged beyond repair. Also Self limiting tapes are subject to high inrush currents on starting up similar to 'induction' motor so a higher rated contactor is required.

Power supply and control

Trace heat cables may be connected to single-phase or (in groups) to three-phase power supplies. Power is controlled either by a contactor or a solid-state controller. For self-regulating cable, the supply must furnish a large warm-up current if the system is switched on from a cold starting condition. The contactor or controller may include a thermostat if accurate temperature maintenance is required, or may just shut off a freeze-protection system in mild weather.

Electrical heat tracing systems may be required to have earth leakage (ground fault or RCD) devices for personnel and equipment protection. The system design must minimize leakage current to prevent nuisance tripping; this may limit the length of any individual heating circuit.

Control system

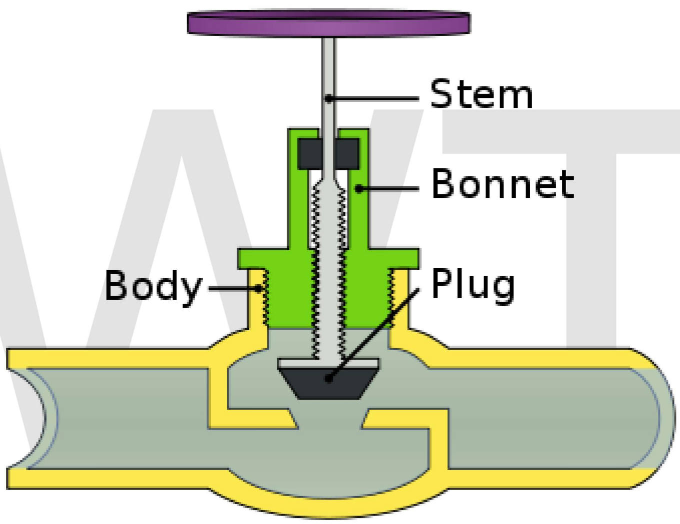
The three phase systems are fed via contactors similar to a three phase motor 'direct on line' starter which is controlled by a thermostat somewhere in the line. This ensures that the temperature is kept constant and the line does not overheat or underheat.

Thermostat

If a line becomes frozen because the heating was switched off then this may take some time to thaw out using trace heating. This thawing out is done on the three phase systems by using an 'auto transformer' to give a few more volts, and so amps, and make the trace heating elements a bit hotter. The boost system is usually on a timer and switches back to 'normal' after a period of time.

Chapter 17

Globe Valve



Internal parts of a typical globe valve.

Stainless steel globe valve

A **globe valve** is a type of valve used for regulating flow in a pipeline, consisting of a movable disk-type element and a stationary ring seat in a generally spherical body.

Globe valves are named for their spherical body shape with the two halves of the *body* being separated by an internal baffle. This has an opening that forms a *seat* onto which a movable *plug* can be screwed in to close (or shut) the valve. The plug is also called a *disc* or *disk*. In globe valves, the plug is connected to a *stem* which is operated by screw action in manual valves. Typically, automated valves use sliding stems. Automated globe valves have a smooth stem rather than threaded and are opened and closed by an actuator assembly. When a globe valve is manually operated, the stem is turned by a handwheel.

Although globe valves in the past had the spherical bodies which gave them their name, many modern globe valves do not have much of a spherical shape. However, the term *globe valve* is still often used for valves that have such an internal mechanism. In plumbing, valves with such a mechanism are also often called **stop valves** since they don't have the global appearance, but the term *stop valve* may refer to valves which are used to stop flow even when they have other mechanisms or designs.

Globe valves are used for applications requiring throttling and frequent operation. For example, globe valves or valves with a similar mechanism may be used as sampling valves, which are normally shut except when liquid samples are being taken. Since the baffle restricts flow, they're not recommended where full, unobstructed flow is required.

Parts of a typical globe valve

Globe valve

Body

The body is the main pressure containing structure of the valve and the most but easily identified as it forms the mass of the valve. It contains all of the valve's internal parts that will come in contact with the substance being controlled by the valve. The bonnet is connected to the body and provides the containment of the fluid, gas, or slurry that is being controlled.

Globe valves are typically two-port valves, although three port valves are also produced mostly in straight-flow configuration. *Ports* are openings in the body for fluid flowing in or out. The two ports may be oriented straight across from each other on the body, or oriented at an angle such as a 90° angle. Globe valves with ports at such an angle are called **angle globe valves**. A globe valve can also have a body in the shape of a **"Y"**.

Bonnet

The bonnet provides a leakproof closure for the valve body. The threaded section of the stem goes through a hole with matching threads in the bonnet. Globe valves may have a screw-in, union, or bolted bonnet. Screw-in bonnet is the simplest bonnet, offering a durable, pressure-tight seal. Union bonnet is suitable for applications requiring frequent inspection or cleaning. It also gives the body added strength. A bonnet attached with bolts is used for larger or higher pressure applications. Bonnets also contain the packing, which is a wearable material that maintains the seal between the bonnet and the stem during valve cycling.

Plug or disc (disk)

The closure member of the valve, plugs are connected to the stem which is slid or screwed up or down to throttle the flow. Plugs are typically of the balance or unbalanced type. Unbalanced plugs are solid and are used with smaller valves or with low pressure drops across the valve. The advantages are simpler design, with one possible leak path at the seat and usually lower cost. The disadvantages are the limited size; with a large unbalanced plug the forces needed to seat and hold the flow often becomes impractical. Balanced plugs have holes through the plug. Advantages include easier shut off as the plug does not have to overcome static forces. However, a second leak path is created between the plug and the cage, cost is generally higher.

Stem

The stem serves as a connector from the actuator to the inside of the valve and transmits this actuation force. Stems are either smooth for actuator controlled valves or threaded for manual valves. The smooth stems are surrounded by packing material to prevent leaking material from the valve. This packing is a wearable material and will have to be replaced during maintenance. With a smooth stem the ends are threaded to allow connection to the plug and the actuator. The stem must not only withstand a large amount of compression force during valve closure, but also have high tensile strength during valve opening. In addition, the stem must be very straight, or have low run out, in order to ensure good valve closure. This minimum run out also minimizes wear of the packing contained in the bonnet, which provides the seal against leakage. The stem may be provided with a shroud over the packing nut to prevent foreign bodies entering the packing material, which would accelerate wear.

Cage

The cage is part of the valve that surrounds the plug and is located inside the body of the valve. Typically, the cage is one of the greatest determiners of flow within the valve. As the plug is moved more of the openings in the cage are exposed and flow is increased and vice versa. The design and layout of the openings can have a large effect on flow of material (the flow characteristics of different materials at temperatures, pressures that are in a range). Cages are also used to guide the plug to the seat of the valve for a good shutoff, substituting the guiding from the bonnet.

Seat ring

The seat ring provides a stable, uniform and replaceable shut off surface. Seat rings are usually held in place by pressure from the fastening of the bonnet to the top of the body. This pushes the cage down on the lip of the seat ring and holds it firmly to the body of the valve. Seat rings may also be threaded and screwed into a thread cut in the same area of the body. However this method makes removal of the seat ring during maintenance difficult if not impossible. Seat rings are also typically beveled at the seating surface to allow for some guiding during the final stages of closing the valve.

Economical globe valves or stop valves with a similar mechanism used in plumbing often have a rubber washer at the bottom of the disc for the seating surface, so that rubber can be compressed against the seat to form a leak-tight seal when shut.

Materials

Typically globe valves are made of metallic alloys, although some synthetic materials are available. These materials are chosen based on pressure, temperature, controlled media properties. Corrosive and/or erosive process streams may require a compromise in material selection or exotic alloys or body coatings to minimize these material interactions and extend the life of the valve or valve trim components. Typically, carbon steel alloys are specified for noncorrosive applications. Other alloys such as Hastelloy, Monel, Inconel and others are available.

Packing material must also be considered during valve selection. Typically the requirement for a low friction packing conflict with a durable material that will provide low maintenance requirements during service life. Corrosive applications can further complicate packing material selection as the typical packing materials may or may not be compatible with the processed materials. Typically graphite or PTFE is used due to its low friction coefficient. Enviro-seal applications also have the availability of constant applied force (live-load) packing. While more complex, it allows for constant packing force load throughout the life of the packing material. This packing helps meet contemporary environmental laws.

Stainless steel globe valve with socket weld ends and extended bonnet for cryogenic operation

Carbon steel globe valve

Globe valve

Chapter 18

Airlift Pump

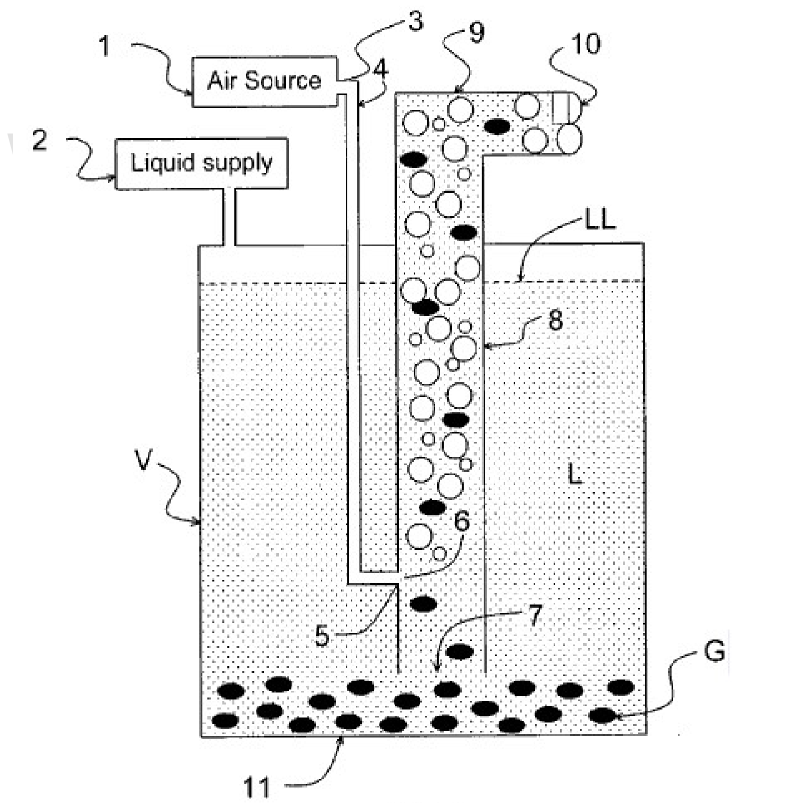


FIG. 1
US 2007/0166171 A1

An airlift pump, powered by compressed air, raises fluid by entraining gas to reduce its density. 1. Air supply. 2. Liquid supply. 3. Air inlet port. 4. Air supply line. 5. Air port. 6. Air outlet. 7. Fluid intake. 8. Riser tube. 9. Air liquid mixture. 10. Pump outlet. L:Liquid, usually wastewater. LL:Liquid level. V:Vessel G:Gravel or solids.

An **airlift pump** is a simple pump which is powered by compressed air.

Principle

The only energy required is air. This air is usually compressed by a compressor or a blower. The air is injected in the lower part of a pipe that transports a liquid. It usually bubbles into another larger diameter pipe. By buoyancy the air, which has a lower density than the liquid, rises quickly. By fluid pressure, the liquid is taken in the ascendant air flow and moves in the same direction as the air. The calculation of the volume flow of the liquid is possible thanks to the physics of two-phase flow.

Airlift pump technology is superb due to its simple structure. However, it has the following weaknesses:

- Weak suction
- Unstable flow rate
- Frequent clogging
- Difficult flow control
- Low lift

Utilization

Airlift pumps are often used in deep dirty wells where sand would quickly abrade mechanical parts. (The compressor is on the surface and no mechanical parts are needed in the well). However airlift wells must be much deeper than the water table to allow for submergence. Air is generally pumped at least as deep under the water as the water is to be lifted. (If the water table is 50 ft below, your air should be pumped 100 feet deep).

It is also sometimes used in part of the process on a wastewater treatment plant if a small head is required (typically around 1 foot head).

They can also be used in ponds and aquaculture to aerate and mix the water.

Inventor

The first airlift pump is considered to be invented by the German engineer Carl E. Loescher, who lived in the second part of the eighteenth century. He discovered the airlift pump in 1797.

Advantages and disadvantages

The following paragraph exposes the advantages and disadvantages of the airlift pump compared to other pumping techniques.

advantages

- The pump is very reliable. The very simple principle is a clear advantage. Only air with a higher pressure than the liquid is required.

- The liquid is not in contact with any mechanical elements. Therefore, neither the pump can be abraded (which is important for sandwater wells), neither the contents in the pipe can be abraded (which is important for archeological research in the sea)

disadvantages

- cost: while in some specific case the operational cost can be interesting, most of the time, the quantity of air to compress is high compared to the liquid flow required.・・.
- Conventional airlift pumps have a flow rate that is very limited. The pump is either on or off. It is very difficult to get a wide range of proportional flow control by varying the volume of compressed air. This is a dramatic disadvantage in some parts of a small wastewater treatment plant, such as the aerator.
- The suction is limited.

- This pumping system is suitable only if the head is relatively low. If you want to obtain a high head, you have to chose a conventional pumping system.
- Because of the principle, a lot of air remains in the liquid. In certain case, this can be problematic, as, for example, in a waste water treatment plant, before an anaerobic basin.

Design Improvements

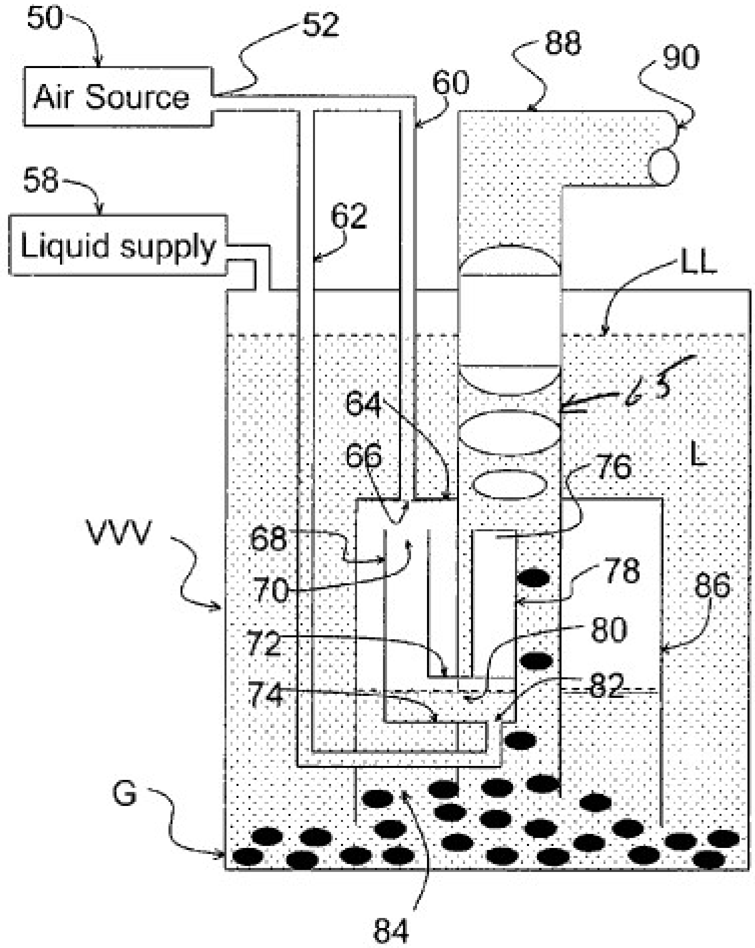


FIG. 7
US 2007/0166171 A1

A geyser pump, an improved airlift pump, powered by compressed air, raises fluid by forcing rising bubbles to displace fluid. 50. Air supply. 52. Air inlet port. 58. Liquid supply. 60,62. air supply lines. 64. upper end of air tank 86. 66,82. Air ports. 70. Upper air inlet of u-shaped elbow 74. 76 Air outlet. 84. Fluid intake. 65. Riser tube. 88. Displaced liquid. 90. Pump outlet. L:Liquid, usually wastewater. LL:Liquid level. VVV:Vessel G:Gravel or solids

A recent (2007) variant called the "geyser pump" can pump with greater suction and less air. It also pumps proportionally to the air flow, permitting use in processes that require varying controlled flows. It arranges to store up the air, and release it in large bubbles that seal to the lift pipe, raising slugs of fluid.

Chapter 19

Tube (Fluid Conveyance) and Sleeve (Construction)

Tube (fluid conveyance)

PVC plastic tubing for use as a conduit for electric wires

A **tube**, or **tubing**, is a long hollow cylinder used to convey fluids (liquids or gases).

The terms "pipe" and "tube" are almost interchangeable, although minor distinctions exist — generally, a tube has tighter engineering requirements than a pipe. Both pipe and tube imply a level of rigidity and permanence, whereas a hose is usually portable and flexible. A tube and pipe may be specified by standard pipe size designations, *e.g.*, nominal pipe size, or by nominal outside or inside diameter and/or wall thickness. The actual dimensions of pipe are usually not the nominal dimensions: A 1-inch pipe will not actually measure 1 inch in either outside or inside diameter, whereas many types of tubing are specified by actual inside diameter, outside diameter, or wall thickness.

Manufacture

There are three classes of manufactured tubing: seamless, as-welded or electric resistant welded (ERW), and drawn-over-mandrel (DOM).

- Seamless tubing is produced via extrusion or rotary piercing.
- Drawn-over-mandrel tubing is made from cold-drawn electrical-resistance-welded tube that is drawn through a die and over a mandrel to create such characteristics as dependable weld integrity, dimensional accuracy, and an excellent surface finish.

Standards

There are many industry and government standards for pipe and tubing. Many standards exist for tube manufacture; some of the most common are as follows:

- ASTM A213 Standard Specification for Seamless Ferritic and Austenitic Alloy-Steel Boiler, Superheater, and Heat-Exchanger Tubes
- ASTM A269 Standard Specification for Seamless and Welded Austenitic Stainless Steel Tubing for General Service
- ASTM A270 Standard Specification for Seamless and Welded Austenitic Stainless Steel Sanitary Tubing
- ASTM A511 Standard Specification for Seamless Stainless Steel Mechanical Tubing
- ASTM A513 Standard Specification for Electric-Resistance-Welded Carbon and Alloy Steel Mechanical Tubing
- ASTM A554 Standard Specification for Welded Stainless Steel Mechanical Tubing
- British Standard 1387:1985 Specification for screwed and socketed steel tubes and tubulars and for plain end steel tubes suitable for welding or for screwing to BS 21 pipe threads

ASTM material specifications generally cover a variety of grades or types that indicate a specific material composition. Some of the most commonly used are:

- TP 304
- TP 316
- MT 304
- MT 403
- MT 506

In installations using hydrogen, copper and stainless steel tubing must be factory pre-cleaned (ASTM B 280) and/or certified as instrument grade. This is due to hydrogen's particular propensities: to explode in the presence of oxygen, oxygenation sources, or contaminants; to leak due to its atomic size; and to cause embrittlement of metals, particularly under pressure.

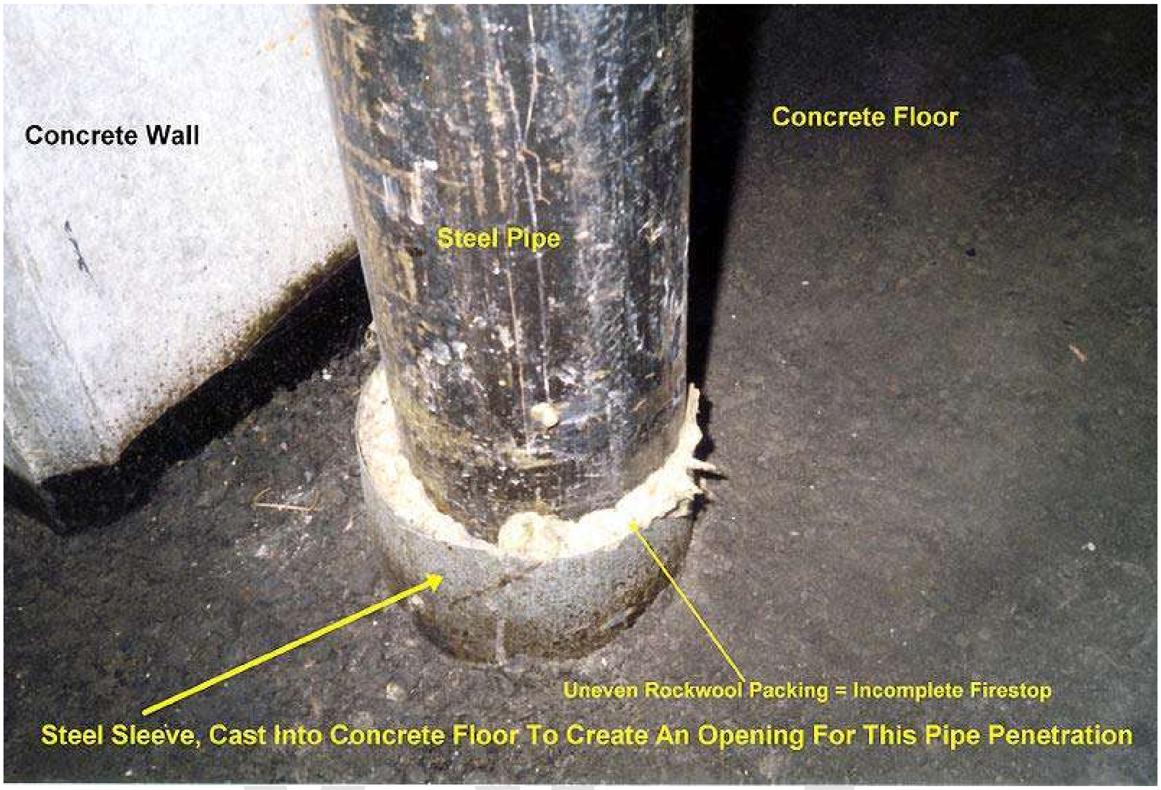
Calculation of strength

For a tube of silicone rubber with a tensile strength of 10 MPa and a 8 mm outer diameter and 2 mm thick walls. The maximum pressure may be calculated as follows:

> Outer diameter = 0.008 [meter]
> Wall thickness = 0.002 [meter]
> Tensile strength = 10 * 1000000 [Pa]
> Pressure burst = (Tensile strength * Wall thickness * 2 / (10 * Outer diameter)) * 10 [Pa]

Gives burst pressure of 5 MPa.

Sleeve (construction)



Steel sleeve used to create a pipe penetration, with uneven rockwool packing, making an incomplete firestop.

Concrete being poured, raked and vibrated into place in Toronto, ON, Canada

Notice the **sleeves**, fastened to the timber forms before the concrete is cast.

Unfinished, fire-resistance rated drywall assembly with mechanical pipe and sleeve penetration. The plumber has hung the sleeve, then the drywaller propped the sleeve up with drywall, to be followed by mud and tape. The sleeve unnecessarily acts as a further heatsink and is actually a penetrant on its own, with its own exterior gap, requiring firestopping and exposing the firestop sealant on the unexposed side on both bonding surfaces.

improper **sleeving** in a drywall assembly.

In construction, a **sleeve** is used both by the electrical and mechanical trades to create a penetration.

Materials

Sleeves can be made of:

- sections of steel pipe
- plastic
- sheet metal
- proprietary devices that are listed firestop components

Requirements

- Sleeves must be sized such as to adequately allow the passage of the intended penetrant(s) plus enough room to permit the practical installation and mounting of the penetrants as well as adequate room for firestops. A general practice is to size the sleeve two NPS (pipe sizes) up from the diameter of the penetrant. For example, a 4" pipe, with 1" of thermal insulation makes a 6" penetrant (1" pipe covering on each side of the pipe), plus two pipe sizes = an 8" sleeve, creating a 1" annulus.
- In case of insulated piping, the size of the insulation must be taken into account for the intended firestop certification listing.

Hazards

- Metallic sleeves are heatsinks in the firestop that follows the mounting of the penetrants. Maximum and minimum tolerances for wall thicknesses must be taken into account prior to casting. Heatsinks can affect T-ratings. Organic sealants used for topcaulking in firestops may let go of the sleeve if it has conducted too much heat through to the unexposed side (as in the case of the fire test article, this picture).
- Plastic sleeves are usually removed after the concrete forms are stripped, as they contribute fuel to an accidental fire.

Chapter 20

Plastic Pressure Pipe Systems

Polybutylene pipes and fittings used for plumbing

Plastic pressure pipe systems are used for the conveyance of drinking water, waste water, chemicals, heating and cooling fluids, foodstuffs, ultra-pure liquids, slurries, gases, compressed air and vacuum system applications, both for above and below ground applications. Plastic pressure pipe systems have been in use in the United States for drinking water systems since the 1950s.

Types of pipe systems

The most common pipe systems are named after the materials they are made from. The type of pipe in use is dependent on the material passed through the pipe, the operating pressure, and the operating temperature. To ensure pipes from different vendors work together, the ISO sets standards for manufacturers to follow.

Materials

In addition to the fittings, valves, and accessories that comprise a pipe system, the pipes themselves vary in size and composition, depending on the application.

Acrylonitrile butadiene styrene (ABS)

ABS is suitable for the conveyance of potable water, slurries and chemicals, and is used for chilled water applications, due to its low temperature properties and compressed airline systems.

In residential settings, it is often used for interior grey and sanitary drain lines, waste and vent piping.

Polyvinyl chloride (PVC)

Polyvinyl chloride is the third most widely produced plastic, after polyethylene and polypropylene. PVC is widely used in construction because it is cheap, durable, and easy to assemble. PVC production is expected to exceed 40,000,000 tonnes (39,400,000 LT; 44,100,000 ST) by 2016.

PVC's intrinsic properties make it suitable for a wide variety of applications. It is biologically and chemically resistant, making it the plastic of choice for most household sewerage pipes and other pipe applications where corrosion would limit the use of metal. It is the predominant material for pressurized main landscape and garden irrigation supply lines; and lateral lines for conventional sprinkler, low-flow—low volume, and drip irrigation systems installations.

Roughly half of the world's polyvinyl chloride resin manufactured annually is used for producing pipes for various municipal, landscape, and industrial applications. In the water distribution market it accounts for 66% of the market in the US, and in sanitary sewer pipe applications, it accounts for 75%. Its light weight, high strength, and low reactivity make it particularly well-suited to this purpose. In addition, PVC pipes can be fused together using various solvent cements, or heat-fused (butt-fusion process, similar to joining HDPE pipe), creating permanent joints that are virtually impervious to leakage. PVC, in the form of unplasticized PVC (uPVC), molecularly-oriented PVC (PVC-O), and modified PVC (PVC-M) are used in pipe manufacture, though uPVC is the predominant material.

Unplasticized polyvinyl chloride (uPVC)

uPVC, commonly known as rigid PVC, or simply PVC, is used where resistance to chemicals and abuse is required.

Molecularly-oriented polyvinyl chloride (PVC-O)

PVC-O, commonly referred to as Molecularly-oriented PVC pipe, is manufactured in the United States by expansion of uPVC pipes. During the expansion process which uses pressure and elevated temperatures, the molecules of the uPVC pipe become oriented in a generally radial or circumferential direction. The molecular re-orientation increases the strength of the pipe in the hoop direction. The resulting Hydrostatic Design Basis (HDB) of the pipe is increased from 4,000 to 7,100 psi (28 to 49 MPa) . Consequently, the resulting pipe has a thinner wall than a conventional uPVC pipe (or "PVC pipe") of the same pressure capacity. The manufacture process of PVC-O in the US is an "offline process," while a second method, the "online process," is more widely used in Europe. In the US and Canada PVC-O pipe is considered a proprietary product. PVC-O is used only in pressure applications and not for gravity piping systems.

Chlorinated polyvinyl chloride (cPVC)

cPVC has many of the same properties as uPVC, and is also resistant to many acids, bases, salts, paraffinic hydrocarbons, halogens and alcohols. It is not resistant to solvents, aromatics and some chlorinated hydrocarbons.

In some places, it has been approved for use in residential water supply systems.

Polypropylene (PP)

Polypropylene is approved for use with foodstuffs, potable and ultra pure waters, hydronic heating and cooling, reclaimed and rainwater systems, compressed air lines, and geothermal applications, as well as within the pharmaceutical and chemical industries. Polypropylene is noted for its resistance to physical and chemical damage. Polypropylene is adversely affected by UV radiation and should have a protective coating if installed outside.

Polyethylene (PE) (XLPE)

When compared to other plastics, polyethylene shows excellent diffusion resistance, and because of this property, polyethylene has been used for gas conveyance for many years. It is used as supply pipe in commercial and residential Low-flow irrigation systems and drip irrigation systems. Cross-linked polyethylene material (XLPE) is being used to replace copper and traditional plastic piping for transporting both hot and cold water.

Oxidative-induction time is a routine test when assessing the quality of polyethylene pipes.

Polyvinylidene fluoride (PVDF)

PVDF is widely used in the chemical industry as a piping system for aggressive liquids. PVDF is a homopolymer without additives such as stabilizers and processing agents. It also displays excellent flame retardant properties.

Polybutylene (PB)

Polybutylene pipes (also known as polybutene-1 or PB-1) share similar properties to polyethylene pipes except the material can be made thinner due to increased creep resistance. PB pipes were used as water supply pipes in the United States and Canada from the 1970s to the 1990s. Due to premature aging of the pipe, leaks occurred frequently and eventually a class action lawsuit against the manufacturers was settled.

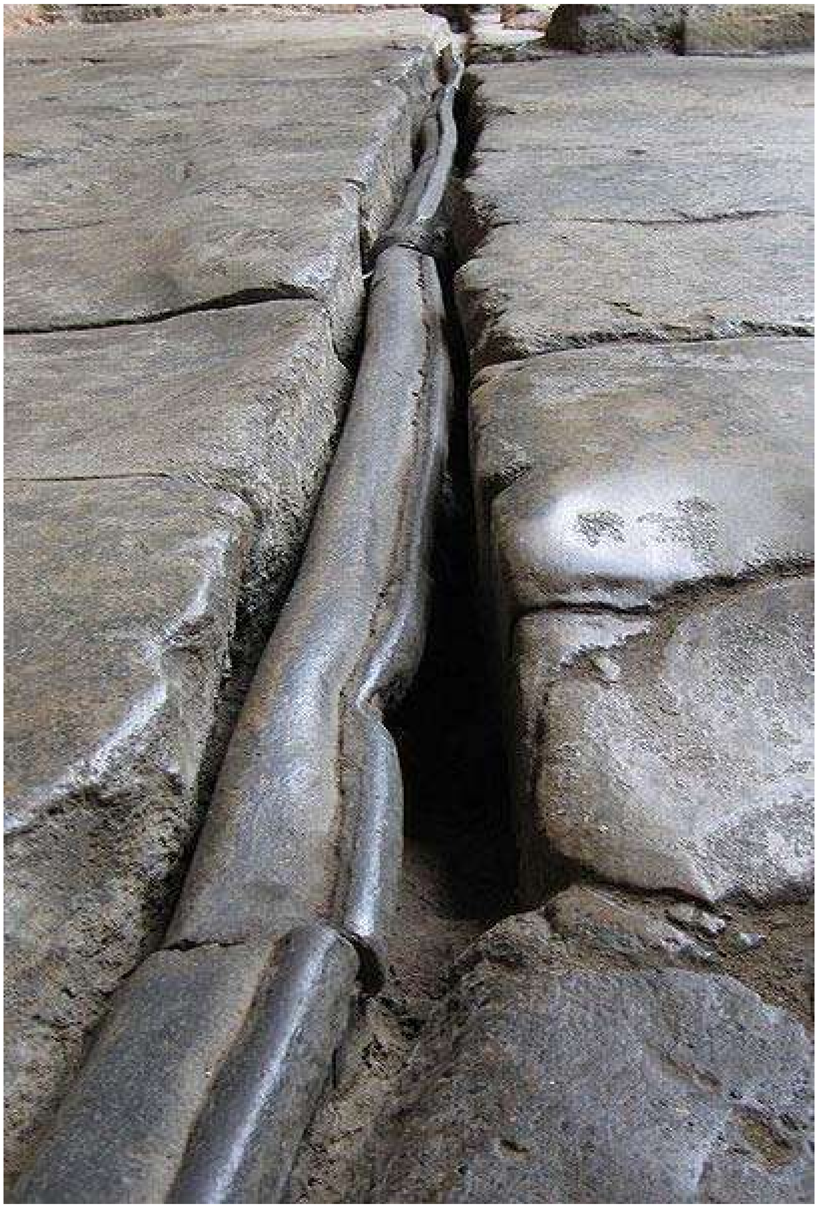
Chapter 21

Water Pipe

A system of copper water tubes used in a radiator heating system.

Water pipes are pipes or tubes, frequently made of polyvinyl chloride (PVC/uPVC), ductile iron, steel, cast iron, polypropylene, polyethylene, or copper, that carry pressurized and treated fresh water to buildings (as part of a municipal water system), as well as inside the building.

History



An original Roman lead pipe with a folded seam, at the Roman Baths in Bath, UK

Old water pipe, remnant of the Machine de Marly near Versailles, France

For many centuries, lead was the favoured material for water pipes, due to its malleability (this use was so common that the word "plumbing" derives from the Latin word for lead). This was a source of lead-related health problems in the years before the health hazards of ingesting lead were fully understood; among these were stillbirths and high rates of infant mortality. Lead water pipes were still in common use in the early 20th century and remain in many households. Lead-tin alloy solder was commonly used to join copper pipes, but modern practice uses tin-antimony alloy solder to join copper in order to eliminate lead hazards.

Despite the Romans common use of lead pipes, they were rarely poisoned by them. Unlike other parts of the world where lead pipes cause poisoning, the Roman water had so much calcium in it, that a layer of plaque prevented the water contacting the lead itself. What often causes confusion is the large amount of evidence of widespread lead poisoning, particularly amongst those who would have had easy access to piped water. This was an unfortunate result of lead being used in cookware and as an additive to processed food and drink, such as a preservative in wine. Roman lead pipe inscriptions provided information on the owner to prevent water theft.

Wooden pipes were used in London and elsewhere during the 16th and 17th centuries. The pipes were hollowed-out logs, which were tapered at the end with a small hole in which the water would pass through. The multiple pipes were then sealed together with hot animal fat. They were often used in Montreal and Boston in the 1800s, and built-up wooden tubes were widely used in the USA during the 20th century. These pipes, used in place of corrugated iron or reinforced concrete pipes, were made of sections cut from short lengths of wood. Locking of adjacent rings with hardwood dowel pins produced a flexible structure. About 100,000 feet of these wooden pipes were installed during WW2 in drainage culverts, storm sewers and conduits, under highways and at army camps, naval stations, airfields and ordnance plants.

Cast iron and ductile iron pipe was long a lower-cost alternative to copper, before the advent of durable plastic materials but special non-conductive fittings must be used where transitions are to be made to other metallic pipes, except for terminal fittings, in order to avoid corrosion owing to electrochemical reactions between dissimilar metals.

Bronze fittings and short pipe segments are commonly used in combination with various materials.

Pipe vs. tube

Typical PVC municipal water main being installed in Ontario, Canada

A plastic water pipe being installed. Note that the inner tube is actually transporting the water, while the outer tube only serves as a protective casing

The difference between pipe and tube is simply in the way it is sized. PVC pipe for plumbing applications and galvanized steel pipe for instance, are measured in IPS (iron pipe size). Copper tube, CPVC, PeX and other tubing is measured nominally, which is basically an average diameter. These sizing schemes allow for universal adaptation of transitional fittings. For instance, 1/2" PeX tubing is the same size as 1/2" copper tubing. 1/2" PVC on the other hand is not the same size as 1/2" tubing, and therefore requires either a threaded male or female adapter to connect them. When used in agricultural irrigation, the singular form "pipe" is often used as a plural.

Piping is available in rigid "joints", which come in various lengths depending on the material. Tubing, in particular copper, comes in rigid hard tempered "joints" or soft tempered (annealed) rolls. PeX and CPVC tubing also comes in rigid "joints" or flexible rolls. The temper of the copper, that is whether it is a rigid "joint" or flexible roll, does not affect the sizing.

The thicknesses of the water pipe and tube walls can vary. Pipe wall thickness is denoted by various schedules. Pipe wall thickness increases with schedule, and is available in schedules 20, 40, 80, and higher in special cases. The schedule is largely determined by the operating pressure of the system, with higher pressures commanding greater thickness. Copper tubing is available in four wall thicknesses: type DWV (thinnest wall; only allowed as drain pipe per UPC), type 'M' (thin; typically only allowed as drain pipe by IPC code), type 'L' (thicker, standard duty for water lines and water service), and type 'K' (thickest, typically used underground between the main and the meter). Because piping and tubing are commodities, having a greater wall thickness implies higher initial cost. Thicker walled pipe generally implies greater durability and higher pressure tolerances.

Wall thickness does not affect pipe or tubing size. 1/2" L copper has the same outer diameter as 1/2" K or M copper. The same applies to pipe schedules. As a result, a slight increase in pressure losses is realized due to a decrease in flowpath as wall thickness is increased. In other words, 1 foot of 1/2" L copper has slightly less volume than 1 foot of 1/2 M copper.

Demand for copper products have fallen due to the dramatic increase in the price of copper, resulting in increased demand for alternative products including PEX and stainless steel, however numerous PEX failures have been reported and rumoured across the US, leading many to question the quality of this type of alternative system.

Monument to water pipe in Mytishchi (Russia)

A specific water pipe made for use with pressure vessels. The pipe can sustain high pressure-water and is relatively small

Concrete water pipe