CHAPTER C7
PROCESS PIPING SYSTEMS

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INTRODUCTION

General Description

Piping is indispensable to petroleum refineries, chemical plants, and other process units. Piping for most process units represents the major item of unit investment. Typical total erected piping cost ranges from 25 to 50 percent of the total cost of a unit. Consequently, the piping engineer often faces the necessity of making careful and realistic compromises between design features and cost without sacrificing minimum safety standards.

This chapter provides a basic guide to the design of *process piping,* with specific emphasis on petroleum refineries, chemical, and other related processing plants. It attempts to provide an overview of the fundamental design principles used by the ASME Pressure Piping Code, Section B31.3, Process Piping. This Code prescribes requirements for materials and components, design, fabrication, assembly, erection, examination, inspection, and testing of piping. References will be made to other chapters within this handbook where more detailed coverage of design analyses and acceptance criteria are provided that relate to the ASME B31.3 Code.[1] This chapter will also provide guidelines for the design and layout of specific systems typically found in petroleum refineries and related petrochemical processing plants.

Prior to the 1976 edition of ANSI B31.3, this Code was titled ‘‘Petroleum Refinery Piping,’’ with direct application to the petroleum refinery industry; by inference it also served as the guiding document for the chemical process industry. The Code then expanded its scope to include areas where it previously had been used as reference, and B31.3 was retitled ‘‘Chemical Plant and Petroleum Refinery Piping.’’ With its current 1996 edition, the title of B31.3 was revised to ‘‘Process Piping’’ to reflect its further expanded scope of including piping typically found in petroleum refineries; in chemical, pharmaceutical, textile, paper, semiconductor, and cryogenic plants; and in related processing plants and terminals. Figure C7.1 provides a schematic diagram illustrating the scope of ASME B31.3 (from the 1996 edition) for

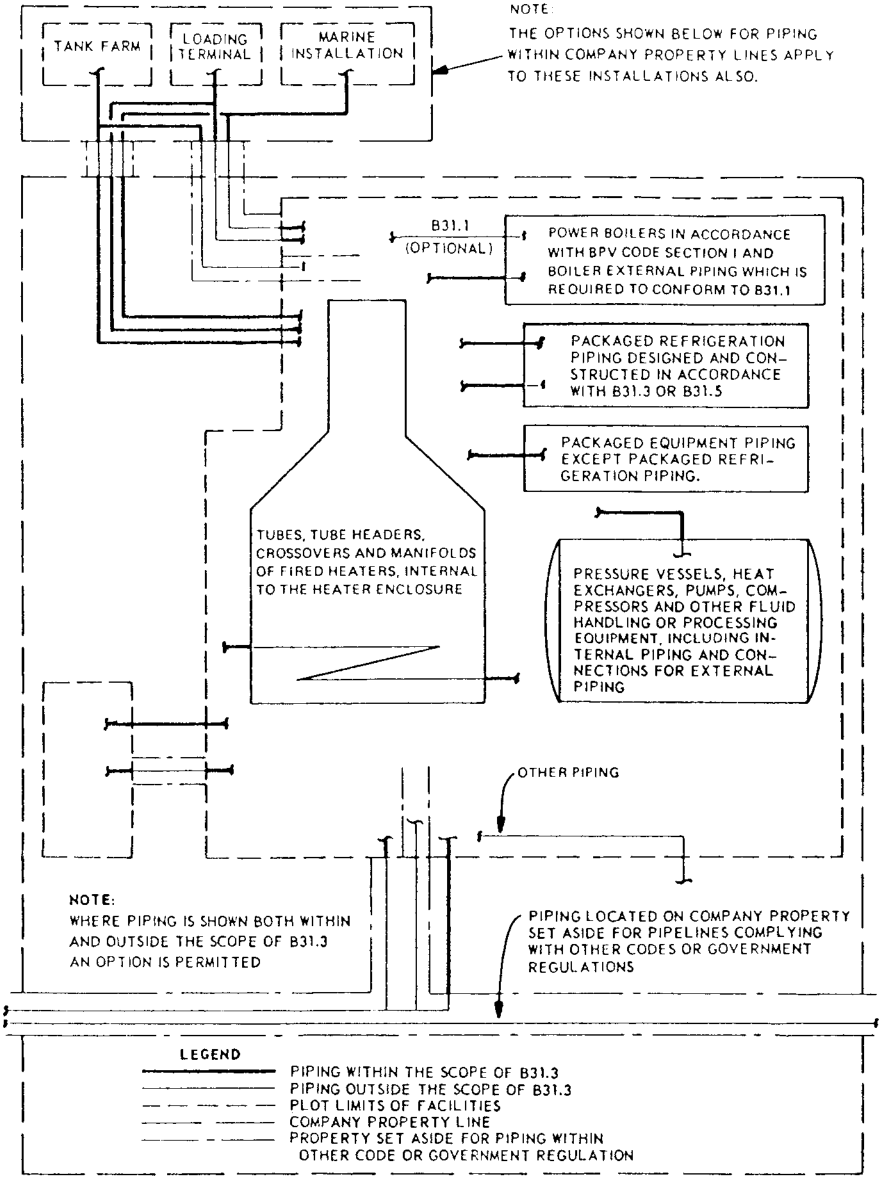


FIGURE C7.1 Scope of ASME B31.3 applicability for process piping (1996 edition). (*Reprinted from ASME B31.3 by permission of the American Society of Mechanical Engineers. All rights reserved.*)

process piping of a typical refinery or chemical plant. Included in this scope are piping systems which convey:

1. Petroleum products
2. Raw, intermediate, and finished chemicals
3. Gas, steam, air, and water
4. Fluidized solids
5. Refrigerants
6. Cryogenic fluids

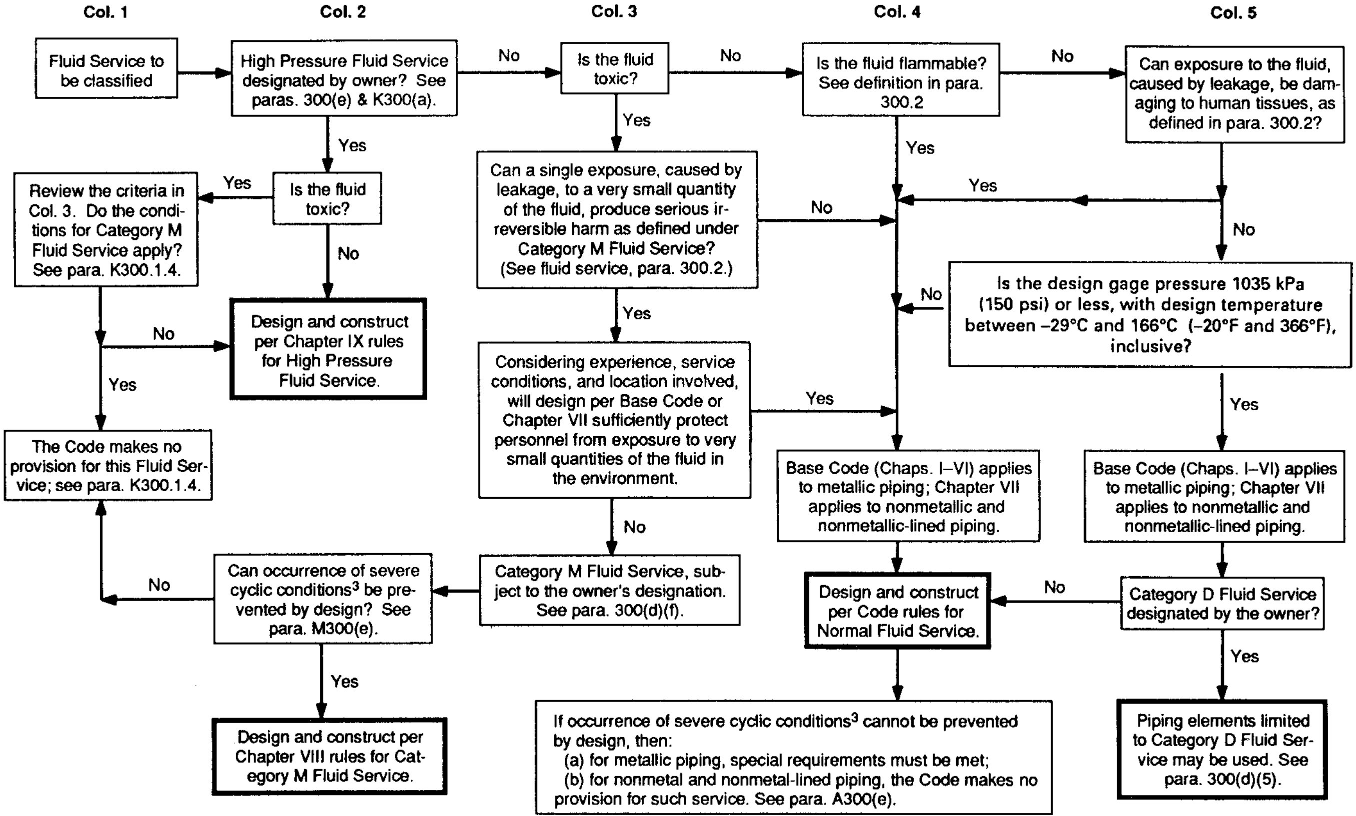
Some fluid services are further categorized by the Code according to the following category services, which need to consider the combination of fluid properties, operating conditions, and other factors which establish the design basis of the piping systems involved:

> ***Category D Fluid Service***—a service in which the fluid handled is nonflammable, nontoxic, and not damaging to human tissue, and the design pressure does not exceed 150 psi (1035 kPa) and the design temperature is between −20 and 366°F (−29 and 186°C). Part 3 (starting with Section 305) of the Piping Code covers specific design and fabrication requirements permitted for piping of Category D fluid services to reflect the less than severe conditions involved for these systems.
>
> ***Category M Fluid Service***—a service in which the potential for personnel exposure is judged to be significant and in which a single exposure to a very small quantity of a toxic fluid, caused by leakage, can produce serious irreversible harm to persons on breathing or bodily contact, even when prompt restorative measures are taken. Chapter VIII (starting with Section M300) of the Piping Code pertains to piping designated by the user as being in Category M fluid service.
>
> ***High-Pressure Fluid Service***—a service in which the user specifies the application of Chapter IX of B31.3 for piping design and construction for fluid services with high design pressures. High pressure is considered by the Code to be pressure in excess of that allowed by the ASME B16.5 Class 2500 rating for the specified design temperature and material group.[2] However, there are no specified pressure limitations for the application of these rules.
>
> ***Normal Fluid Service***—a fluid service pertaining to most piping covered by B31.3, i.e., not subject to the rules for Category D, Category M, or High Pressure Fluid service, and not subject to severe cyclic conditions.

The flow chart given by Fig. C7.2 has been taken from Appendix M of the Piping Code B31.3 to help the user determine the applicability of Category D and Category M Fluid services as distinguished from Normal services (and high-pressure services covered by Chapter IX of the Code).

Types of Systems

As applied to this section, *process piping* refers, except as excluded below, to all piping within the property limits of a chemical or petroleum processing plant installation. In addition to the main process units, this will typically include feed and product loading terminals, fuel oil and gas processing facilities, utility systems, waste and water treatment units, and bulk and atmospheric storage tank farms.



NOTES:
(1) See paras. 300(b)(1), 300(d)(4) and (5), and 300(e) for decisions the owner must make. Other decisions are the designer's responsibility; see para. 300(b)(2).
(2) The term "fluid service" is defined in para. 300.2
(3) Severe cyclic conditions are defined in para. 300.2. Requirements are found in Chapter II, Parts 3 and 4, and in paras. 323.4.2 and 341.4.3.

FIGURE C7.2 Determination of ASME B31.3 category M and D fluid services. (*Reprinted from ASME B31.3 by permission of the American Society of Mechanical Engineers. All rights reserved.*)

This is reflected in the scope of ASME B31.3 provided by Fig. C7.1. It should be noted that this figure was last published in the 1996 edition of the code and subsequently revised in a recent addenda. The earlier diagram as shown, however, provides a better illustration of the applicable process piping systems covered by the B31.3 Code for a typical refinery or chemical plant. Excluded from code jurisdiction are various low-pressure piping systems, plumbing, fired heater piping, and other special applications.

Petroleum Refinery Piping. The wide range of piping typically found in a refinery complex can vary from small-diameter instrument takeoffs to very large-diameter product processing piping, constructed from a number of steel and alloy materials. Operating over a broad range of pressures, principally below 1000 psi (6900 kPa) and at elevated temperatures of up to 1300°F (705°C), most refinery piping is used for conveying hydrocarbons or is in close proximity of hydrocarbon-containing equipment.[3] Consequently, the potential for a fire is ever present. The piping layouts depicted in Fig. C7.3 provide a good example of the complex interconnections involved in a typical refinery.

FIGURE C7.3 Typical process plant piping.

Chemical Plant Piping. As compared to refinery systems, typical chemical plant piping applications are usually smaller in size, mostly below NPS 8 (DN 200). Operating pressures for some services can be higher, but temperatures are generally lower and the presence of corrosive fluids is typical. The use of exotic alloy materials, thermoplastics, and thermoset resin materials in piping construction is common because of the highly corrosive nature of some chemicals. Many chemical plant piping systems convey flammable and/or toxic substances.

Other Related Processing Plants. Modern process facilities handle a myriad of chemical substances and compounds at various process temperatures and pressures. The piping systems specified to transport these fluids must be compatible with the intended service conditions. Since most of these facilities are one of a kind, the process piping materials selected for construction will be specific application driven. Today, numerous construction materials are available, both metallic and nonmetallic in nature. Installed cost variations may be as much as tenfold or even more, depending on the materials suitable for the application. Life cycle cost considerations must also be taken into account during the material selection phase to reflect subsequent repair and replacement requirements.

Whereas process piping material selection is specific application driven and will vary dramatically on a case by case basis, utility piping systems are basically the same across various process plants. Basic materials of construction and mode of construction will differ little from one plant to another for services such as air, water, and steam.

Table C7.1 is a hypothetical illustration of services and various piping material classes for a typical process facility. Note the material variations on the process side of the plant, compared to the relatively constant material types in the utility area of the facility.

Most metallic process piping is welded construction, except where flanged disas-

TABLE C7.1 Hypothetical Process Plant X, Y, Z Piping Service Index

Service	ASME Class	Temperature range		Piping material
		°F	°C	
Hydrocarbon processes				
Crude feed/Sour hydrocarbons	150	−20 to 200	−29 to 95	Carbon steel
Fractionation/Light hydrocarbons	150	−20 to 650	−29 to 343	Carbon steel
Catalytic cracking product	150	−20 to 900	−29 to 482	Type 316 SS or low alloy 5 Cr
Catalytic cracking regeneration	150	−20 to 1280	−29 to 693	Refractory lined CS or type 316 SS
Flare header	150	−50 to 750	−45 to 400	Killed carbon steel (low temp grade)
Fuel gas	150	−20 to 500	−29 to 260	Carbon steel
Hydrofiner feed product	300	−20 to 800	−29 to 427	Low alloy (1¼ Cr) or type 316 L SS
Propane	300	−50 to 250	−45 to 120	Killed carbon steel (low temp grade)
Methane feed	300	−20 to 925	−29 to 496	Low alloy (1¼ Cr)
Catalytic reformer/Hydrogen	600	−20 to 1100	−29 to 595	Low-alloy (1¼ or 2¼ Cr)
Ethane	600	−300 to 500	−184 to 260	Type 304L SS
Hot oil heating	600	−20 to 750	−29 to 399	Type 304 SS
Hydrocracker/Hydrocarbon	1500	−20 to 850	−29 to 454	Low alloy (1¼ Cr to 2¼ Cr)
Other Systems				
Acetic acid	150	−50 to 160	−45 to 70	Type 304 stainless steel
Caustic (15% by weight)	150	−20 to 150	−29 to 65	Monel
Chloride/Chlorine (Dry)	150	−20 to 125	−29 to 50	Carbon steel
Hydrochloric acid	150	−50 to 150	−45 to 65	Hastelloy
Liquid sulfur	150	−20 to 500	−29 to 260	Carbon steel jacketed or traced pipe
Hydrocarbons/Wet chlorine	300	−20 to 500	−29 to 260	Inconel or plastic-lined steel
Utilities				
Instrument air	150	−20 to 150	−29 to 65	Carbon steel galvanized/ SS tubing
Nitrogen/Utility air	150	−20 to 300	−29 to 149	Carbon steel
Potable water	150	−20 to 120	−29 to 50	Carbon steel—galvanized
Firewater	150	−20 to 500	−29 to 260	Carbon steel
Low-pressure steam/ condensate	150	−20 to 500	−29 to 260	Carbon steel
Boiler feed water	300	−20 to 500	−29 to 260	Carbon steel
High-pressure steam	600	−20 to 750	−29 to 399	Carbon steel

sembly is required, typically at equipment and valve connections. Due to the high value added cost of the process fluid and its potential for damage to personnel or the environment upon release, integrally welded joints for all size ranges are common.

Energy costs have made integrally welded joints for steam and other utility services more attractive when evaluated against conventional threaded joints and their potential for leakage. Threaded joint construction is still used for low-severity service, but it is typically limited to NPS 2 (DN 50) and smaller sizes, and to services that offer little or no threat to personnel safety or environmental harm.

REFERENCE CODES AND STANDARDS

Code application, jurisdiction, and specific scopes are covered in detail in Chap. A4, ''Piping Codes and Standards,'' in this handbook. This chapter closely parallels the requirements as outlined in ASME B31.3, ''Process Piping,'' 1996 Edition. Codes and standards referenced in this chapter are provided by Table C7.2. Refer to App. E10 for international codes and standards.

DESIGN CONDITIONS

The definitions in this section have been extracted from Process Piping Code, ASME B31.3.

Design Pressure

The design pressure of each component in a piping system shall not be less than the pressure at the most severe condition of coincident internal or external pressure and temperature (minimum or maximum) expected during service. The most severe condition of coincident pressure and temperature is that which results in the greatest required pipe thickness and the highest flange rating. When more than one set of pressure-temperature conditions exist for a piping system, the conditions governing the rating of components conforming to applicable standards may differ from the conditions governing the rating of components in accordance with ASME Code B31.3 pressure design criteria.

Design Temperature

The design temperature is the temperature at which, under coincident pressure, the greatest wall thickness or highest component ratings is required as explained above and shall be determined as follows:

1. *For fluid temperatures below 150°F (65°C),* the metal temperature shall be taken as the fluid temperature unless solar radiation or other effects result in a higher temperature.
2. *For fluid temperatures 150°F (65°C) and above,* the metal temperature for uninsulated components shall be no less than the following values, unless a lower average wall temperature is determined by test or heat transfer calculations:

TABLE C7.2 Referenced Codes and Standards

ASME Pressure Piping Code	
B31.1	Power Piping
B31.3	Process Piping
ASME Boiler and Pressure Vessel Code	
Section II	Materials, Part D
Section VIII	Boiler & Pressure Vessel Code—Pressure Vessels, Division 1
Section IX	Welding and Brazing Qualifications
ASME Standards	
B1.20.1	Pipe Threads, General Purpose (Inch)
B16.1	Cast Iron Pipe Flanges and Flanged Fittings
B16.3	Malleable-Iron Threaded Fittings, Class 150 and 300
B16.5	Pipe Flanges and Flanged Fittings
B16.9	Factory-Made Wrought Steel Butt-welding Fittings
B16.10	Face-to-Face and End-to-End Dimension of Ferrous Valves
B16.11	Forged Fittings, Socket-Welding and Threaded
B16.20	Metallic Gaskets for Pipe Flanges-Ring-Joint, Spiral-Wound, and Jacketed
B16.21	Nonmetallic Flat Gaskets for Pipe Flanges
B16.24	Bronze Pipe Flanges and Flanged Fittings, Class 150 and 300
B16.25	Butt Welding Ends
B16.28	Wrought Steel Buttwelding Short Radius Elbows and Returns
B16.34	Valves—Flanged, Threaded, and Welding End
B16.36	Steel Orifice Flanges, Class 300, 600, 900, 1500 and 2500
B16.39	Malleable Iron Threaded Pipe Unions, Class 150, 250 and 300
B16.42	Ductile Iron Threaded Pipe Unions
B16.47	Large Diameter Steel Flanges, NPS 26 Through NPS 60
B16.48	Steel Line Blanks
B36.10M	Welded and Seamless Wrought Steel Pipe
B36.19	Stainless Steel Pipe
ANSI/AWWA Standards	
C110	Ductile Iron and Gray Iron Fittings, 3 in. Through 48 in. for Water and Other Liquids
C111	Rubber Gasket Joints for Cast-Iron and Ductile-Iron Pressure Pipe and Fittings
C115	Flanged Cast-Iron and Ductile-Iron Pipe with Threaded Flanges
C151	Ductile Iron Pipe, Centrifugally Cast in Metal Molds or Sand-Lined Molds, for Water or Other Liquids
C504	Rubber Seated Butterfly Valves
API Standards	
594	Wafer and Wafer-Lug Check Valves
599	Steel and Ductile Iron Plug Valves
600	Steel Gate Valves—Flanged and Butt-welding Ends, Bolted and Pressure Seal Bonnets
602	Compact Steel Gate Valves—Flanged, Threaded, Welding, and Extended-Body Ends
603	Class 150, Cast, Corrosion-Resistant, Flanged-End Gate Valves
608	Metal Ball Valves, Flanged, Threaded, and Welding End
609	Butterfly Valves, Lug-Type and Wafer-Type Valves
610	Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Service
611	General-Purpose Steam Turbines for Refinery Service

TABLE C7.2 Referenced Codes and Standards (*Continued*)

API Standards (Continued)	
617	Centrifugal Compressors for Petroleum, Chemical, and Gas Industry Services
618	Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services
650	Atmospheric Storage Tanks
660	Shell and Tube Heat Exchangers for General Refinery Service
661	Air-cooled Heal Exchangers for General Refinery Service
674	Positive Displacement Pumps
RP 686	Recommended Practice for Machinery Installation and Installation Design
API Specification	
5L	Specification for Line Pipe
ASTM Standards and Specifications⁽¹⁾	
A53	Pipe, Steel, Black and Hot-Dipped, Zinc-Coated Welded and Seamless
A106	Seamless Carbon Steel Pipe for High-Temperature Service
A193/A193M	Alloy-Steel and Stainless Steel Bolting Materials for High-Temperature Service
A312/A312M	Seamless and Welded Austenitic Stainless Steel Pipe
A320/A320M	Alloy Steel Bolting Materials for Low-Temperature Service
A333/A333M	Seamless and Welded Steel Pipe for Low-Temperature Service
A335/A335M	Seamless Ferritic Alloy-Steel Pipe for High-Temperature Service
A358/A358M	Electric-Fusion Welded Austenitic Chromium-Nickel Alloy Pipe for High-Temperature Service
A426	Centrifugally Cast Ferritic Alloy Steel Pipe for High-Temperature Service
A451	Centrifugally Cast Austenitic Steel Pipe for High-Temperature Service
A494/A494M	Castings, Nickel and Nickel-Alloy
A671	Electric-Fusion-Welded Steel Pipe for Atmospheric and Lower Temperatures
A672	Electric-Fusion-Welded Steel Pipe for High-Pressure Services at Moderate Temperatures
A691	Carbon and Alloy Steel Pipe, Electric-Fusion Welded for High-Pressure Service at High Temperatures
B165	Nickel-Copper Alloy (UNS N04400) Seamless Pipe and Tube
B167	Nickel-Chromium-Iron Alloy (UNS N06600) Seamless Pipe and Tube
B241/B241M	Aluminum and Aluminum-Alloy Seamless Pipe and Seamless Extruded Tube
B407	Nickel-Iron-Chromium Alloy Seamless Pipe and Tube
B423	Nickel-Iron-Chromium-Molybdenum-Cooper Alloy (UNS N08825 and N08221) Seamless Pipe and Tube
B705	Nickel-Alloy (UNS N06225 and N08825) Welded Pipe
F436/F436M	Hardened Steel Washers
MSS Standards	
SP44	Steel Pipe Flanges
SP-45	Bypass and Drain Connections
Pipe Fabrication Institute (PFI) Specification	
ES-5	Cleaning of Fabricated Piping
ES-7	Minimum Length and Spacing of Welded Nozzles
ES-24	Pipe Bending Methods, Tolerances, Process and Material Requirements

Note: (1) Refer to Appendix A and Table 326.1 of ASME B31.3 for a more complete listing of ASTM Standard and Specifications.

- Threaded and welding end valves, pipe, welding fittings, and other components having wall thickness comparable to that of pipe: 95 percent of the fluid temperature
- Flanged valves, flanged fittings, and flanges (except lap joints): 90 percent of the fluid temperature
- Lap joint flanges: 85 percent of the fluid temperature
- Bolting: 80 percent of the fluid temperature

3. *Externally insulated piping:* The fluid temperature shall be used unless calculations, previous tests, or service experience based on measurements support the use of other temperatures. Where piping is heated by heat tracing or jacketing, the effect of such heating or cooling shall be incorporated in the establishment of the design temperature.

4. *Internally insulated piping:* The design metal temperature shall be based on heat transfer calculations or tests.

Design Minimum Temperature

The design minimum temperature is the lowest component temperature expected in service. This temperature may establish special design requirements and material qualification requirements, as required for low-temperature toughness testing of metals per Para. 323.2.2 of ASME B31.3.

Cooling Effects on Pressure

The cooling of a gas or vapor in a piping component may reduce the pressure sufficiently to create an internal vacuum. In such a case, the piping component must be capable of withstanding the external pressure at the lower temperature, or provisions must be made to break the vacuum.

Ambient Effects

Consideration needs to be given to low ambient temperature conditions for displacement stress analysis, and for possibly setting the design minimum temperature just discussed. Where the design minimum temperature of a piping system is below 32°F (0°C), the possibility of moisture condensation and buildup of ice shall be considered and provisions made in the design to avoid resultant malfunctions. This applies to surfaces of moving parts of shutoff valves, control valves, pressure-relief devices including discharge piping, and other components.

DESIGN LOADING CONSIDERATIONS

This section will discuss some of the more common loading conditions which need to be considered in the design of a piping system.

Imposed Pressure Including Transient Effects

In determining the system design pressure, it is important to consider the maximum differential operating pressure that can exist between the interior and exterior portions of the system. This needs to reflect the full range of anticipated operating conditions imposed of the system, including normal operation, startup, and shutdown conditions. All pressure sources need to be considered in determining the governing design pressure, including the following effects additive to the maximum operating pressure:

- Hydrostatic head effects due to differences in elevation between high and low points in the system
- Friction losses and back-pressure effects
- Pump shutoff heads
- Variations in system controls and other operating pressure surges

It is realistic to expect that short-duration transient system pressure excursions will occur during normal system operation. Provisions of ASME B31.3 allow for some acceptable level of overpressure transients for metallic and not brittle materials provided that the amount of time that the transient condition occurs does not exceed a specified percentage of the total system operating time per the following:

1. When the increased operating condition will not exceed 10 hours at any one time, or 100 hours per year, it is permissible to increase the pressure rating or the allowable stress for pressure design at the temperature existing during the increased operating condition by a maximum of 33 percent.
2. When the increased operating condition will not exceed 50 hours at any one time, or 500 hours per year, it is permissible to increase the pressure rating or the allowable stress for pressure design at the temperature existing during the increased operating condition by a maximum of 20 percent.

Some of the conditions which should be investigated for the short time period are the centrifugal pump shutoff pressure, or the pressure at the maximum point of the pump characteristic curve, centrifugal compressor surge-point pressure, stalling pressure of reciprocating pumps and reciprocating compressors, and the set pressure of relief valves which limit pressure in the piping.

Fluid Expansion Effects

The Code states that provision shall be made in the piping design either to withstand or to relieve increased pressure caused by the heating of static fluid in a piping component. Most operators, however, have found it unnecessary to provide a relief valve on piping components which may be blocked in. The reason for this is that leaks through valve seating surfaces relieve the pressure before it becomes excessive as the result of the heating of the blocked-in fluid. Valves utilizing resilient seating materials have made this more of a problem, however, because of their ability to seal even more tightly as the pressure increases. Consequently, when such valves are used, greater consideration should be given to the problem of possible pressure buildup in the valve body cavity. A similar problem can be created in a blocked-in section of process piping by the increase in pressure which can result from the evolution of gas caused either by an increase in fluid temperature or by a chemical reaction (e.g., hydrogen release as a product of corrosion).

Weight Effects

In the design of piping and its supports, it is required that live loads, dead loads, and loads and forces from other causes be taken into account. *Live load,* as used here, is taken as the weight of fluid transported plus snow and ice loads in localities where such conditions exist. *Dead load* is the weight of the piping components and insulation and other superimposed permanent loads. Reference is made to Chap. B2 of this handbook for more details in considering weight effects.

Other Mechanical Loads

The pipe wall must be sufficiently thick to prevent overstress, damage, collapse, or buckling due to superimposed loads from supports, ice formation, backfill, and other causes. In those cases where it is impractical to increase the thickness or if a thickness increase would cause excessive local stresses, the factors that would contribute to the damage of the piping are required to be corrected by other design methods. Examples of these considerations would be pipelines that run under railroad tracks or roadways, where steel pipe sleeves may be required to preclude excessive local bearing stresses being imposed on the pipe wall.

Dynamic Effects

The Code requires that the piping designer take into account wind and earthquake forces, although not concurrently, in design of his piping. It also requires that the designer consider impact forces (including hydraulic shock) and vibration. Vibration and impact forces create complex design problems. This is especially true in the case of vibration because difficult-to-detect low-amplitude high-frequency vibrations often produce the most dangerous stresses. Refer to Chap. B4 of this handbook for stress analysis of piping systems.

Most piping systems will vibrate to some extent. Vibration in piping may be generated by the following exciting forces:

1. Mechanical vibration of connected equipment, such as compressors, pumps, and vessels.[4]
2. Wind-produced vortices that form alternately on opposite sides of cylindrical surfaces.
3. Internal pulsations in flowing fluids, such as those set up by reciprocating pumps and compressors. Vibration from this latter cause can generally be kept within controllable limits by limiting pressure pulsations to 1 to 3 percent of line pressure.
4. Hydraulic transient effects, such as those caused by water hammer impact effects and relief valve discharge. Of all the loading conditions that a piping system may experience in service, hydraulic transients are among the most damaging. Typical damage could be the failure of pipe supports, restraints, and/or supporting structures. Breaches of pressure integrity can also be experienced, especially where large-diameter thin-walled piping is involved.

Where vibration is expected, good design should include the following:

- Adequate foundations, especially for reciprocating pumps and compressors.
- Strategic location of pipe guides and supports to reduce vibration. They should be installed so as to cause minimum restraint to normal thermal movements. The use of sway braces of the energy-absorbing or instant-counterforce-acting type is recommended for control of undesirable pipeline movement. Rigid braces are also effective in controlling movement, provided their restraining effect is taken into account in the piping flexibility design. Where pulsating flow exists, piping should be supported at all changes in direction, and cantilever sections should be avoided.
- Avoidance of small branch connections. Additional supports, such as gusset plates, to stiffen piping may help reduce certain vibration problems.
- An acoustical study to determine whether dampening equipment is needed. Failure can be caused by resonance of some part of the system with the pulsation frequency. Pressure pulsations can be minimized by the use of hydra-pneumatic accumulators, snubbers, or surge drums. These pulsation-reducing devices should be installed as close as possible to the pulsation-producing equipment.
- Any sudden change in the flow velocity or pressure in a liquid line will produce hydraulic shock (water hammer). Typical water hammer problems can be attributed to the rapid closure of a valve that results in hydraulic shock waves in the piping system upstream of the valve.

Water hammer requires careful consideration because it can damage equipment associated with piping and instrumentation even though the permissible pressures for piping components may not be exceeded. In addition to the utilization of slow-closing valves, the installation of surge tanks, pneumatic chambers, spring-operated relief valves, or shock absorbers are sometimes used to help control this phenomenon. Refer to Chap. B8 of this handbook for more details in dealing with this type of dynamic loading.

Another particular type of flow-induced pulsation warranting specific attention is associated with gaseous-flow pressure regulators and flow control valves.[5] These may produce high acoustic energies associated with both turbulence and flow separation. When operating with a severe pressure drop, such valves have high flow velocities that generate significant turbulence. This acoustic energy can couple with the acoustic and natural frequencies of the system to create severe vibration problems. Experience in the gas, petrochemical, power generation, and aerospace industries has shown that high-capacity pressure-reducing systems are prone to severe vibrations, which have caused piping fatigue failures in as short a period as 12 hours after initial commissioning of the system. Piping systems of particular concern include high capacity {>200,000 lb/hr (91,000 kg/hr) flow rate} and/or high pressure drop (>3.0 upstream to downstream pressure ratio) systems. Reference No. 5 provides more details on this type of vibration and considerations for mitigation, which is limited to low-noise-producing valve designs to avoid excessive acoustic energy generation.

Thermal Expansion and Contraction Effects

The following thermal effects, combined with loads and forces from other causes, need to be taken into account in the design of piping:

Thermal loads due to restraints. These loads consist of thrusts and moments that arise when free thermal expansion and contraction of the piping are prevented by restraints or anchors, including connections to fixed equipment.

Loads due to temperature gradients. These loads arise from stresses in pipe walls resulting from large rapid temperature changes or from unequal temperature distribution as may result from a high heat flux through a comparatively thick pipe or stratified two-phase flow causing bowing of the line.

Loads due to differences in expansion characteristics. These loads result from differences in thermal expansion where materials with different thermal expansion coefficients are combined, as in bimetallic, lined, or jacketed piping, or with metallic-nonmetallic composite piping systems.

Corrosion and Erosion Allowances

A commonly used nominal value for corrosion allowance is 1⁄16 in (1.5 mm) for carbon steel and low-alloy steel piping in hydrocarbon service. Larger corrosion allowances [typically up to ¼ in (6 mm)] for these materials may be required to allow for severe corrosion and/or erosion anticipated for the fluid service involved. Higher-alloy materials, including austenitic steels, are typically required for very corrosive service environment. The allowance for corrosion or erosion should be considered for all surfaces exposed to the process fluid. Determinations for recommended corrosion/erosion allowances are typically based on corrosion monitoring techniques and representative process experience. In addition, the possibility of external corrosion should be considered for piping systems located in aggressive environments such as at marine terminals off coastal waters.

Threading and Grooving Allowances

Calculations for the thickness of piping components which are to be threaded or grooved are required to include a dimensional allowance equal to the depth of the cut plus the required tolerance. For threaded components, the nominal thread depth (dimension *h* of ASME B1.20.1, or equivalent) should apply.[6] For machined surfaces or grooves where the tolerance is not specified, the tolerance is taken as 0.02 in (0.5 mm) plus the depth of cut. Threading and grooving allowances, weld joint factors, and other mechanical strength factors shall be as required by the applicable Code.

Allowable Stresses

Allowable stress values (S) are provided by Table A-1, and Table A-2 for bolting, of the Process Piping Code ASME B31.3, which are used in principal design calculations within this Code. The stress values in these tables are basic allowable stresses in tension which are grouped by material specifications and product forms, and are for stated temperatures up to specified maximum limits. Design equations within the code often stipulate the product of S and E, where:

$$S = \text{Material allowable stress}$$
$$E = \text{Quality factor}$$

The factor E (formerly defined by the code as *joint efficiency factor*) represents one of the following quality factors:

- Casting quality factor E_c is provided by Table A-1A of the Code based on the listed material specification and the type of casting inspection examinations. The code also describes various supplementary inspections which permit the allowable stresses and casting quality factors to be increased. The casting quality factors, however, do not apply to valves, flanges, and fittings that conform to the standards listed in Table 326.1 of the code.
- Weld joint quality factors E_j is tabulated in Table A-1B of the Code for straight or spiral welded joints for pressure-containing components. This is further defined by Table 302.3.4 of the Code. As in the case of casting quality factors, the Code allows for increased joint quality factors for certain kinds of welds if additional examination is performed beyond that required by the product specification.

If a component is made of castings joined by longitudinal welds, both a casting and a weld joint quality factor applies to reduce the material allowable stress in accordance with the Code.

The bases for establishing the basic allowable stress values for ferrous, nonferrous, and nonmetallic materials are described in the Code. The Code user will need to refer to this only in those cases where he or she desires to establish allowable stresses for an unlisted material.

The allowable stress values in shear and bearing are 0.80 and 1.60, respectively, times the values contained in the Code.

For other than normal operations, the allowable adjustments in pressure-temperature ratings as just set forth are applicable to allowable stress values in calculations concerning components, such as pipe, which do not have established pressure-temperature ratings.

The designer should remember that a more severe operating condition may be caused by increased contents load than by increased temperature or pressure. For example, a pipeline may have been designed for gaseous service. Subsequent process changes required the pipeline to see liquid service at nominally the same pressure and temperature as the previous gas service. The basic pipe spans would need to be reevaluated due to the increase in the dead-weight bending loads caused by the added weight of the liquid contents.

Limits on Calculated Stresses Due to Sustained Loads and Thermal Expansion

This subject is covered in detail in Chap. B4 of this handbook. Design considerations in the application of these criteria to process system piping will be covered in subsequent sections of this chapter.

Pressure-Temperature Ratings for Piping Components

Pressure-temperature ratings have been established for certain piping components. Those that have been accepted by ASME B31.3 are maintained in the standards listed in Table 326.1 of this Code. These established ratings should not be exceeded by the expected normal operating conditions. However, during shutdown, startup, or an interruption in the normal operation of a process unit, conditions more severe than normal may be characteristic of a service. Depending on the frequency and duration of these more severe conditions, the Code permits adjustment of the pressure ratings as previously discussed on transient pressure effects. Extrapolation of accepted pressure-temperature ratings is permitted when these ratings do not extend to the upper material temperature limits allowed by the code, provided this is done in accordance with the applicable rules of the standard involved.

PRESSURE DESIGN OF PIPING COMPONENTS

Straight Pipe

The equations given in the Code consider pressure, mechanical, corrosion, and erosion allowances. In addition to these factors, the Code requires that all designs (not only those for straight pipe) be checked for adequacy of mechanical strength under the applicable loadings discussed previously. The Code gives equations for determining the thickness of straight pipe for the outside diameter/thickness ratios D_o/t greater than 6. The pressure design of piping having a diameter/thickness ratio of 6 or less requires special considerations which encompass design and material factors, such as theory of failure, fatigue, and thermal stress. These considerations are addressed in Chap. IX of the Code for High Pressure Piping. Refer to Chap. B2 of this handbook for the calculation of the required minimum wall thickness of the pipe.

Piping lengths subjected to external pressures will also need to be sufficiently stiff to resist buckling. The Piping Code refers to the procedures of the ASME Boiler and Pressure Vessel (BPV) Code, Section VIII, Div. 1, for piping subjected to external pressure, which should be specifically reviewed in case of relatively large-diameter and thin-walled piping systems.[7] This may require the addition of external stiffening rings or thicker pipe walls to resist buckling. Refer to Chap. B2 of this handbook for calculating pipe wall thickness when piping is subjected to external pressure.

Bends and Elbows

The minimum required wall thickness at a pipe bend after bending should be determined as for straight pipe, provided the bending operation does not produce a difference between the maximum and minimum diameters greater than 8 percent for internal pressure service and 3 percent for external pressure. The centerline radius of pipe bends should typically be a minimum of 3 times the nominal pipe diameter. Smaller radius bends as tight as 1½ *D* are possible, such as that obtained with induction bending methods with appropriate heat treatment. Specific manufacturing experience and process procedures in these circumstances should be reviewed by the process plant owner in assessing cost incentives over more conventional pipe bends or elbows.

Elbows that are manufactured in accordance with any of the standards listed in Table 326.1 of the ASME B31.3 Code are considered to be suitable for use at the pressure-temperature rating specified in the listed standard. In the case of standards under which elbows are made to a nominal pipe thickness, such as ASME B16.9, the elbows are considered suitable for use with pipe of the same nominal thickness.[8]

Miters

The thickness of each segment of a miter must be designed in the same manner as straight pipe. The thickness, however, does not allow for the discontinuity stresses that exist at junctions between the segments of a miter. These stresses are reduced for a given miter as the number of segments is increased. An angular offset of 3° or less does not require design considerations as a miter bend, and the same design basis applies as is used for straight pipe. The Code requires multiple miter bends with miter angle cuts not greater than 22.5°, which requires a minimum of 2 miter cuts to achieve a short-pattern full 90° bend. Single miter bends are allowed with a miter cut angle greater than 22.5°, but different design rules apply. Miters in process plants are typically limited to relatively large diameter and low-pressure [50 psig (345 kPa) or less] piping systems, especially where elbow fittings are not readily available. Even for these services, 90° miter bends should have three or more segments. Refer to Fig. C7.4.

The wall thickness of mitered segments of pipe subjected to external pressure must be designed in the same manner as required for straight pipe.

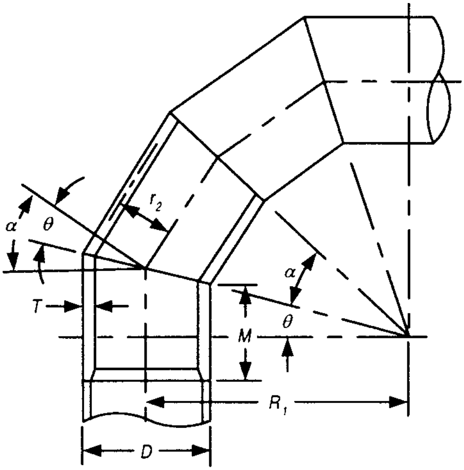
Branch Connections

Branch connections may be made by the use of integrally reinforced fittings (e.g., tees, extruded outlets, branch outlet fittings, laterals, and crosses), welding outlet fittings or by welding the branch pipe directly to the run pipe, with or without added reinforcement as covered by the Code. The Code gives rules governing the design of pipe-to-pipe branch connections to sustain internal and external pressure in those cases where the angle between the axis of the branch and of the run is between 45° and 90°. Branch connections in which the smaller angle between the axis of the branch and the run is less than 45° impose special design and fabrication problems. The rules given in the Code for angles between 45° to 90° may be used as a guide, but sufficient additional strength must be provided to ensure safe and satisfactory service, and the design must be substantiated by the provisions of the Code for nonstandard piping components.

Branches at angles other than 90°, such as laterals, should be avoided except when flow and pressure drop considerations greatly outweigh the difficulty in obtaining satisfactory welds and the greater difficulty in adequately reinforcing such connections.

For welded pipe-to-pipe branch connections, the stress concentration at the junction increases rapidly as the size of the branch approaches the size of the run. This is also true with most welding outlet fittings. Consequently in services which involve considerable cycling due to pressure or temperature or both, it is usually good practice to make the branch connections with butt-welding tee fittings, or socket-welding fittings in the case of small-diameter piping. The use of butt-welding tees is also considered good practice for full-sized branches in most process services. If there is at least one size reduction in the branch, fabricated pipe-to-pipe branch connections should, as a rule, be acceptable for all services except those with severe cycling. The use of reinforcing pads for fabricated branch connections should also be avoided for elevated temperature services greater than 800°F (426°C) due to concerns for high differential thermal expansion strains.

Strength of Branch Connections. The opening made in a pipe for a branch connection weakens the pipe, and unless the wall thickness of the pipe is sufficiently in



Where:

D = outside diameter of pipe

r_2 = mean radius of pipe using nominal wall T

T = miter pipe wall thickness (measured or minimum per purchase specification)

C = sum of mechanical and corrosion/erosion allowances

θ = angle of miter cut

α = angle of change in direction at miter joint
= 2θ

R_1 = effective radius of miter bend, defined as the shortest distance from the pipe center line to the intersection of the planes of adjacent miter joints

The ASME piping Code, B31.3, requires that the value of R_1 shall not be less than:

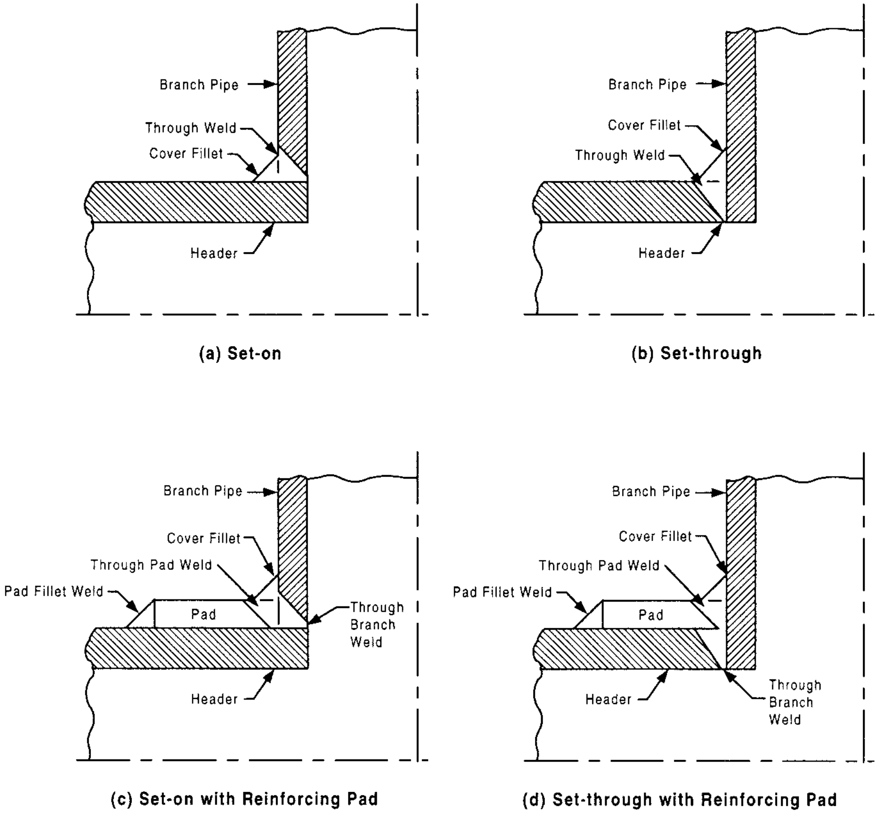
$$R_1 \geq \frac{A}{\tan\theta} + \frac{D}{2}$$

Where:

A = an empirical value defined by Section 304.2.3 of this code.

FIGURE C7.4 Nomenclature for miter bends.

excess of that required to sustain the pressure, it may be necessary to provide reinforcement. Typical welded branch connections permitted by the Code are illustrated in Fig. C7.5 shown with and without added reinforcement. The amounts of reinforcement required to sustain the pressure in welded pipe-to-pipe branches are outlined in Sec. 304.3 of ASME B31.3. Certain branch connections may be made without the necessity of their use being supported by engineering calculations. This includes, for example, branch connections made by welding a threaded or socket welding coupling or half-coupling directly to the pipe run, provided the size of the



(a) Set-on **(b) Set-through**

(c) Set-on with Reinforcing Pad **(d) Set-through with Reinforcing Pad**

FIGURE C7.5 Fabricated branch connections.

branch does not exceed NPS 2 (DN 50), and the coupling has a minimum rating of Class 2000 per ASME B16.11.[9]

Other Design Considerations for Branch Connections. In addition to pressure loadings, external forces and movements are applied to a branch connection by thermal expansion and contraction, dead and live loads, and movement of piping terminals and supports. Due consideration must be given to the design of a branch connection to withstand these forces and movements. Fabricated branch connections made by welding the branch pipe directly to the run pipe also should be avoided when the branch size exceeds 0.8 times the run size or where repetitive stresses may be imposed on the connection by vibration, pulsating pressure, temperature cycles, and so forth. In such cases, it is recommended that the design be conservative and that considerations be given to the use of tee fittings or complete encirclement types of reinforcement.

Closures

The design of welded flat closures, ellipsoidal, spherically dished, hemispherical, and conical closures is encountered relatively infrequently. Closure fittings manufactured in accordance with ASME B16.9 and B16.11 are considered suitable for use at the pressure-temperature ratings specified by such standards. In the case of standards under which closure fittings are made to nominal pipe thickness, the closure fittings shall be considered suitable for use with pipe of the same nominal thickness. In process plant piping the most commonly used closure is probably the butt-welding cap. Bolted flanged covers are used where access is needed.

Openings in Closures. Code rules govern the design of openings in closures when the size of the opening is not greater than one-half of the inside diameter of the closure. The basis for the design of these openings in closures is the same as it is for branch connections. Closures with larger openings must be designed as reducers, except that flat closures must be designed as flanges.

Reducers

Reducers, either concentric or eccentric, are typically provided as forged or wrought fittings in accordance with an accepted standard (e.g., ASME B16.9 in the case of wrought steel butt welding fittings). Concentric reducers are typically made in conical or reversed curve sections, or a combination of such sections, and the design requirements of the Code for conical and toriconical closures apply.

Flanges

Flanges manufactured in accordance with ASME Standards B16.5, B16.36, B16.1, B16.24, B16.42, and B16.47 are considered suitable for use at the pressure-temperature ratings specified by such standards. Flanges not made in accordance with the standards listed shall be designed in accordance with Sec. VIII Div. 1 of the ASME Boiler and Pressure Vessel Code, except that the requirements for fabrication, assembly, inspection, and testing, and the pressure and temperature limits for materials of ASME B31.3 shall govern. ASME Section VIII, Division 1, design requirements with allowable stresses from B31.3 are also referenced for the design of blind flanges.

Blanks

The Piping Code provides design bases for determining the minimum pressure design thickness for permanent blanks, which are used to isolate or dead-end piping systems. Corrosion or erosion allowances and manufacturer's minus tolerance must be added to the thickness thus determined. Standard dimensions for permanent blanks and figure 8 blinds are provided by ASME B16.48 (formerly covered by API 590), Steel Line Blanks, which are typically used for most process refinery applications.[10]

In the design of temporary blanks which are not to be used during operation of the piping (e.g., during shutdowns or during testing), an allowable stress equal to 90 percent of the material's yield strength is sometimes used. It is suggested, however, that ¼ in (6.0 mm) is a practical minimum thickness for carbon-steel blanks.

Expansion Joints

Thermal expansion of piping systems within process plants is normally accommodated with the inherent flexibility achieved with elbows, bends, and pipe expansion loops. There are some special cases, however, where the layout requirements of the piping require the use of expansion joints. This may be the case, for example, if the system cannot tolerate appreciable pressure losses with the addition of elbows or bends. Instead, system thermal expansion or contraction requirements can be accommodated using a suitably designed expansion joint. Since expansion joints are comparably more vulnerable to potential damage and fatigue failures, they should only be considered after all other normal flexibility alternatives have been explored.

Several different types of expansion joints are available, ranging from rubber hose to metal bellows, which are covered in Chap. A2 of this handbook. If used in process plants, expansion joints are typically the metal bellows type, using U-shaped convolutions. The design of metal bellows type expansion joints is covered by App. X of the Process Piping Code, ASME B31.3. In addition to the pressure and thermal expansion design of the bellows, it is important to ensure that piping movements and external bending loads will not be beyond the limits of the joint design. Potential problems caused by pressure thrust must be considered. Refer to Chap. A2 for more details.

Attachments

Attachments to piping, both external and internal, are required to be designed so that they will not cause flattening of the pipe, excessive localized bending stresses, or detrimental thermal gradients in the pipe wall. It is important that such attachments be designed to minimize stress concentrations, particularly in cyclic services or systems prone to imposed vibrations. Gusseting of small piping connections ($\leq$ NPS 1½, or $\leq$ DN 40) should be considered for equipment and piping in vibrating services to provide proper bracing of these appurtenances against potential fatigue failures.

Pressure Design of Non-standard Components

In general, all pressure-containing components need to satisfy code requirements. However, if the design of similarly shaped or proportioned components has been proven successful by performance under comparable service conditions, provision for the use of such components is allowed by the Code. Alternatively, the Process Piping Code, Sec. 304.7.2, permits the pressure design of the non-standard component to be proven either by an experimental stress analysis or by tests made in accordance with the ASME Boiler and Pressure Vessel Code, Sec. VIII.

SELECTION AND LIMITATIONS OF PIPING COMPONENTS

Pipe and Fittings

Table C7.3 lists typical piping materials for commonly used pipe found in process plants. It includes both welded and seamless pipe per the applicable specification.

TABLE C7.3 Piping Material Specifications

Material	Requirements
Cast iron	ANSI/AWWA C115 (Centrifugally Cast)
Ductile iron	ANSI/AWWA C151
Carbon steel	API 5L; ASTM A53, A106, A333/A333M, A671, A672, A691
Ferritic alloy steel	ASTM A335/A335M, A426, A671, A672, or A691: Classes 11, 22, 32, or 42
Austenitic Cr-Ni steel	ASTM A312/A312M, A358/A358M, A451
Monel	ASTM B165
3½ Ni or 9 Ni	ASTM A333/A333M
Inconel	ASTM B167
Aluminum	ASTM B241/B241M
Incoloy	ASTM B407, B423, B705

The majority of process plant piping is carbon steel, either longitudinally welded or seamless.

Cast-iron and ductile-iron pipe materials are usually limited to Category D water services not subject to freezing for most process plants, and typically are specified as centrifugally cast material. Low-melting-point alloys, such as aluminum, brass, and bronze should not be used in flammable or combustible fluid services.

The following list provides some guidelines on the application of welded pipe as typically used within hydrocarbon processing plants:

1. All longitudinally or spiral-welded pipe should be hydrostatically tested, and inspected by either ultrasonic or electromagnetic means by the manufacturer.
2. The use of furnace butt-welded pipe in typical process plants is usually limited to a maximum size of NPS 4 (DN 100) and restricted to water service per Category D of the B31.3 Piping Code.
3. Longitudinally welded carbon steel pipe is usually supplied to either electric-welded or fusion-welded specifications and typically acceptable for most applications requiring carbon steel pipe.
4. Spiral-welded pipe, as specified by API 5L, is primarily used outside of normal process units, typically for carbon steel offsite piping, including tank farms and terminal transfer piping. The spiral seams should be double-submerged arc-butt-welded.

Applicable standards and sizes of fittings are summarized in Table C7.4.

TABLE C7.4 Recognized Standards for Fittings

Fittings	Size range	Applicable Standards
Steel buttwelding fittings	NPS ½ thru 24 (DN 15 thru 600) Over NPS 24 (>DN 600)	ASME B16.9 ASME B31.3
Steel socket welding and threaded fittings	NPS ½ thru 2 (DN 15 thru 50)(1)	ASME B16.11(2)
Malleable iron threaded fittings(3)	NPS ½ thru 2 (DN 15 thru 50)	ASME B16.3
Gray iron and ductile iron fittings(4)	NPS 2 thru 48 (DN 50 thru 1200)	ANSI/AWWA C110
Flanged fittings	NPS ½ thru 24 (DN 15 thru 600)	ASME B16.5

Notes:
(1) Normally used sizes.
(2) Covers NPS ⅛ (DN 6) through NPS 4 (DN 100) fittings.
(3) Limited to air, inert gas, and water service.
(4) Gray iron limited to water service. Ductile iron limited to nonhydrocarbon service.

There are many Code mandated restrictions for the use of fittings, bends, and other related components which are not universally applicable to all process plant services. Some guidelines, however, are of value to the designer and are listed in the following paragraphs.

- In typical process complexes, flanged connections should be limited to locations where their use is considered essential to the operation and maintenance of the unit. This is particularly the case for critical services where welded fittings and connections should be used to reduce the potential for leakage associated with flanged connections.
- Butt-welding elbows are typically of the long-radius type unless specific layout restrictions require the special application of short-pattern elbows.
- In services with very high corrosion rates, butt-welding fittings are preferred to threaded and socket-welding fittings.
- Pipe couplings or threaded fittings made of cast, malleable, or wrought-iron are not permitted for flammable fluids within process limits or hazardous fluids in any area.
- Large-radius pipe bends are preferred to butt-welding elbows for reciprocating compressor suction and discharge piping, vapor relief-valve discharge piping, and piping conveying corrosive fluids (such as acid) where turbulence in a fitting may cause excessive corrosion.
- Threaded plugs are preferred to pipe caps for threaded end closures to reduce dead-end corrosion problems caused by inadequate draining of trapped corrosive fluids.
- The use of bell-and-spigot fittings is limited to water and drainage service.

Special Considerations for Fittings in Abrasive Fluidized Solid Services. The following additional guidelines are offered for fittings and other pipe components in fluidized solids services where internal erosion concerns exist:

- Long radius bends should be used for dense-phase flow of pulverized abrasive solids and for all piping which handles either pulverized or granular solids suspended in liquids or granular solids suspended in gases.
- Long radius bends or dead-end tees should be used for piping which conveys pulverized abrasive solids suspended in gas in the dilute phase. Dead-end tees (so arranged that the flow will impinge against the dead end) have a longer life than bends in abrasive service and should be used if the system can be designed to accommodate the resulting increase in pressure drop.
- Similarly, if the flow is through a branch into a header (or run pipe) in a piping system which transports pulverized abrasive solids suspended in gas in the dilute phase, a dead-end cross (so arranged that the flow will impinge against the dead end) should be considered.

Piping Joints

The type of piping joint used must be suitable for the pressure-temperature conditions and should be selected by giving consideration to joint tightness and mechanical strength under the service conditions (including thermal expansion), and to the nature of the fluid handled with respect to corrosion, erosion, flammability, and toxicity. In general, the number of disassembly joints is minimized; most joints are welded if the material is weldable.

Welded piping is used almost exclusively for transporting hydrocarbons and other flammable fluids. This includes bypass piping, alternate process connections, and auxillary piping systems such as gland oil, seal oil, lubricating oil, fuel gas, fuel oil, heating or cooling oil, flushing oil, flue gas, blowdown piping and the like. Welded construction is also used for all piping outside process unit limits which is used for the transfer of hydrocarbons or most other process fluids.

Welded Joints. The Code permits welded joints in all instances in which it is possible to qualify welding procedures, welders, and welding operators in conformance with the rules of the Code. There are, however, a few minor additional considerations for seal-welded (threaded) and socket-welded joints, which are typically limited to pipe sizes NPS 2 (DN 50) and smaller, except for air or water below 250°F (121°C). For example, the Code cautions against the use of socket-welded construction in cases where severe crevice corrosion or erosion could occur. The Code also states that seal welds may be used to avoid joint leakage but that they shall not be considered as contributing any strength to the joint.

Flanged Joints. The number of bolted flanged joint connections in a piping system is usually determined by maintenance and erection considerations, including flanged joints needed for the insertion of blanks during shutdown and for system isolations during initial hydrostatic testing. Where flanges of different ratings are bolted together, the rating of the joint must not exceed the lower rated flange. The selection of flanges is a topic within itself, which will be discussed in more detail in a subsequent section.

Threaded Joints. Economics will limit the use of threaded piping to small pipe sizes, NPS 2 (DN 50) and smaller, for most services. It is also used for most galvanized piping connections. The threading of pipe with a wall thickness less than ASME B36.10M standard wall is not permitted.[11] The use of threaded joints also should be avoided where crevice corrosion, severe erosion, or cyclic loading may occur.

All pipe threads on piping components must be taper pipe threads in accordance with ASME B1.20.1, except that:

- Pipe threads other than taper pipe threads may be used for piping components where tightness of the joint depends upon a sealing surface other than the threads (e.g., a union comprising of male and female ends joined with a threaded union nut), and where experience or tests have demonstrated that such threads are suitable for the condition.
- Couplings, NPS 2 (DN 50) and smaller, with straight threads may be used only for Category D Fluid Service, and only with taper-threaded mating components.

Seal welding of threaded joints is recommended for all services except for Category D fluid services. Threaded joints also do not need to be seal welded if the joint is for instrument connections or for piping components that require periodic removal for maintenance. Similarly, seal welding is typically not required for plugs and caps for drain and vent valves, and for union ring threads.

Expanded Joints. This type of joint is more commonly used on the piping and tubes for refinery heaters or steam generators. Expanded joints are excluded for use in hazardous and/or toxic services and under severe cyclic conditions. Adequate means must be provided to prevent separation of the joint if used. Expanded joints are not typically used in process applications, and if they are used, considerations must be given to the tightness of the expanded joint when subjected to vibration, or differential expansion or contraction due to temperature cycling or external mechanical loads.

Flared, Flareless, and Compression Joints. The use of flared, flareless, or compression type tubing fittings may be considered for tubing connections, as may be required for instruments or other similar devices, within the limitations of applicable component standards or specifications. In the absence of such standards or specifications, the adequacy of the fitting should consider the following:

- The pressure design must meet the requirements of the Code.
- A suitable quantity of the type and size of fitting to be used should meet successful performance tests to determine the safety of the joint under simulated or similar service conditions.
- Fittings and their joints must be suitable for the tubing with which they are to be used.
- Fittings must not be used in services which exceed the manufacturer's maximum pressure and temperature limits and recommendations.

Caulked Joints. The term *caulked joints* applies to joints of the bell-and-spigot type which are permitted only for Category D water service and to a temperature of not over 200°F (93°C). They also must be used within the pressure-temperature limitations of the pipe to which they are applied. Provisions must be made to prevent disengagement of the joints at bends and dead ends and to support lateral reactions produced by branch connections or other causes. Further details on this type joint are covered in Joining Cast-Iron Pipe in Chap. A2 of this handbook.

Brazed and Soldered Joints. Fillet-brazed or fillet-soldered joints may not be used in process piping, but the use of soldered and silver-brazed socket-type joints is permitted in nonflammable nontoxic service. The melting point of brazing alloys should be considered where possible exposure to fire is involved.

Other Proprietary Joints. Coupling-type, mechanical-gland type, and other proprietary-type joints are available and may be considered for use provided adequate provision is made to prevent separation of the joints. The design should be verified according to the procedures of ASME B31.3 for special fittings, which should include the performance testing of a prototype joint to confirm the safety of the joint under simulated service conditions. These tests should incorporate anticipated loading conditions, including the simulation of vibration, fatigue, cyclic conditions, low temperature, thermal expansion, or hydraulic shock.

Selection and Limitations of Flanges

Flange components used in most process plants follow the design and material requirements of the standards listed in Table C7.5. It is important to note that large-diameter flanges specified by ASME B16.47 ‘‘Large Diameter Steel Flanges’’ are available in 2 different size categories: Series A, which are dimensionally the

TABLE C7.5 Flange Material Specifications

Flange material	Size range	Applicable standard
Carbon steel Ferritic alloy steel Austenitic Cr-Ni steel 3½% Ni steel	NPS ½ thru 24 (DN 15 thru 600)	ASME B16.5
	NPS 26 thru 60 (DN 650 thru 1500)	ASME B16.47 Series A and B(1)
Cast-iron	NPS 1 thru 48 (DN 25 thru 1200)	ASME B16.1
Nickel Nickel copper (monel) Nickel-chromium-iron (inconel) Hastelloy B-2 and C-276	NPS ½ thru 24 (DN 15 thru 600)	ASME B16.5
	NPS 26 thru 60 (DN 650 thru 1500)	ASME B31.3(2)
Aluminum bronze	NPS ½ thru 24 (DN 15 thru 600)	ASME B31.3(3)
Aluminum alloy	NPS ½ thru 24 (DN 15 thru 600)	ASME B31.3, Appendix L(3)

Notes:

(1) ASME B16.47 Series A flanges (previously specified by MSS SP-44) and Series B flanges (previously API-605 now withdrawn) specify different flange patterns for most sizes.

(2) Dimensions including flange face finish per ASME B16.47, Series A or B as specified by the User.

(3) Dimensions including flange face finish per ASME B16.5.

same as those covered by MSS SP-44, and Series B which are dimensionally the same as those previously covered by API-605 (withdrawn).[12] Most large flange installations in process piping are to Series B flange patterns, except where ASME B16.47 Series A flanges may be required to accommodate flangeless or lug type valves or other similar flangeless components, or to mate with existing equipment flanges.

Flanges of materials other than those listed in applicable standards or flanges with special dimension for mating to equipment should be in accordance with ASME B31.3 following the design requirements of the ASME BPV Code Sec. VIII, Div. 1.

Flange Types. Several different flange types are permitted by the standards listed in Table C7.5, as principally covered by ASME B16.5. These include different types of attachment to the pipe including threaded, lapped, and welded as covered in more detail by Chap. A2 of this handbook. Of the welded type, most flanges are the butt-welded, slip-on, or socket-welded types. The majority of flanges are butt-welded, which are more commonly referred to as the welding neck flange. Socket-welded flanges are typically limited to small-diameter connections less than NPS 2 (DN 50). Slip-on flanges fit over the outside diameter of the pipe and are attached with fillet welds at both the pipe end and off the hub end of the flange.

Typical restrictions on the use of slip-on flanges include:

- While available in most pressure classes, slip-on flanges are more typically limited to Class 300 or lower pressure rating in process plant piping. The available raised face gasket seating area can preclude commonly used gaskets in the case of slip-on flanges for higher class piping.
- They are limited to services with design temperatures below 750°F (400°C).
- They should not be used where the specified corrosion allowance exceeds 0.125 in (3 mm).

The Code restricts the use of threaded flanges as it does any threaded pipe joint. Some limits on the application of threaded flanges include:

- The use of cast, nodular, wrought and malleable iron threaded flanges should be avoided.
- Threaded steel flanges for steel pipe are usually limited to water or air (or other Category D) services for sizes NPS 6 (DN 150) or smaller and with design temperatures not exceeding 250°F (121°C).
- Threaded flanges on cast iron or ductile iron pipe should be steel material.

The following recommended limitations should be considered with the use of lap joint flanges for process plant applications:

- Lap joint flanges should not be used where the combined longitudinal stresses in the pipe at the lap-joint stub-end (resulting from pressure, weight, and thermal expansion) exceeds the ASME B31.3 basic allowable stress at the pipe design temperature.
- The flange may be of a material different from that of the pipe, provided the flanged joint will not be subject to galvanic corrosion (e.g., carbon steel flanges may be used on lap-joint stub-ended 18 Cr 8 Ni pipe in above ground services).
- Stub-ends for lap joint flanges, if fabricated by welding, should be made with full penetration welds

The following additional limitations on flanges are included for the designer's guidance.

- In services with very high corrosion rates, the bore of weld neck flanges should be the same inside diameter as the attached piping (if not the same, consider taper-boring the component with the smaller inside diameter).
- ASME Standard B16.47 "Large Diameter Steel Flanges" governs steel flanges in sizes NPS 26 through 60 (DN 650 through 1500). However, the designer must ensure that the flange drilling on such flanges will match that of the equipment to which it is to be attached. Use Series A for previous installations with MSS SP-44 "Steel Pipe Line Flanges," and Series B for flanges mating to equipment with API 605 "Large-Diameter Carbon Steel Flanges."

Selection of Flange Facings

Several different types of flange faces are used as the contact surfaces to seat the sealing gasket material. In the case of Class 125 cast iron flanges, full faces are provided with a phonographic finish. ASME B16.5 and B16.47 define various types of flange facings, including the raised face, the lapped, and the large male and female facings which have identical dimensions to provide a relatively large contact area. Other flange facings covered by these standards include the large and small tongue-and-groove facings, and the ring joint facing specifically for ring joint type metal gaskets. Chapter A2 of this handbook provides detailed descriptions of the various flange faces and their uses.

When flat face (FF) Class 125 cast iron or nonmetallic flanges are bolted to Class 150 steel flanges, the 1⁄16 in (2 mm) raised face on the steel flanges should be removed to preclude possible damage to the mating flange.

The raised face (RF) flange face is the most common type used in process plant applications. This face type allows the use of a wide combination of gasket designs, including flat ring sheet types and metallic composites such as spiral wound and double jacketed types. The typical flange face finish for ASME B16.5 RF flanges is 125 to 250 μin Ra (3 to 6 μm Ra). The use of ring joint gaskets specifically requires the use of grooved ring joint (RJ) flanges. These are typically used in relatively high pressure (Class 600 and higher rating) and/or high temperature services above 800°F (427°C), and are usually the gasket of choice for highly cyclic temperature services.

Selection and Limitations of Gaskets

A considerable variety of gaskets is in common use for the flanges located within process plants. These can be nonmetallic or metallic, or a composite of nonmetallic and metallic materials.[13] The majority of nonmetallic gaskets are soft sheet materials such as rubber, vegetable, and other mineral fibers, cork, asbestos, PTFE (polytetrafluoroethylene), and graphite. These sheet gaskets are manufactured to the dimensional standards of ASME B16.21.[14] The composite gasket types combine metal and a soft material, the metal to provide added strength to withstand higher pressures and temperatures of the confined fluid, and the soft material to provide resilience. Spiral wound (SW) gaskets with metal strip spirally wrapped with resilient filler material, and metallic double jacketed with soft material filler are two of the most common gaskets of this type. Metallic gasket types come in various shapes and constructions, including flat and ring types. Ring joint gaskets typically of the oval cross section are used in some of the more critical fluid services.

Until the last decade, asbestos was without question the principal gasket material used in petroleum and petrochemical plants. While the importance of finding acceptable substitutes to asbestos is generally recognized within the industry, it is widely accepted that comparable gaskets with all of the same attributes of asbestos have yet to be identified. Due to its unique properties of chemical inertness, thermal behavior, and excellent sealability, asbestos has been a major ingredient of many gasket compositions for the past century.

In recent years, flexible graphite has become the leading gasket material to replace asbestos for many users. This is particularly the case for the petroleum and petrochemical industries, where a broad range of application is required, including services at elevated temperatures. Yet, even flexible graphite gaskets have some significant limitations and continue to be the subject of ongoing research to evaluate long-term service characteristics at elevated temperatures.[15]

Principal characteristics for the ideal gasket within the petroleum and petrochemical industry (and other related processing plants) should include the following performance factors and other attributes:[16]

- *Overall Mechanical Integrity.* The mechanical strength of a gasket is a primary consideration to ensure sufficient strength against crushing and possible in-service blowouts. *Gross leaks* occur because, for some reason, the bolt load has been reduced to the point where the hydrostatic end force at the joint is roughly equal to the total bolt load. *Gasket stiffness* is an important consideration in precluding gross leakage. Another important mechanical integrity consideration of a gasket is its ability to resist *gross instability* or *crushing* with gasket seating during initial boltup and subsequent in-service retightening.

  Some recent experience with spiral wound gaskets filled with flexible graphite has demonstrated the importance of ensuring sufficient crush strength resistance.[17] A significant percentage of installed SW gaskets for a refinery expansion were found during the final stages of precommissioning to have gross buckling of the inner windings. The gaskets were specified without inner retaining rings, which raised questions about current standards (ASME B16.20) requirements for inner rings. While this phenomena is the subject of industrywide evaluation, ASME B16.20 recommends the use of inner retaining rings with flexible graphite filled spiral wound (SW) gaskets where experience has demonstrated inward buckling to be a problem.[18] Considering the extent of buckling experience reported to date, and the potential for severe leakage and consequential damage due to entrained spiral fragments migrating into downstream equipment, some users specify inner rings for all NPS 4 (DN 100) and larger SW gaskets with flexible graphite filler.
- *Leak Tightness.* A gasket for elevated temperature service must have good creep and stress relaxation resistance, and leak tightness. When addressing the sealability of gasket materials all of the operating parameters for a specific service impose their influence, to some extent, on the overall performance of the gasket. These include, for example, the physical nature of the fluid (i.e., gas, liquid, molecular weight, aggressiveness of the fluid on the gasket material, and fluid temperature and pressure). *Gasket creep and stress relaxation* first occurs during boltup and may also occur during heatup and subsequent cyclic loading, leading to additional creep losses. *Gasket degradation* results in gasket thickness loss, which further reduces bolt preload over time and increases the vulnerability of the joint. Degradation is the result of pyrolysis, oxidation, and other chemical reactions because

of high-temperature exposure and interaction with the process fluid. *Aging effects* as the result of prolonged exposure to service environments and temperature can lead to further degradation, affecting the useful life and sealing performance of the gasket.

- *Fluid Service and Gasket Material Compatibility.* Will the gaskets tolerate the chemicals with which they will be in contact; that is, are they compatible with the contained chemicals? The user should *not* assume that: (1) if a gasket is good at one concentration and/or temperature range, it will be acceptable for other concentrations and/or temperatures, or (2) if it is good for two or more chemicals alone, it will be good for a mixture of these chemicals. This also needs to be reviewed for all material components of composite gasket constructions. Industry experience is very valuable here in confirming the suitability of the gasket material for the intended service.

  Galvanic corrosion may be a problem if an electrically conducive fluid is present with a gasket material, such as flexible graphite, that is also electrically conductive. Graphite is near the cathodic end of the galvanic scale, between silver and gold. The wider the distance between the two materials, the more rapid the corrosive attack of the anodic material.

  As flexible graphite is a relatively fragile material, most process plant gaskets have metal inserts. These can suffer galvanic corrosion if coupled with the flexible graphite under certain electrochemical environments. Salt water service, for example, has proven to be a problem with composite flexible graphite gaskets, where galvanic attack can cause severe corrosion of the metallic insert.

  The manufacturer should be consulted if there is any doubt about the compatibility of a gasket for the intended service. This is also the case for any potential concerns for galvanic coupling between the gasket material and metal reinforcement of a proposed gasket for an electrolytic chemical environment.

- *Fire Safety.* The integrity of gasketed flanged joints in flammable services, exposed to fires, is a key consideration in accepting substitutes for asbestos in petrochemical and refinery plants. Asbestos gaskets have been generally recognized as being inherently fire safe as demonstrated by the favorable service experience accumulated over the years. Of the numerous nonasbestos products now on the market, many would appear to have questionable fire integrity capabilities (e.g., sheets based on aramid, glass fibers, or on PTFE). This is a principal advantage for flexible graphite-based gaskets, which have demonstrated capabilities of being inherently fire safe.

- *Broad Range of Application.* Prior to falling out of favor, asbestos-based gaskets represented about 95 percent of all refinery and chemical service gasket applications. Ideally, substitutes should also exhibit a wide range of service applications. The obvious advantage of standardizing on one or two gasket materials is that doing so helps to minimize the chances of misapplication. Standardization also simplifies procurement and stocking requirements, which could get out of hand if many different types of gasket materials were kept in the warehouse stores.

Adding to the merits of flexible graphite as a gasketing material is the wide spectrum of gasket styles that are commercially available. These styles include the more commonly used reinforced flexible graphite sheet (RFG) gaskets, and flexible graphite-filled spiral wound (SW) and double jacketed (DJ) gaskets. Other less conventional styles such as corrugated metal covered with flexible graphite (CMCG)

TABLE C7.6 Gasket Material Specifications

Gasket type	Standards	Design range	
		Class	Temperature
Compressed Asbestos Fiber (CAF) sheet	ASME B16.21	≤300	−50 to 750°F (−45–400°C)
Metal Reinforced Flexible Graphite (RFG) sheet	Dimensions per ASME B16.21	≤300	−250 to 750°F (−157–400°C)
Corrugated Metal Flexible Graphite Covered (CMGC)	Dimensions per ASME B16.21	≤300	−250 to 750°F (−157–400°C)
Grooved Metal profile flexible Graphite Covered (GMGC)	Manufacturer's standards	≤300	−250 to 750°F (−157–400°C)
Corrugated Double Jacketed (DJ) filled with flexible graphite	ASME B16.20 with corrugated jacket	≤300	up to 875°F (up to 468°C)
Spiral Wound (SW)—Flexible graphite filled	ASME B16.20	≤900	up to 875°F (up to 468°C)
—Asbestos filled			up to 1000°F (up to 538°C)
—PTFE filled			up to 400°F (up to 204°C)
Ring Joint (RJ)	ASME B16.20 for oval shape	≤2500	Any

Notes:
(1) Use of asbestos-based gaskets subject to local restrictions.
(2) Typical fill materials for SW and DJ gaskets can be asbestos, flexible graphite, and PTFE (for nonflammable services).
(3) Both inner and outer retaining rings are recommended for spiral wound (SW) flexible graphite filled gaskets for all sizes greater than NPS 4 (DN 100), or if gasket design temperatures exceed 800°F (427°C).

and grooved metal covered with flexible graphite (GMCG) have also evolved with good user experience.

Table C7.6 provides a listing of the more commonly used gaskets within refinery and chemical plant process units, and the applicable standards available for their design and construction.

The temperature ranges indicated by Table C7.6 are approximate and will vary according to the service involved. This is particularly the case with flexible-graphite based materials, where the extent of material degradation and oxidation will vary according to the fluid service involved. As discussed in the previous subsections, gasket material compatibility should be confirmed for the specific fluid service intended.

A more detailed list of gasket materials for specific services is provided in Chap. A2 of this handbook. These include various elastomeric nonasbestos gasket materials, which should be considered to have relatively low service temperatures and generally are all non-fire safe.

TABLE C7.7 Bolting Material Specifications

Design metal temperature		Flange rating	Bolts		
°F	°C	ANSI Class	Type	ASTM Std.	Grade
−20 to 400	−29 to 204	≤150	Bolt	A307	B
−20 to 800	−29 to 427	Any	Stud	A193/A193M	B7
800 to 1100	427 to 593	Any	Stud	A193/A193M	B16
1100 to 1200	593 to 650	Any	Stud	A193/A193M	B5
1100 to 1500	593 to 815	≤300	Stud	A193/A193M	B8M Class 1(1)
−150 to −20	−101 to −29	Any	Stud	A320/A320M	L7(2)
−325 to −20	−198 to −29	Any	Stud	A320/A320M(3)	B8 Class 2(4)

Notes:

(1) Class 1 (low yield) bolts should not be used for Class 400 or higher flanges nor for flanged joints using metallic gaskets unless supported by appropriate design calculations per ASME B31.3, Par. 309.2.1.

(2) Test temperature for impact testing of all L7 bolts, per ASTM A320/A320M, should be −150°F (−101°C).

(3) ASTM A 193/A193M Grade B8 Class 2 bolts with ASTM A194/A914M Grade 8 nuts may be used as an alternate.

(4) Grade B8 bolts must be strain hardened (i.e., Class 2 of designated ASTM material standard).

Selection and Limitations of Bolting

Bolting as typically used within the processing industry is threaded in accordance with ASME Standard B1.1 for Unified Screw Threads. In diameters 1 in (25 mm) and smaller, the threads conform to the coarse thread series. For larger bolt diameters, the eight-pitch thread series applies for bolting to this standard used in process plants.[19]

Table C7.7 lists typical bolting materials and recommended design pressure and temperature rating limits for flanges found in process plants. A more complete listing of permissible bolting materials allowed by ASME B16.5 for steel pipe flanges is provided in Chap. B2 of this handbook.

While carbon-steel machine bolts may be used to make flange connections for bolt metal temperatures from −20 to 400°F (−29 to 204°C) inclusive, they are considered to be low-strength bolts and should be limited to noncritical low-pressure (Class 150) services. However, ASME B16.5 permits the use of these bolts for flanges up to Class 300 with the use of nonmetallic gasketing material.

The most widely used bolting materials in process plants are ASTM A193 Grade B7 stud bolts with ASTM A194 Grade 2H heavy semifinished hexagonal nuts. A number of operating companies, in fact, use these low-alloy materials almost exclusively, to simplify inventories and to reduce the possible misapplication of low-strength carbon-steel bolting. While the code permits the use of Grade B7 bolts from −50 to 1000°F (−45 to 540°C), a more conservative temperature range is recommended, as indicated by Table C7.7. At the high end, the use of Grade B16 low-alloy bolting is recommended instead of Grade B7, since the latter has greater creep relaxation concerns at elevated temperatures, which could lead to in-service loosening of the flange. At the lower temperature range, A320 Grade L7 bolts are more typically used below −20°F (−29°C), consistent with the use of impact tested carbon steel and other low temperature flange materials.

With the exception of carbon-steel machine bolts, the materials listed in Table

C7.7 refer to stud bolts. These should be threaded full-length with continuous threads to minimize stress concentrations within the bolt. The use of hardened washers, typically to ASTM F436, also should be provided under the nuts for the larger-size bolts [typically 1½ in (38 mm) and larger bolts] to minimize galling of the flange back face.

Selection and Limitations of Blanks

In a process plant, blanks are usually required to isolate individual pieces of equipment at shutdown and to positively block off selected process lines at the process unit limits. They are also needed during operation wherever positive shutoff is required to prevent leakage of one fluid into another. Blanks, especially for larger-size flanges, are typically provided with a companion spacer which has a full-size opening consistent with the inside bore diameter of the flange. Figure-8 blinds (also called *spectacle blanks*) combine both the blank and spacer with a tie bar. Figure C7.6 provides typical details for handle-type blanks, spacers, and figure-8 blanks.

Typically, operating line blanks, spacers, and figure-8 blinds, if specified for installation between ASME B16.5 flanges, are designed in accordance with the requirements of ASME B16.48, Steel Line Blanks (API 590, withdrawn), to accommodate the full rating pressure of the flange class involved. Blanks can also be designed in accordance with ASME B31.3.

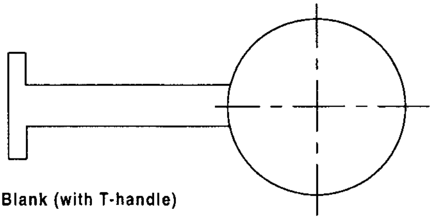
Blanks ideally should be located in horizontal lines to ease their installation and removal. Blanks should not be used in vertical water and steam lines in climates where danger of freezing exists.

The use of figure-8 blanks obviously ensures that the companion spacer is on hand when needed (and vice versa). However, these are difficult to handle in the larger sizes [i.e., above NPS 12 (DN 300)], and instead separate spacers and blanks are used. The paddle handle provided on these devices should make it clear at a glance whether a bank or a spacer is installed within mating flanges. An accepted convention is to provide a T-bar off the end of the paddle handle for blanks, and a drilled hole or formed eye in the handle-end of spacers, which allows the lifting of these respective devices yet clearly distinguishes them from each other.

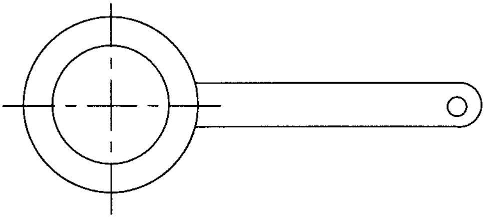
Piping systems should be equipped with spacers, figure 8 blanks, or designed with sufficient flexibility and flanges to permit blinds to be readily installed for isolation of equipment in accordance with the following criteria:

- In the piping or at the nozzle of all process and utility connections to vessels where necessary to provide safe entry for inspection and maintenance personnel
- In the suction and discharge lines of all turbines and compressors, except atmospheric suction of air fans
- At the inlets and outlets of process piping to fired heaters
- All fuel and pilot gas headers to each fired heater
- Spared equipment capable of being bypassed for maintenance
- Safety valve bypass lines
- Process battery limits

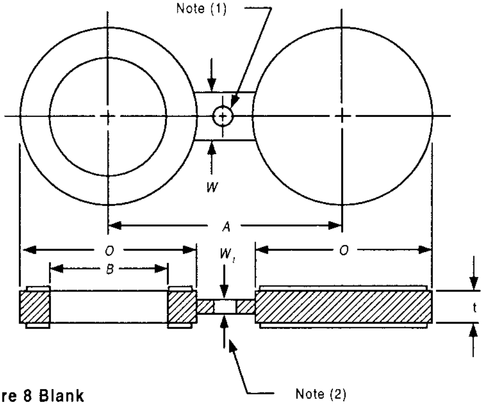
Blanks should be made from a plate or forging specification, approved for use by ASME B31.3, of essentially the same chemical composition as the mating flanges and piping involved.



(a) Paddle Blank (with T-handle)



(b) Paddle Spacer



(c) Figure 8 Blank

NOTES:

(1) Hole size (where required due to bolt spacing) should be the same as the flange bolt hole.

(2) The thickness of the web (or tie bar) dimension W_t should be 0.25 in (6 mm) minimum, or equal to t if less than 0.25 in. (6 mm).

FIGURE C7.6 Paddle-type and figure-8 blanks and spacers.

Selection of Strainers

Strainers are an important component of piping systems to protect equipment from potential damage due to dirt and other debris that may be carried by the process fluid. This includes the use of temporary strainers that may be placed upstream of mechanical equipment to protect it from construction debris left in the pipe. Permanent strainers are also provided for some inlet piping to protect equipment from in-service corrosion products and other product residues. Typical strainer designs and construction details are provided in Chap. A2 of this handbook.

Centrifugal and reciprocating pumps handling material containing solids should have permanent strainers provided in the suction lines to the pump or in the vessel from which the pump takes suction. The free area of such strainers should be not less than three times the cross-sectional area of the suction line. The location of permanent strainers (as contrasted to the temporary cone type which is installed at a flanged joint) also merits attention.

Some typical strainer opening or mesh sizes are provided by Table C7.8 for various equipment. The mesh sizes (or openings) are the usual maximums for normal operation. These opening sizes vary with the application, but should not exceed the value recommended for the particular type of equipment. The available pressure differential usually determines the minimum clear opening for screens.

The material for the strainer body (including bolting) should be equal to the material specified for the valves in the same service. The screen material generally should be the same as the valve trim (e.g., 11 to 13 percent chrome or Type 316 stainless steel for most services).

Permanent strainers should have baskets that can be flushed clean during operation or easily removed for cleaning. If considerable clogging of strainers is anticipated the strainers should be of the self-cleaning or the duplex type to permit continual flow of clean liquid.

Valve Applications and Limitations on Use

The successful performance of any process plant piping system is dependent on the proper selection and location of the valves that control and direct the flow of the piped fluids. There are numerous valve types and intended applications within a typical process plant, and to cover them all is beyond the scope of this chapter. More justice, however, is given this topic in Chap. A10 of this handbook, which provides detailed descriptions of valves and their features. This section will overview the application of the more commonly used valves within process plants, which can be categorized according to their function.

Block (Isolation) Valves. Block valves, as the name implies, are used to stop flow or isolate a portion of a system. Basic design requirements of a block valve are to offer minimum resistance to flow when fully opened, and conversely to achieve tight shutoff (nil leakage) when fully closed. Principal block valve types include *gate, globe* (although used mostly to regulate flow), *ball, butterfly, plug, ram*, and *diaphragm* valves. These achieve the required objectives in varying degrees, so all types can typically be found in a large process complex. Of these, however, the gate valve is the most commonly used block valve for refinery and chemical plant applications.

Throttling (Regulating) Valves. Throttling valves are principally used to regulate the flow of fluid within a piping system. This is achieved by varying the valve's open position to impart the required pressure drop to regulate the volume of flow. In the case of process control valves, throttling valves are used to control flow, pressure, or temperature, and in all situations the task is achieved by increasing or decreasing the flow through the valve in response to a signal from a pressure, flow, or temperature controller. Typical throttle valves include *globe, needle, butterfly, ball, plug* and *diaphragm* valves, which as previously noted can also serve a dual function to block flow.

Backflow Protection. *Check valves* are used to prevent backflow. A principal requirement of all check valves is that they be self-actuating, with little resistance

TABLE C7.8 Strainer Screen Openings for Equipment Inlet Piping

Equipment	Service	Pipe or flange size, NPS (DN)	Strainer type (Temporary) (Permanent)	Mesh size or opening, in
Pumps				
Centrifugal: Horizontal single stage, Vertical inline	Suction	3 (80) and under	TEMP	5 × 5
		3 to 6 (80–150)		3 × 3
		Over 6 (150)		½
Horizontal multistage, Vertical deepwell	Suction	6 and under	TEMP	20 × 20
		Over 6		⅛
Reciprocating	Suction	All sizes	TEMP	5 × 5
Rotary, turbine	Suction	All sizes	TEMP	20 × 20
Compressors				
Centrifugal:	Air, Suction	All sizes	PERM	3 × 3
	Gas, Suction		TEMP	5 × 5
Reciprocating:	Air, Suction	All sizes	(PERM Filter)	—
	Gas, Suction		TEMP	20 × 20
Rotary screw:	Air, Suction	All sizes	PERM	20 × 20
	Gas, Suction		TEMP	20 × 20
Axial:	Air, Suction	All sizes	PERM Screen on Dry Filter	5 × 5
	Gas, Suction		TEMP	5 × 5
Turbines				
Gas:	Inlet Air	All sizes	PERM Screen on Dry Filter	5 × 5
Steam:	Inlet	All sizes	PERM	⅛
Other equipment				
Fuel-oil lines to burners	Inlet	All sizes	PERM	⅛
Air supply to pneumatically actuated equipment	Inlet	All sizes	PERM	40 × 40
Upstream of restriction orifices in bleed services	Inlet	All sizes	PERM	1⁄16
Energizing fluids to ejectors	Inlet	All sizes	PERM	¼

Acceptable Metric Equivalent Dimensions for Above Table

Screen						Perforated plate opening		Pipe size, NPS	
Meshes (per linear in)	Wire diam in	Wire diam mm	Average opening width in	Average opening width mm		in	mm	in	mm
100 × 100	0.004	0.102	0.006	0.15		1⁄16	1.5	3	80
80 × 80	0.0055	0.140	0.007	0.18		⅛	3	6	150
40 × 40	0.010	0.254	0.015	0.38		½	13		
20 × 20	0.016	0.406	0.033	0.85					
5 × 5	0.063	1.6	0.137	3.50					
3 × 3	0.063	1.6	0.272	6.90					

to forward flow and rapid closure triggered by reverse flow. The closing of the disk can be achieved with gravity effects or with the assistance of springs or pneumatic actuators to assist in the rapid closure of the valve. Typical check valves include the *swing disk, dual-disk butterfly, tilting disk, ball,* and *piston* types.

Pressure-Relief Devices. These devices are used to protect piping and equipment from being subjected to pressures that exceed their design pressures. Some pressure-relief or safety valves achieve this with a spring-retained disk which pops when sufficient pressure lifts it off a sealing seat. Another type incorporates a pilot valve which uses system pressure to control the movement of the relieving disk. Rupture discs, although not valves, can also achieve rapid pressure relief, which is accomplished by the disk bursting open at a predetermined pressure. These have the advantages of being leak-tight up to the rupture pressure and of being capable of relieving large rates of flow. However, they cannot adjust the set pressure, as can relief valves. Another major factor for considering relief valves versus rupture disks is that the rupture disks don't reseat when the pressure goes back below the set point.

Valve Standards/Specifications

Table C7.9 provides some of the specific standards used in the manufacture of block and check valves for process plants. Most valves conform to the standard pressure and temperature ratings specified by ASME B16.34.[20] The pressure-temperature ratings of B16.34 for standard-class valves parallels that of ASME B16.5 (for steel flanges) except B16.34 provides for higher pressure-temperature ratings for welding-end special-class valves that receive additional prescribed nondestructive examinations. As indicated by Table C7.9, several API Standards provide detailed design and manufacturing requirements for the specific valve types covered to supplement the principal design requirements stipulated by ASME B16.34. Refer to Chap. A10 for details. The points that follow will highlight several application

TABLE C7.9 Valve Standards for Process Plant Applications

ASME Standards	
B16.34	Valves—Flanged, Threaded, and Welding End
API Standards	
594	Wafer and Wafer-Lug Check Valves
598	Valve Inspection and Testing
599	Steel and Ductile Iron Plug Valves
600	Steel Gate Valves, Flanged and Buttwelding Ends
602	Compact Steel Gate Valves—Flanged, Threaded, Welding, and Extended-Body Ends
603	Class 150, Cast, Corrosion-Resistant, Flanged-End Gate Valves
607	Fire Test for Soft-Seated Quarter-Turn Valves
608	Metal Ball Valves, Flanged, Threaded, and Welding End
609	Butterfly Valves, Lug-Type and Wafer-Type
ASTM Standard	
A494/A494M	Castings, Nickel and Nickel Alloy
ANSI/AWWA Standard	
C504	Rubber Seated Butterfly Valves

considerations associated with some of the more commonly used valves covered by these standards.

Gate Valves. The majority of steel gate valves for use in refinery and chemical process plants are specified to API 600 covering Steel Gate Valves.[21] This standard provides for greater corrosion allowance and hence heavier wall thickness than ASME B16.34 for the same pressure rating. This allows the broader application of the same API 600 gate valve across multiple-service classes. API 600 also stipulates that the valve be of the Outside Screw and Yoke (OS&Y) type for the actuating stem works to minimize corrosion damage of this mechanism by locating the screw threads external to the valve.

Additional application considerations for gate valves include:

- The wedge design for gate valves should be the flexible type to allow for better sealing of both the upstream and downstream side of the gate to the valve body seats. It also compensates for differential thermal expansion effects that can occur between the valve body and the gate wedge. Solid wedges, however, may be used for small-diameter [NPS 2 (DN 50) or smaller] or lower-pressure-class valves (≤ Class 150).
- Valve trim materials for the stem and gate/body seats are typically specified by the user for the intended service in accordance with the trim alternatives defined by API 600. For critical nonlubricating services, valve seats are hard-faced to minimize seat travel wear.
- If the pressure differential across a closed gate valve is approximately equal to the pressure rating of the valve, consideration should be given to providing a pressure-equalizing bypass around the valve. Consideration should also be given to bypasses for valves in steam lines for warm-up purposes. When bypasses are provided, they should be sized in accordance with MSS SP-45, *Bypass and Drain Connection Standard*.[22]
- Gate valves with soft-seal (e.g., PTFE) inserts in the seat rings can provide improved leak-tight performance. However, it is important to confirm that proper metal-to-metal seat contact is achieved between the gate and body seats prior to installing the soft seals. This is needed to obtain normal gate sealing as a secondary backup to the soft seals should they be damaged during a fire.

Other Block Valves. *Butterfly valves, ball valves, nonlubricated plug valves*, and *lubricated plug valves* may be considered as possible alternates to gate valves. The majority of these valves rely on soft-seal materials to effectively achieve leak-tight performance. Table C7.10 identifies recommended temperature limits for several of the more common soft-seal materials used with these block valves.

TABLE C7.10 Valve Soft Seal Material Temperature Limits

Soft seal material	Temperature limit	
	°F	°C
PTFE (Polytetrafluoroethylene)	450	230
FEP (Perfluoro (Ethylene-Propylene) Copolymer)	400	200
VITON-A	400	200
BUNA N	250	120
NEOPRENE	200	90

Other design considerations for soft-sealed block valves include the following:

- Fire-tested type ball, plug, or butterfly valves should be certified per the requirements of API Standard 607, *Fire Test for Soft-Seated Quarter-Turn Valves,* if intended for flammable or other dangerous material services.[23] These fire-tested valves are specifically designed with metal-to-metal secondary sealing to minimize leakage across the block should the primary soft seals be destroyed during exposure to a fire.
- Soft-seated valves in liquid service should be provided with pressure relief for the body cavities. The liquid is usually relieved to the upstream side. This is needed to relieve pressure buildup and possible valve damage due to liquid thermal expansion within the body cavity, which cannot escape because of the leak-tight soft seals.

Globe Valves. As a general rule, hand-operated throttling valves for services where fine control is not required, and those for control valve bypasses, should be globe valves (integral stem and plug preferred). For severe throttling service, and where close control is required, a conventional control valve with a hand operator should be used. The only other common application for globe valves in process service is for mixing purposes where relatively tight shutoff is required.

In most process plants, internal corrosion is a greater problem than external corrosion. Consequently, it is common practice that all NPS ¾ (DN 20) and larger steel and cast-iron [and all NPS 2½ (DN 65) and larger brass] gate, globe, and angle valves (located above grade) be of the outside screw and yoke type.

Check Valves. The following design considerations are offered in the specification of check valves for typical process plant applications:

- Do not use check valves in vertical lines in which the flow is downward.
- Dual- and single-plate wafer check valves should be designed to API-594, *Wafer and Wafer-lug Check Valves,* requirements.[24] These types of check valves are not recommended for reciprocating compressor or reciprocating pump services, which could otherwise lead to pulsation-induced fatigue failures of the valves' spring-assist closure mechanisms.
- Ball or piston check valves should be of the self-closing type (gravity or spring assisted) and should not depend on flow reversal, or only the spring, to effect closure.
- Lift check valves are not recommended for use in services subject to fouling, coking deposits, or erosion.

Double Block and Bleed Valves. Under certain conditions double block valves are needed to prevent product contamination or where it is necessary to remove essential equipment from service for cleaning or repairs while the unit continues in operation. Of course, such equipment must be provided with a spare or it must be possible to bypass it temporarily without shutting down the unit. The nature of the fluid, its pressure and temperature, and many other factors must be considered when determining the need for double block valves.

Generally, double block valves should be considered for the onstream isolation of equipment if the fluid is flammable or otherwise hazardous, or if the fluid is in high-pressure or high-temperature service. Where double block valves are used, a NPS ¾ (DN 20) or larger bleed valve should be installed between the block valves

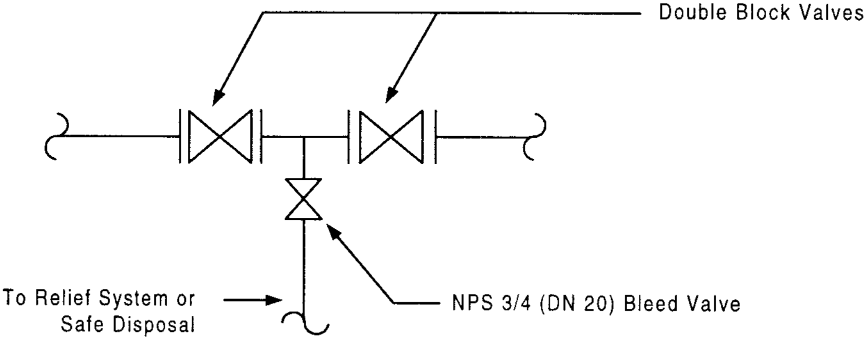


FIGURE C7.7 Double block and bleed valves.

(see Fig. C7.7). The purpose of the bleed valve is twofold. First, the bleed ensures that the upstream valve is in fact tight before slipping in a blind off the downstream block valve. The bleed connection also permits the safe withdrawal of moderate leakage from the upstream valve to again assure the tight shutoff of the downstream valve.

Depending on the service conditions, it may be possible to use a single block valve with a body bleed to provide *double block and bleed* provisions for onstream isolation of equipment. Gate valves with flexible wedges and with body or bonnet bleed valve can serve this purpose if specifically tested in accordance with API-598 for double block and bleed quality valves.[25] Some ball valves and nonlubricated plug valves, when equipped with a valve body bleed between the seats, can also be satisfactory substitutes for double block valves. Testing for double block and bleed quality valves requires the pressure-testing of each seat, with leakage measured through the valve body bleed as a means of substantiating the independent leak tightness of both the upstream and downstream seats of the valve.

GENERAL PROCESS PIPING SYSTEM CONSIDERATIONS

In previous sections, emphasis was placed on individual piping components. This section will look at the composite of these components by highlighting some of the important considerations required in the overall system design of process piping.

Materials Related Considerations

Proper materials selection is a key parameter in determining the adequacy of the performance of a piping system to sustain the extremes of temperature, chemical attack, or erosion. Such materials related considerations include the specific chemical, metallurgical, and physical properties of a piping system's material constituents, which can ultimately determine its suitability for a particular service.[26] Chapters A3 and B2 of this handbook expand on some of the principal considerations involved in the selection of materials for a specific piping system, which would include:

- *Strength.* The strength of a piping component or system is usually determined by the Process Piping Code, ASME B31.3, as it relates to the allowable working stresses for the materials under consideration. These allowable stresses are typically based on specified percentages of the material's yield and tensile strengths. It also considers creep and rupture stress rate properties for any material operating in temperatures within its creep range.
- *Toughness, or Ductility.* Toughness is the ability of a material to resist impact or to absorb strain energy when stressed beyond the elastic limit. Steel piping materials are normally considered to be ductile. Under certain conditions, however, steel may behave in a brittle manner and shatter like glass. In piping, this behavior typically occurs only at low temperatures. Temperatures below the *transition temperature* for any steel represent temperatures at which it will behave in a predominantly brittle manner. Hence, steel with a high transition temperature is more likely to behave in a brittle manner during pressure testing or in service. It is important that the material's transition temperature be well below the design minimum temperature expected in service for the piping system involved.
- *Corrosion Resistance.* This material property is a measure of a piping system's material ability to resist chemical attack from a specific process fluid throughout the range of expected operating temperatures and fluid compositions, or from its exposure to environmental effects. All common piping system materials react with some process fluid corrodants at certain temperatures. When specifying a material for a particular application, it is important to select a material whose corrosion rate in the presence of expected corroding is acceptable over the design life of the piping system.
- *Other Material Considerations.* In addition to corrosion, it is also worth mentioning other materials related degradation phenomena which need to be considered in the selection of the piping system materials. These would include, for example, materials resistance to *hydrogen attack* at elevated temperature, which is a particular concern of many refinery processes, and is generally attributed to the formation of methane (CH_4). This can occur for carbon-steel materials exposed to fluids with a high concentration of hydrogen at elevated temperatures. It is usual practice to specify low-alloy ferritic steel materials, increasing the amount of chromium composition between 1 to 5 percent depending on the hydrogen concentration and fluid temperature involved, to preclude hydrogen attack. Another materials related concern is *stress corrosion cracking,* which can occur with certain grades of austenitic stainless steel materials under a broad range of services and fluids. *Erosion* of piping materials can be another factor limiting the life of components. This is a principal concern for systems with fluids with some solids contents or high flow velocities resulting in significant material loss.

Unfortunately, the list of other special materials-related concerns for process piping can be quite extensive and well beyond the scope of this chapter, but these are covered to some extent in Chap. A3 of this handbook. It is important for the designer to have an appreciation of the service experience of the proposed materials for the intended fluid media to confirm its overall compatibility for these fluid service conditions.

Refer to App. E5 for piping and tubing material specifications for use in B31.3 applications. App. E6 provides some international pipe specifications.

Pressure Integrity

The pressure integrity design of a piping system needs to first determine the minimum required pipe wall thickness. The second consideration is the determination of the pressure rating of all the piping components, such as fittings and valves, within the system. Thus, verification is required that all of the individual components of the piping system are specified with sufficient wall thickness to be acceptable for the imposed pressure-temperature design conditions.

The designer is cautioned that regardless of the combination of operating pressure and temperature which results in the most severe condition from a stress standpoint, the selection of materials will often be governed by the extremes of operating temperature and pressure. In designing piping systems, it is simpler to use fluid temperature than metal temperature. Substantial savings, however, can be realized by making appropriate thermal calculations or tests to determine the metal temperature, especially if the fluid temperatures are high or if the system is internally insulated. Not only can flange (and valve) ratings and pipe thicknesses often be reduced, but occasionally less expensive materials can be used.

In considering metal rather than fluid temperatures, any savings in the cost of piping components must be balanced against the present worth of the additional heat to be lost from the piping components if the insulation is omitted. Flanges and valves which are to be left bare should be clearly marked on the piping drawings so that they are not inadvertently insulated.

Operability, Maintenance, Safety, and Accessibility

The overall piping system design will need to consider the operability, maintenance, and accessibility of the principal components. These factors are very dependent upon each other, which also need to be considered in the context of assuring the overall safety of the piping system.

Operability. From the process unit operators' perspective, the layout of the piping system needs to provide easy access to key components that must be operated frequently. This typically includes accessible positioning of the more frequently used block and control valves, and readable instruments installed directly off the piping. It is not possible, however, to make every valve and instrument directly accessible. Instead, consideration should be given for the frequency of operation and the degree of physical effort needed to perform the required operation. Important operable valves and instruments should be reachable while standing at grade or from an elevated platform provided for that purpose. The position of any valve handwheel or instrument control device should be such that the force needed to operate it can be applied without excessive strain on or undue contortions by the operator. It is also important that adjacent valves, lines, or other equipment not interfere with these operations.

Maintainability. The piping system layout must consider the maintenance requirements, whether anticipated or not, of the piping and equipment involved. The arrangement of the piping should ensure that sufficient space is provided for the maintenance of equipment and for the piping system, and the maintenance of the components within it. This should include, as examples, sufficient space allocations for the pulling of exchanger bundles, major equipment laydown spaces, machinery rotor and furnace tube removals, and for the dismantling of equipment where required. Maintenance requirements will also dictate the location of isolation block valves, especially those required for the onstream isolation of the key equipment and instruments. It is important to design the facilities so that the appropriate accessibility is provided to accomplish the required maintenance, including provision for any lifting equipment, such as davits, cranes, or trolley-beam hoists.

Safety Considerations. In laying out piping for operability and maintenance, it is important that equipment, valves, and other components are placed in locations where they do not create hazards to personnel. These could be tripping obstacles, head-knockers, or other obstructions which could lead to bodily injury. Safety design requirements for stairs, platforms, ladders, means of egress aisleways, and minimum headroom clearances, for example, need to be considered to provide a safe work environment. These requirements, obviously, should be reflected in the overall process unit design.[27]

Accessibility. This has already been discussed in some detail in terms of space and treatments to help workers do their job as related to the operability and maintenance of the piping system. Even for remote valve locations, the inclusion of a platform could be justified, considering the importance of the component involved and the associated possibility of personnel injuries if not provided.

Flexibility and Support of Process Plant Piping

The general challenge of flexibility and expansion of piping systems is treated in Chap. B4 of this handbook, and the support of piping systems is covered in Chap. B5. Techniques, methods, and procedures developed in those chapters are applicable to process plant piping. Appendix E9 lists the capabilities of piping related computer programs.

The need for detailed analyses of piping systems must reflect the acceptability of imposed reaction loads to equipment terminations and not just the thermal flexibility stressing of the pipe itself.[28] The determination and analysis of equipment reaction loads will in fact justify the need for detailed thermal flexibility and sustained longitudinal stress analyses for a considerable number of piping systems within a typical process plant. Recommendations in this regard would suggest that, as a minimum, *formal computer flexibility analyses* be performed for each of the following piping systems:

- Process, regeneration, and decoking lines to and from all fired heaters and steam generators
- Process lines to and from all compressors and all blowers
- All NPS 3 (DN 80) and larger lines connected to other rotating equipment, including pumps, steam or gas turbines, and mixers
- Main process and regeneration lines to and from all process reactors
- All lines NPS 4 (DN 100) and larger with a design temperature of 450°F (232°C) or more
- All lines NPS 8 (DN 200) and larger with a design temperature of 350°F (177°C) or more
- All lines NPS 12 (DN 300) and larger with a design temperature of 250°F (121°C) or more
- All lines NPS 20 (DN 500) and larger, regardless of design temperature
- All lines that contain expansion joints

- All lines with internal refractory lining
- All lines NPS 4 (DN 100) and larger connected to air-cooled heat exchangers
- All lines NPS 12 (DN 300) and larger connected to storage tanks

Other piping systems not covered by this list will still need to be evaluated using conventional thermal flexibility evaluation techniques to verify the acceptability of the planned layout and supporting arrangements.[29] Depending on the system, these screening evaluations may establish whether a more detailed computer flexibility analysis is required because of the complexity of the piping layout, and its interconnections with other piping or equipment involved. An example in this regard would be the tie-in of a new branch line to an existing piping system, where the thermal expansion effects of the new composite system need to be verified, and where the complexity of the system or the load sensitivity of the connecting equipment involved would justify a more detailed analysis.

Fabrication, Assembly, and Erection of Process Plant Piping

These topics are covered at length in Chap. A6 of this handbook. Detailed requirements which relate to fabrication, assembly, and erection of the process piping systems are given in ASME B31.3. Important phases of the Code treatment of these topics are covered briefly in this section.

Materials for Welding. All filler materials must comply with the requirements in Sec. IX of the ASME Boiler and Pressure Vessel Code.[30] If backing rings are used in services where their presence will result in severe corrosion or erosion, it is required that the backing ring be removed after welding and the internal joint ground smooth. When it is impractical to remove the backing ring in such a case, consideration should be given to welding without backing rings or to the use of consumable inserts or removable nonmetallic backing rings.

Welding End Preparation. ASME B16.25 provides dimensional standards for weld end bevels.[31] Preferably, the ends of pipe and the edges of plate used to form pipe should be shaped by machine. Other methods of shaping may be employed, provided that a reasonably smooth surface suitable for welding and free from tears, slag, scale, and grease is attained. Oxygen or arc cutting is acceptable only if the cut is reasonably smooth and true, and all slag is cleaned from the flame-cut surfaces.

If piping component ends are machined on the inside for backing rings, such machining must not result in a finished wall thickness, after welding, less than the minimum design thickness plus corrosion and erosion allowances.

Generally a root gap of ⅛ in (3 mm) is used for girth butt joints (including branch connections) without backing rings, except that where the pipe wall thickness is less than $\frac{3}{16}$ in (5 mm), a $\frac{1}{16}$ in (1.5 mm) root gap is generally used.

Welding Alignment Considerations. The following requirements should be considered in the final alignment of the completed welded connection for the type indicated:

- Radial misalignment at the joining ends of piping components should be limited to ⅛ in (3 mm) or ¼ of the pipe wall thickness, whichever is less. Internal radial misalignment exceeding $\frac{1}{16}$ in (1.5 mm) should be taper trimmed so that the adjoining internal surfaces are flush. However, the resulting thickness of the welded joint should not be less than the minimum design thickness plus the specified corrosion allowance.

- Longitudinal seams in adjoining lengths of welded pipe should be staggered and located to clear openings and external attachments.
- Flange bolt holes should straddle the established centerlines unless other orientation is required to match the flange connections on equipment.
- Slip-on flanges should be positioned so that the distance from the face of the flange to the pipe end is about equal to the nominal pipe wall thickness plus ⅛ in (3 mm).
- Welding neck orifice flanges should be the same bore as the pipe to which they are attached and must be aligned accurately.

Welding Requirements/Procedures. Specific welding procedures are usually defined by the welding procedure specification (WPS). However, the following restrictions, limitations, or guidelines generally apply to the welding of process piping:

- Qualification of the welding procedures to be used and of the performance of welders and welding operators is required to comply with Sec. IX of the ASME Boiler and Pressure Vessel Code.
- Before welding, all surfaces must be cleaned and free from paint, oil, rust, scale, or other detrimental material. Furthermore, welding is prohibited if there is impingement of any rain, snow, sleet, or high wind on the weld area.
- Projection of weld metal into the pipe bore at welded butt joints should not exceed 1⁄16 in (1.5 mm) for pipe NPS 8 (DN 200) and smaller or ⅛ in (3 mm) for larger pipe. Excessive projections on accessible joints should be removed. Welds attaching welding neck orifice flanges to pipe should be ground smooth on the inside.
- The Code does not permit cracks in fillet or seal welds and limits undercutting to 1⁄32 in (0.8 mm) for these welds. Fillets welds may vary convex to concave.
- If *seal welding of threaded joints* is performed, the code requires that all exposed threads be covered by the seal weld and that the welding be done by qualified welders. In addition to the Code requirements, all threaded joints to be seal welded should be made without thread compound or PTFE tape. Seal welds should be at least two pass welds using a 3⁄32 or ⅛ in (2.4 or 3 mm) electrode, except a 5⁄32 in (4 mm) electrode is acceptable for NPS 2½ (DN 65) and larger pipe sizes.

The following Code requirements apply to *girth butt welds* and any *longitudinal butt welds* in piping components which are not made in accordance with a standard or specification.

- If the external surfaces of the two components are not aligned, the girth butt weld must be tapered between the two surfaces.
- Tack welds, if not made by a qualified welder using the same procedure as the completed weld, must be removed. Tack welds that are not removed should be made with an electrode which is the same as or equivalent to the electrode to be used for the first pass. Tack welds which have cracked must be removed.
- Peening (mechanical working) is prohibited on the root pass and final pass of a weld.

- No welding should be done if there is impingement on the weld area of rain, snow, sleet or excessive wind, or if the weld area is frosted or wet.

Preparation and Welding Procedure for Welded Branch Connections. Branch connections (including specially made integrally reinforced branch connection fittings) which abut the outside surface of the run wall or which are inserted through an opening cut in the run wall must be so arranged as to provide a good fit and attached by means of full penetration groove welds.

The recommendations for spacing and location of branch connections contained in Pipe Fabrication Institute (PFI) Standard ES7 should be followed.[32] A good fit must be provided between reinforcing rings and saddles and the parts to which they are attached. Reinforcing pads, when required, should be added as a subsequent fabrication step after visual inspection of the branch-to-header weld.

When rings or saddles are used, a drilled vent hole, minimum ⅛ in (3 mm), is provided at the side and not at the crotch of the ring of saddle to reveal leakage in the weld between branch and main run and to provide venting during welding and heat-treating operations. A pad or saddle may be made in more than one piece if joints between pieces have strength equivalent to the pad or saddle parent metal, and if each piece has a vent hole.

Defect Repairs. Weld defects that require repair must be removed. All repair welds must be made with the same welding procedure initially used for making the original weld.

Fabrication Tolerances for Welded Piping. A widely accepted tolerance on face-to-face and center-to-face dimensions of welding piping is ±⅛ in (3 mm). As for the location of the flanges, their lateral translation in any direction from the specified position should not exceed 1⁄16 in (1.5 mm). Also, the alignment of flanges should not deviate from the specified position, measured across any diameter, by more than 1⁄32 in (0.8 mm).

The tolerance for flange connections to rotating equipment or other load-sensitive equipment is typically specified to be much tighter, usually 1⁄32 to 1⁄64 in (0.8 to 0.4 mm) for the maximum translation or rotation of the flange, depending on the size of the nozzle connection.

Bending and Forming. Pipe may be bent by any hot or cold method consistent with material characteristics of the pipe being bent and the intended service. It may be bent to any radius that will result in a bend arc surface which is free of cracks and buckles. However, it is recommended that the centerline radius of pipe bends shall be equal to at least three times the nominal pipe diameter, and fabrication should be in accordance with ES-24, *Pipe Bending Methods, Tolerances, Process and Material Requirements*, of the Pipe Fabrication Institute.[33] Tighter bends approaching 1½ D are possible, such as that obtained with induction bending methods with appropriate heat treatment. Specific manufacturing experience and process procedures in these circumstances should be reviewed by the process plant owner, which is recommended in assessing cost incentives over more conventional pipe bends or elbows. Hot bending and forming must be done within a temperature range consistent with material characteristics, end use, or postweld heat treatment.

When pipe must be threaded before bending, forging, or heat treating, all exposed threaded surfaces should be protected during heat treatment.

Heat Treatment. Heat treatment is used to avert or relieve the detrimental effects of high temperature and severe temperature gradients inherent in welding, and to relieve residual stresses created by bending and forming. The welding procedure qualification describes the necessity for preheating and postweld heat treatment of welds (and the temperatures and soaking period to be used) in order to restore or obtain the physical properties of the materials (such as strength, ductility, and corrosion resistance) needed to satisfy end-use requirements. Specific requirements for preheat and post weld heating are provided by Sec. 330 and 331, respectively, of ASME B31.3.

In the case of dissimilar materials, the heat treatment of welded joints between dissimilar ferritic metals or between ferritic metals using dissimilar ferritic filler metal should be at the higher of the heat treatment temperature ranges specified by the Code for the materials in the joint. Heat treatment of welded joints including both ferritic and austenitic components and filler metals should be as required for the ferritic material or materials.

Cleaning After Fabrication. Following fabrication, all loose scale, weld spatter, slag, sand, and other foreign material should be removed from the piping. Piping Fabrication Institute (PFI) Standard ES-5, *Cleaning of Fabricated Piping*, is an acceptable standard for cleaning fabricated piping.[34] Piping is typically painted, at least primed, before leaving the fabricating shop (i.e., before it has been erected and tested). However, it recommended that all welded joints for buried piping systems or for piping within environmentally sensitive areas be left unprimed and unpainted for examination during pressure testing.

Bolting Procedure for Flanged Joints. Proper assembly of bolted joints is as important as proper welding in assuring leak-free performance of piping systems. Chapter A7 of this handbook provides a detailed discussion of bolted joints. For the majority of flanges, it is recommended that specific *bolt-up procedures* be developed, and that field personnel be qualified by assembling one or more joints, in much the same way as welding procedures and welder qualifications are handled. The selection of the proper technique of tightening the bolts of a flange joint is a complex process requiring experience and good engineering judgment. In addition, the successful application of any technique requires qualification of the tools to be used and the crew.[35] The following steps are recommended as a general approach to flange makeup:

1. Check studs and nuts for proper specification stamp. Check bolts or studs, nut threads, and nut contact face for cleanliness and burrs. Bolts and nuts should be cleaned using a wire brush and visually examined after cleaning to ensure that they are free from burrs.
2. Lubricate the bolt and nut threads uniformly on all contact surfaces, including the nut-bearing surface contacting the flange, with an appropriate high temperature colloidal nickel compound. The use of hardened steel washers is recommended under the nuts of bolts 1½ inch in diameter and larger.
3. Clean gasket seating surface on flange face using a wire brush (use stainless steel bristles on alloy components). Ensure that the surface is free from scratches, dirt, scale, remnants of old gaskets, and other protrusions. Flange faces with radial scratches or tool marks that form leakage paths should be refaced.
4. Check the alignment of the two mating flanges in the field to verify that it is within accepted fabrication tolerances. Alignment should be achieved by cutting and rewelding the pipe where possible. Excessive force should not be used to

move flanges into alignment, particularly for piping attached to machinery or other load-sensitive equipment.

5. Visually examine the gasket prior to installation to ensure that it is free from defects. Make sure the gasket type, size, and materials of construction are in accordance with the specifications.
6. Insert the gasket between the flanges carefully to ensure proper placement (centering in the joint), taking care not to damage the gasket. If absolutely necessary to use something to hold the gasket in place, a light spray of adhesive can be used. Alternatively, thin cellophane or masking type tape may be used on the outside edges of gasket with enough material protruding to allow removal during the initial tightening process. Tape should be located with care to avoid infringing on the flange face/gasket seating surfaces.
7. Install bolts and hand-tighten. Tighten bolts with qualified tools, torque or hydraulic stud tensioners, and procedures. Tightening of the bolts should follow usual crisscross sequential pattern to approximate uniform preload seating of the gasket.
8. A multipass tightening procedure should be implemented to ultimately tighten the bolts to the target bolt-preload stress.
9. Increase torque or hydraulic pressure to 100 percent of the value necessary to achieve the desired residual stress level. The majority of flange joints in process plants are assembled based on 50 ksi average preload stress using ASTM A 193 Grade B7 bolts. However, there are some combinations of flange type, rating, and bolting material for which lower bolt stress values are appropriate.
10. Depending on the critical nature of the flange service, consideration should be given to measuring the elongation (stretch) achieved in the bolt to verify the target bolt preload has been obtained and relatively uniform for all bolts of the flange. The use of bolt elongation measurements should be specifically considered as part of the qualification procedures of the boltup methodology, tools, and the work crew in achieving the required target preload.

The completed bolt loading should exert a compressive force of at least twice that generated by the internal pressure to compensate for not only the internal pressure, but for other factors including bolt and gasket relaxation effects, and possible bending loads which are imposed on the flange pair during operation.

Steel-to-cast iron flanged joints must be assembled carefully in order to prevent damage to the cast iron flange. Both flanges in steel-to-cast iron flanged joints should be flat-faced and full face gaskets should be used. These joints should be made up with extreme care, taking up on bolts uniformly after fitting flanges into close parallel and lateral alignment. Flanges that connect piping to mechanical equipment, such as pumps, turbines, or compressors, should be fitted up in close parallel and lateral alignment prior to tightening the bolting.

Bell and Spigot Joints in Cast Iron Piping. Bell and spigot joints in cast iron piping should be assembled using poured lead or other joint compound suitable for the service. Usually each cast-iron bell and spigot joint is packed with hemp, poured full of lead (with a minimum number of pours), and then caulked. The depression of lead below the face of the bell, after joint caulking, should not exceed ¼ in (6 mm). Lead wool can be used where it is not permissible to pour lead.

Threaded Piping. Any compound or lubricant used on threads must be suitable for the service conditions and compatible with both the service fluid and the piping materials. Threaded joints which are to be seal welded should be made up without any thread compound or PTFE tape.

Erection of Metal Bellows Expansion Joints. Metal bellows expansion joints should be installed as shipped from the manufacturer or compressed for the cold condition at erection depending on anticipated direction and magnitude of movement after the piping reaches operating temperature. The manufacturer's recommended total travel should preferably straddle the calculated travel. The bellows assembly of expansion joints in piping systems should be equipped with a removable external steel cover designed to protect the bellows from external mechanical damage. The cover should be designed so that it does not prevent the required thermal movement of the joint.

Erection of Valves. The manual operation of principal block and control valves should be checked to the extent practicable before they are fully installed within the system. In the case of gate valves, this should specifically check that the gate travel is in proper contact with the body seats when in the fully closed position. Similarly, the closure mechanisms of check valves should be checked to ensure good seat alignment and ease of operation. Valve packing glands should also be checked for the quality and quantity of packing, and lubricated plug valves should be provided with proper lubricant.

Erection of Pipe Supports and Springs Hangers. In addition to the major supports specified by the design drawings, minor supports as found necessary in the field should also be installed to prevent undesirable vibration, sag, lateral movement, or stresses. Spring hangers and pedestals, including the constant-support type, should be checked for proper adjustment of travel and be correctly positioned for the cold condition of erection. Springs should be provided with spring travel indicators and scales to allow the monitoring of these supports while in service from grade or nearby platforms.

Cleaning of Lines After Assembly and Erection. After the completion of erection, scale, dirt, welding electrodes, slag, and other foreign material should be removed from the lines. Particular attention should be given to the cleaning of air lines, equipment lubricating and seal-oil systems, and compressor, blower, pump, and turbine inlet piping.

All practical precautions should be taken to prevent the introduction of foreign matter into pumps, instruments, and other equipment. Cleaning may be accomplished by flushing out the lines. Temporary strainers should be used at pumps during the flushing operation unless spools or valves can be conveniently dropped out and suitable deflectors provided to prevent refuse from entering the pumps. Consideration should be given in dismantling those lines which cannot be adequately cleaned by flushing.

Examination, Inspection, and Testing

Prior to initial operation, a piping installation should be inspected to the extent necessary to assure compliance with the engineering design, and with the material, fabrication, assembly, and test requirements of the code. An employee representative of the owner should be responsible for this inspection. This examiner may delegate performance of any part of the inspection to inspectors who may be employees of his own organization, of an engineering or scientific organization, or of a recognized insurance or inspection company.

A nondestructive examination (NDE) plan should be consistent with service severity, incorporating process and mechanical factors. The NDE plan focus should be on those pipelines where failure would produce the most harm to personnel or property. Some issues that the designer should consider when developing the NDE plan are:

- *Service factors*: The hazardous natures of flowing media including their degree of corrosivity, toxicity, and flammability are some considerations to which the designer would want to apply a sound NDE program in order to detect flaws in these dangerous streams.
- *Mechanical factors*: Temperature, pressure, cyclic conditions, thermal bending stresses, and vibration can contribute to fatigued and highly stressed lines, which are more likely to fail than low stressed lines. Detection and removal of flaws can provide additional service life.

Visual Examination. Visual examination consists of observations by the examiner of whatever portions of a component or welds that are exposed to such observation, either during or after manufacture, fabrication, assembly, or testing. Sufficient materials and components, selected at random, need to satisfy the examiner that they conform to specifications and are free from defects.

Types of Examination. The following types of examination are or may be specified by engineering either when required by the Code or considered necessary because of special service conditions requiring a high degree of freedom from imperfections. If such examination is specified for a weld, it is only required that the weld examined be repaired, if necessary, so that the weld imperfections comply with the limitations in the Code for the type of examination used. ASME B31.3 requires certain NDEs be performed in accordance with the methods described in ASME Sec. V, Nondestructive Examinations.[36] If supplementary types of examination are specified they should be performed after completion of any postheat treatment where required. If any of the following types of examination are specified by the engineering design, they should be performed to the extent that follows:

- *Magnetic Particle.* Magnetic particle examination is essentially a surface-type examination, although some imperfections just below the surface are detectable. This type of examination is limited to materials which can be magnetized (hence it is not appropriate for austenitic stainless steels). An area to be examined by magnetic particle examination can be completely examined or examined on a random sampling basis, as specified.
- *Liquid penetrant examination.* Penetrant-type examinations are suitable for surface examinations only but are very sensitive. The most common case is a red dye penetrant with a white developer.
- *Random Radiography.* X-ray or gamma ray method radiography may be used. The selection of the method should be dependent upon its adaptability to work being radiographed. When random radiography of welds is specified by the engineering design, it should be done on the number of welds designated. The engineering design shall specify the extent to which each examined weld should be radiographed. Random radiography may also be used for examination of piping components such as a valve or fitting to any extent specified by the engineering design.

- *100 percent Radiography.* If 100 percent radiography is specified for welds in piping, each weld in the piping shall be completely radiographed.
- *Ultrasonic Examination.* Ultrasonic examination is used in piping for the detection of defects in welds and materials as well as for determining material thickness. The ability of UT to detect discontinuities depends a great deal on the part geometry and defect orientation. Therefore, the search technique must be carefully chosen to assure that it will cover all possible defect orientations.

Hardness Tests. The extent of hardness testing required shall be as specified by Code or by the engineering design, considering the severity of the service, type of material, and other pertinent factors.

Pressure Tests. Prior to initial operation, piping must be pressure tested to assure leak tightness. If repairs or additions are made following the pressure tests, the affected piping is retested, except that in the case of minor repairs or additions the owner may waive retest requirements. The pressure test is maintained for a sufficient time to determine whether there are any leaks but not less than 10 minutes.

Water is commonly used as the test fluid, except when there is a possibility of damage due to freezing, or if the operating fluid or piping material would be adversely affected by water. If hydrostatic testing is not considered practical, a pneumatic test using air or another nonflammable gas may be substituted. However, pneumatic testing involves the hazard of released energy stored in compressed gas. Particular care must therefore be taken to minimize the chance of brittle failure during a pneumatic leak test. Test temperature is important in this regard and must be considered when the designer chooses the material of construction.

Hydrostatic Pressure Tests. Hydrostatic tests are conducted at 1.5 times nominal design pressure, adjusted for temperature, per the following equation from ASME B31.3:

$$P_T = 1.5P \frac{S_T}{S}$$

where P_T = minimum test gage pressure
P = internal design gage pressure
S_T = allowable stress value at test temperature
S = allowable stress value at design temperature

If the test pressure as defined in the preceding equation would produce a stress in excess of the yield strength at test temperature, the test pressure may then be reduced to the maximum pressure that will not exceed the yield strength at test temperature.

Test Preparation. All joints, including welds, are to be left uninsulated and exposed for examination during the test. If a joint has been previously tested in accordance with the code it may be insulated or covered. Piping designed for vapor or gas shall be provided with additional temporary supports, if necessary, to support the weight of the test liquid.

Expansion joints shall be provided with temporary restraint, if required, for the additional pressure load under test or shall be isolated from the test.

Equipment which is not to be included in the test should be either disconnected from the piping or isolated by valves or blanks. If a pressure test is to be maintained for a period of time and the test liquid in the system is subject to thermal expansion, precautions must be taken to avoid excessive pressure buildup.

All pressure gages, gage glasses, flowmeter pots, liquid level float gages, and all other pressure parts of instruments, together with the piping connecting the instruments to the main piping, should be included in the hydrostatic test. Relief valves and rupture disks should not be subjected to the pressure test.

Pneumatic Testing. If piping is tested pneumatically, the test pressure is set at 110 percent of the design pressure, which is considerably less than the test pressure required by ASME B31.3, if tested hydrostatically. Pneumatic tests include a preliminary check at the lesser one-half the test pressure or 25 psig (172 kPa), and the pressure is then increased gradually in steps providing sufficient time to allow the piping to equalize strains during the test and to check for leaks. Again, particular care must be taken to minimize the chance of brittle failure during a pneumatic leak test.

Test Records. Records must be made of the tests, including date of test, identification of piping tested, test fluids, test pressure, and approval by inspector.

SPECIAL DESIGN PIPING SYSTEMS

Refractory Lined Pipe

Often elevated temperature pipelines or systems in erosive fluid solids service can be candidates for refractory lined piping systems. A principal application of refractory lined piping systems can be found in catalytic cracking units typical of most large refineries. A catalytic cracking (Cat) unit brings together a heavy feed and an active catalytic agent to produce lighter, more valuable petroleum products.[37] Catalytic cracking combines the action of heat and a catalyst to produce higher yields of motor fuels and other valuable products. In typical Cat units, the catalyst is fluidized and continuously circulated between a reactor vessel operating at around 1000°F (538°C) and a regenerator vessel where carbon is burned off the catalyst at about 1300°F (704°C). Operating pressures are usually well below 100 psig (690 kPa). The vessels and interconnecting reaction and regeneration piping are all refractory lined because of the economic material advantages that can be gained by applying thermal insulation on the inside of the vessel and pipeline rather than on the outside when very high operating temperatures are involved. Some of the immediate advantages include:

- Pipe wall (pressure boundary) temperature is considerably lower, thereby, allowing the use of lower alloy or carbon steel material at higher allowable stresses. In fact, process developments continue to push design temperatures to higher limits, upwards of 1300°F (704°C) and beyond, where refractory lined equipment and piping is the only feasible alternative to allow operation at these temperature extremes.
- Decreased thermal expansion will allow a tighter piping layout. However, as will be discussed in subsequent text, the refractory lining will significantly increase the stiffness of the pipe system, which needs to be considered in the thermal flexibility of the piping involved.
- Another advantage of refractory lined systems is the potential for improved erosion resistance, relative to bare steel, which is an important feature when fluidized solids processes are involved as in the case of Cat units.

These factors affect lower installed cost. The economic advantage becomes increasingly significant as temperatures, pressures, and pipe sizes increase.

The design of internally lined pipe entails a number of unique considerations. First, the effect of the process fluid on the thermal conductivity of the refractory needs to be considered. Low molecular weight gases, such as hydrogen, tend to permeate refractory linings. Influencing parameters include pressure, temperature, refractory density and composition, application techniques, and refractory cell structure. Empirical correction factors based on field experience have been developed for various processes and combinations of refractory types.

Selection of appropriate lining materials and design details are important to ensure a properly functioning system. Depending on service conditions, either a single layer or dual layer lining can be used. Some designs are depicted in Figs. C7.8, C7.9, and C7.10.

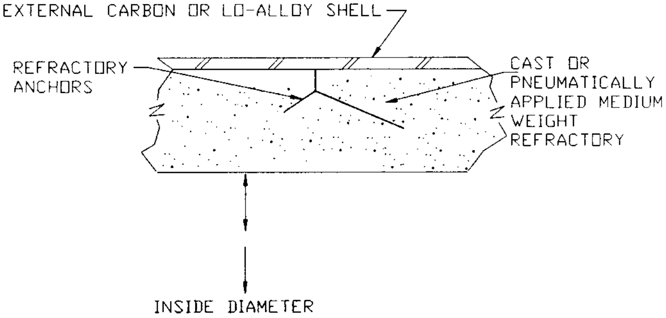


FIGURE C7.8 Single layer refractory lining for clean service.

An advantage of the dual layer is that the internal layer can be made of a relatively dense refractory with good strength and erosion-resistance properties without concern for insulating values. This thickness should be sufficient to prevent through-wall cracking and should reflect the minimum required for the anchoring detail specified.

The outer layer next to the pressure boundary pipe wall can be a light-weight

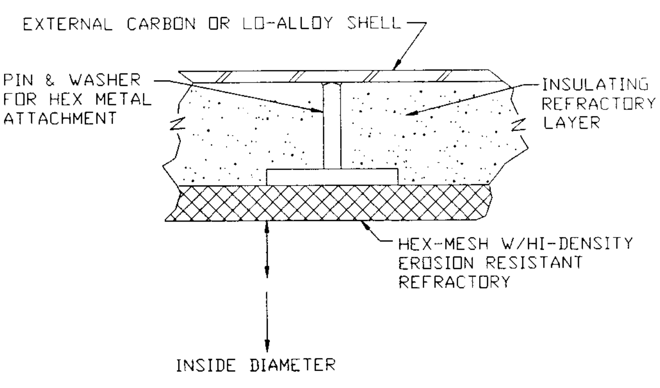


FIGURE C7.9 Dual layer refractory lining for erosive service.

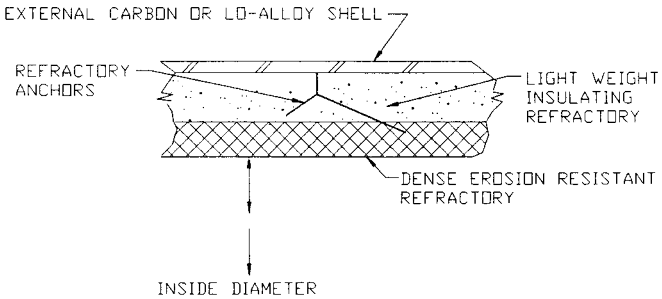


FIGURE C7.10 Dual-layer refractory lining for hydrogen-bearing streams.

refractory with good insulating properties to provide maximum temperature reduction. Various schemes for refractory installation have been used for dual-layer linings. See Figs. C7.9 and C7.10.

While the advantages of refractory lined pipe are quite apparent, the lining will significantly increase the stiffness of the piping. The stresses in the pipe will be higher, but more important, there will be much higher reaction loads at all equipment connections and thermal expansion restraints. The thermal flexibility analysis of refractory lined pipe is relatively complex and will typically require the use of computer tools with experimentally determined influence factors to account for the increased stiffness and line weight attributed to the refractory lining.

Typical applications for refractory lined steel shell transfer lines are again found in process applications when high temperatures, greater than 1000°F (538°C), and significant flow rates (and corresponding large diameter pipelines) are concurrent design parameters. In addition to catalytic crackers, there are other refinery services where high temperature fluid solids are involved, such as fluidized cokers and catalytic reformer processes, which will use refractory lined equipment and piping. Many such lines, for example, can be found in large refinery operations with diameters of NPS 60 (DN 1500) and larger that typically carry flue gases from regeneration vessels, cokers, and crackers. Transfer lines from certain thermal cracking type heaters are also typically refractory lined.

Jacketed Pipe

Jacketed pipelines (see Fig. C7.11 for typical construction) are commonly employed for conveyance of certain fluids in process facilities where external heating (usually by steam or other heating fluids) is required to maintain process temperatures under very controlled conditions. Process fluids that require stringent temperature control (i.e., molten sulfur) are good candidates for jacketed pipe applications. Molten materials (i.e., polymers) where high temperature maintenance is required are also candidate applications for jacketed pipe construction.

The advantages afforded by jacketed pipeline construction over other (i.e., tracing) heat transfer methods can be briefly described as:

- Uniformity of heat input around circumference of process pipe
- Tighter temperature control over entire pipeline length

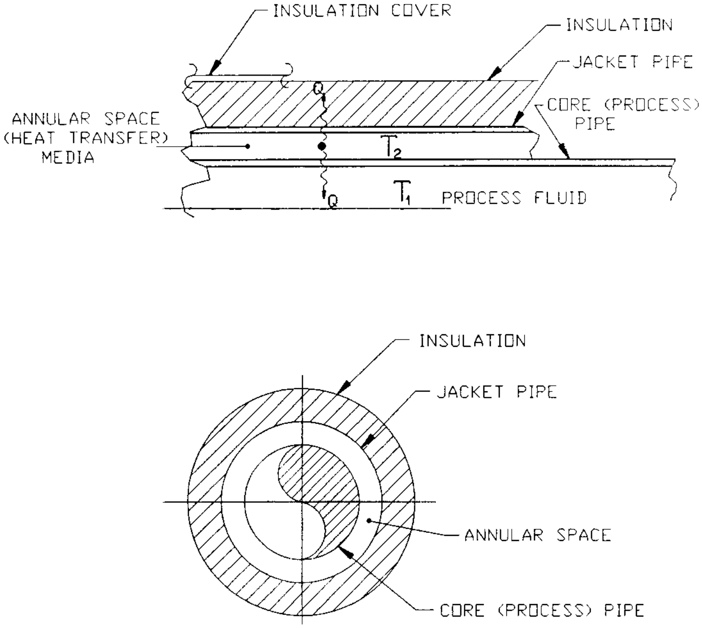


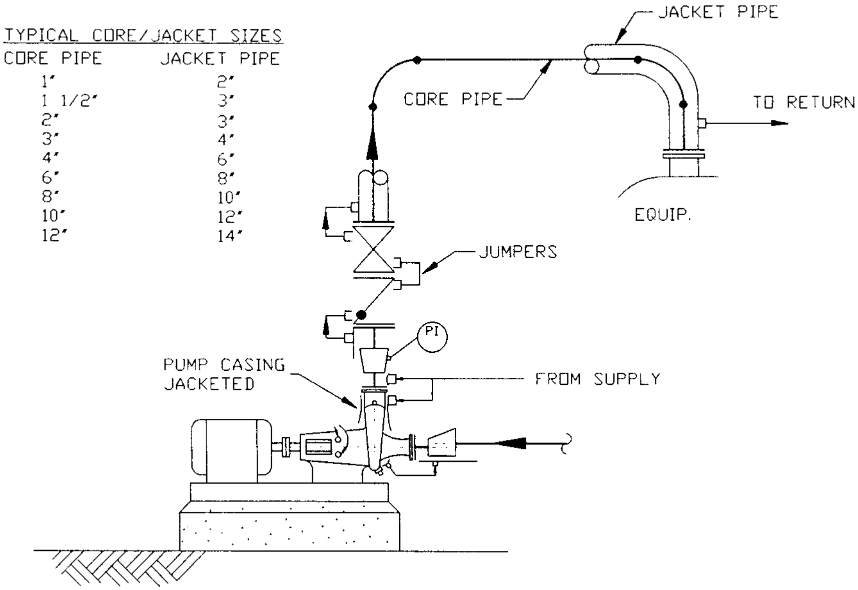
FIGURE C7.11 Heat transfer jacketed pipe.

- Elimination of "cold spots" that may cause process fluid degradation or localized freezing

Various heating media are used for temperature control of the process fluid. Liquid and vapor phase fluids are employed, each with their own specific advantages and design requirements.

Liquid Phase. As shown by Fig. C7.12, liquid-phase jackets are considered as circuits each having its own valved supply and return connections from the pipe header. The number of jackets included in a circuit is a function of heating medium heat loss, pressure drop through the jacket circuit, and position and location of the piping. As indicated in Fig. C7.12, fluid supply is introduced at the lowest tapping of a jacketed part; passes through the jacket and exits at the highest jacket tapping. This method of piping continues for the length of the circuit. Jumpers, as shown by Fig. C7.13, are used to carry the liquid across flanged connections. The fluid is then returned to the heater via the return header and a new connection from the supply main feeds the next circuit. Temperature of any circuit is controlled by throttling the quantity of fluid flowing to the jackets.

Vapor Phase. The number of jacket sections heated with a condensing vapor in any one circuit has the same considerations as liquid heating mediums. Unlike liquid phase heat transfer fluids, a jacketed pipeline heated with a condensing vapor (see Fig. C7.14) requires that the vapor inlet pipe be connected to the uppermost jacket tap rather than the lowest tap as in liquid heating. Jump overs, as shown by



TYPICAL CORE/JACKET SIZES

CORE PIPE	JACKET PIPE
1″	2″
1 1/2″	3″
2″	3″
3″	4″
4″	6″
6″	8″
8″	10″
10″	12″
12″	14″

FIGURE C7.12 Jacket liquid phase—circuitry.

Fig. C7.15, carry vapor to the top of each section or flanged joint. The condensate is drained from each section or flanged joint, collected, and piped to a trapped common return header. Low pressure steam is typically the heating media of choice for most vapor jacketed piping systems.

Jacketed pipeline construction details vary depending upon process factors. When maximum heat transfer is desired, a full jacket is used (where the jacket pipe is welded to the back of oversize flanges). This technique will minimize any potential cold spots. Partial jackets are used for those services where product contamination or danger of hazardous conditions could arise if product and heating media could mix, or where temperature control is not critical and localized cold spots would not be detrimental to pipeline performance.

The design of integral jacketed piping needs to consider the increased stiffness resulting from the addition of the external jacket. As previously discussed for refractory lined systems, this will require sophisticated piping flexibility analyses

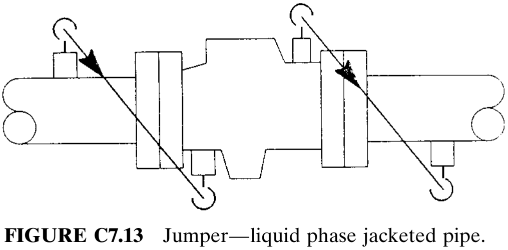


FIGURE C7.13 Jumper—liquid phase jacketed pipe.

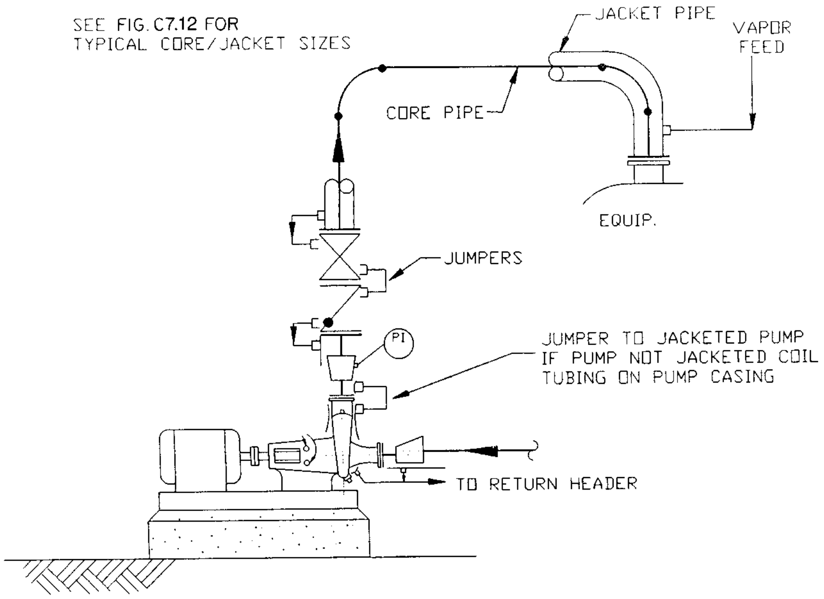


FIGURE C7.14 Jacket vapor phase—circuitry.

to properly determine piping thermal flexibility stresses and imposed equipment loads that account for the increased stiffness of the integral jacketing construction.

Nonintegral or strap-on jackets are usually employed to provide a means of heat transfer to a pipeline component that may not be adaptable to integral jacketing (e.g., valve bodies). In all cases, the heat transfer distribution circuitry must be properly designed and installed for satisfactory performance.

Vacuum jacketed piping systems are employed to transfer cryogenic temperature

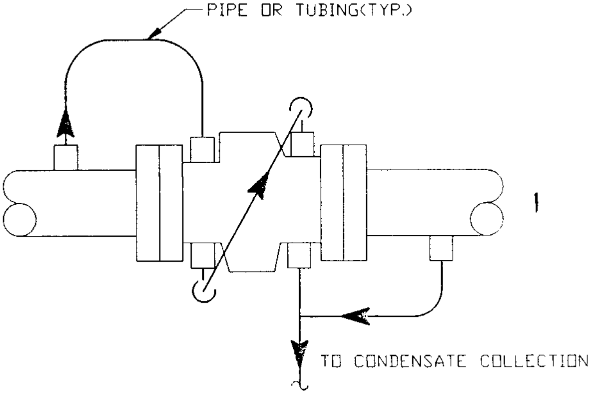


FIGURE C7.15 Jumper—vapor phase jacketed pipe.

process fluids. The vacuum is established to minimize heat gain from the atmosphere to the cryogenic fluid. With the addition of external insulation little heat gain and resulting fluid vaporization will be realized. Cryogenic systems piping is covered in depth in Chap. C8 of this handbook.

Plastic Lined Pipe

Internal plastic liners are available in numerous materials that can be selected for use for a specific media. Some lining materials that are commonly used include PP (polypropylene), PVDC (polyvinylidene chloride), PTFE (polytetrafluoroethylene), FEP (perfluoro (ethylene-propylene) copolymer), ETFE (ethylene-tetrafluoroethylene), PFA (perfluoroalkoxy), and PVDF (polyvinylidene fluoride). Refer to Chap. B12 for details on plastic lined piping.

The properties of plastic-lined piping components permit these materials to be considered for the transportation of a variety of combinations and concentrations of fluids that are often very aggressive in normal steel piping systems.[38] Corrosion resistance is clearly a prime consideration for use of plastic-lined piping. However, there are other applications where plastic lined piping might be considered, including the following:

- Maintenance of process fluid purity, such as the processing of food products.
- Water treatment facilities and laboratory waste disposal systems.
- For secondary containment of dangerous, flammable, or environmentally damaging liquids. Because of its steel outer shell construction, the lined pipe will remain structurally self-supporting at higher temperatures and is less likely to rupture than solid plastic pipe.

Thermoplastic and thermoset resin piping systems are described in some detail in Part D, ''Nonmetallic Piping,'' of this handbook. Since these materials are not inherently fire safe, their application in typical refinery and chemical plant processes is very limited.

Glass and Glass-Lined Pipe

Borosilicate glass is used for specific piping services in the chemical and pharmaceutical industries. Some advantages afforded by glass piping are:

- Outstanding corrosion resistance for a variety of aggressive chemicals
- Smooth, pore-free surface
- Transparency
- Lack of product contamination effects, including those affecting taste, odor, and color
- Inertness

Glass lined piping components offer much of the same advantages afforded by solid glass piping and offer secondary containment, increased resistance to shock loads, and installed economics compared to other corrosion-resistant systems. The glass lining is extended from the pipe bore to cover the gasket seating areas of flanges. Gasket materials are typically limited to nonmetallic sheet gaskets suitable for the service to minimize compression seating forces exerted on the glass lined flange face.

SYSTEM LAYOUT CONSIDERATIONS

Piping arrangement and layout is discussed in depth in Chap. B3 of this handbook. This section will provide some important considerations in the design and layout of several of the more common types of piping systems found in process plants.

General Piping Arrangement

A general rule in piping layout is that lines should be located in as neat and orderly a manner (in groups or banks whenever practicable) as is consistent with economical design, pressure loss considerations, and satisfactory supporting arrangements. With the exceptions of water, drainage, and pumpout lines, the accepted practice on a process unit is to run the piping overhead, providing 7 ft (2.2 m) or more of clear headroom over walkways and platforms. Piping in a process unit should not be located at grade, especially in areas where frequent personnel traffic is likely.

All piping and equipment requiring regular attention of the operating and maintenance personnel should be readily accessible. Also, adequate clear working spaces, typically having a minimum width of 3 ft (1 m), should be maintained around equipment such as pumps, heat exchangers, control valves, instruments, and tower manways, which require frequent servicing. Consideration should be given to providing lateral and vertical clearance for the use of motorized materials-handling and crane equipment in maintenance work. To the extent practicable, principal valves should be located so they may be replaced and operated from grade, permanent platforms, or small portable platforms. If the bottoms of the handwheels are more than 6 ft above a platform or grade level, or if otherwise inaccessible, the valve should be equipped with extension stems or chain operators.

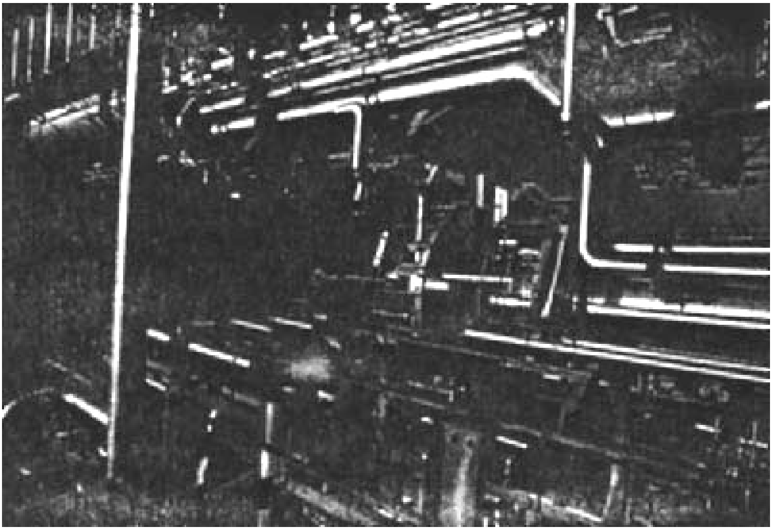
High temperature lines in a process plant pose problems for other piping and equipment. For example, hot lines, with temperature higher than 100°F (38°C), should be routed so as to avoid electrical conduits. Steam and condensate should not be discharged into the ground in the vicinity of electrical conduits. Lines containing corrosive chemicals should not be located near hot lines or other sources of heat.

Pressure Vessel (Reactors/Towers/Drums) Piping

The piping designer is cautioned that often limitations concerning piping connections at vessels are detailed in Sec. VIII of the ASME Boiler and Pressure Vessel Code. This would typically include piping between the vessels protected by the same relief valve, and piping between a vessel and its pressure relief safety valve. The piping designer should coordinate piping requirements with the vessel designer to achieve the optimum nozzle locations.

In the case of tall vertical reactors and most towers, the piping will be supported directly off the vessel as shown, for example, by Fig. C7.16. For economy and ease of support, piping in these situations should drop or rise immediately upon leaving the tower nozzle and run parallel along the side of the vessel as close as reasonably possible to limit wind-imposed loadings to the vessel nozzles. Thermal flexibility provisions will need to consider the differential thermal expansion between the vessel shell and the piping being supported.

Connections off the bottom head of skirt supported vertical vessels should locate the nozzle flange outside of the skirt. This minimizes the possibility of flange leakage within the confined spaces of the vessel skirt. Hence, bottom nozzles are usually



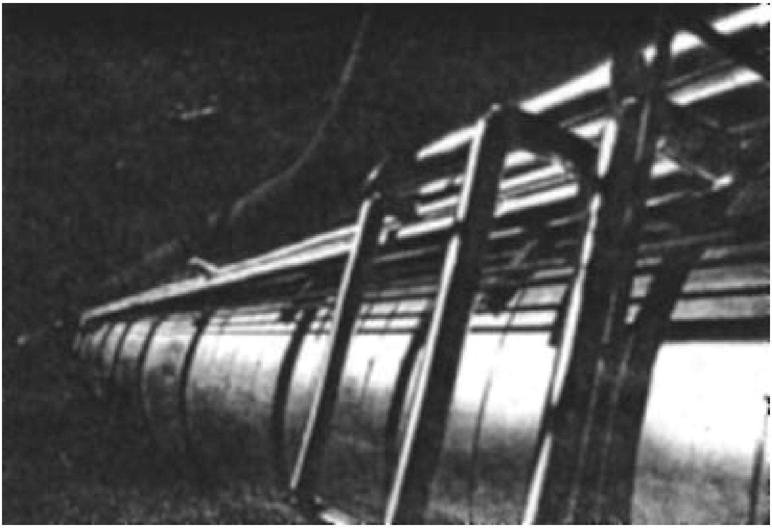


FIGURE C7.16 Typical tower piping layouts.

angled in these cases to locate the nozzle flange just outside of the skirt. Piping flange connections in general should be avoided within the vessel skirt.

The location of isolation valves should consider the possible rupture of a line connected below the vessel liquid level (or to the dense phase in a fluid-solids vessel), which could drain the vessel unless there was a valve to stop the drainage. In deciding whether these valves are needed, the likelihood of mechanical damage to the line will be the prime consideration. Small lines, NPS 2 (DN 50) and smaller, are obviously more susceptible to damage than large lines, and hence are most often supplied with suitable isolation valves.

Compressor Piping

Special precaution is necessary in the design and fabrication of the piping at or near compressors, especially for reciprocating compressors, to reduce fatigue failures. This piping should be designed to have the minimum of overhanging weight. This is mostly a problem with high pressure compressors, where valves are very heavy. Butt welding fittings should be used wherever practical, and fit-up should be accurate. Braces should be provided as needed to reduce vibration, and consideration should be given to grinding all welds to remove surface discontinuities.

Reciprocating Compressors. Means to reduce excessive surge and vibration should be provided as necessary in the suction and discharge lines of all reciprocating compressors, and located as close as practical to the compressor. In the case of most reciprocating process compressors, pulsation suppression devices are installed at the suction and discharge flanges of each compression stage. Pulsation suppressors are not typically required at the air intake suction of an air compressor, or at the interstage of an integral interstage cooler unless pulsations are expected to occur. Where surge chambers are provided, the connecting pipe should extend into the bottom of the chamber.

The need for detailed pressure pulsation analysis and for acoustic simulation and mechanical vibration analyses should be considered for reciprocating compressor systems to confirm the acceptability of proposed suction and discharge piping layouts and support/restraint locations needed to contain the pressure pulsation vibrations generated by the compressor. The composite compressor piping system needs to be designed so that it avoids acoustical natural frequencies in the system which coincide with the natural mechanical frequencies of the piping or the lower range of compressor harmonic frequencies. Special hold-down supports and thermal expansion restraints are typically required for reciprocating compressor piping systems even with pulsation bottles installed off the suction and discharge nozzles of the compressor.[39] Acceptance criteria for nozzle loads are provided by API Standard 618, *Reciprocating Compressors for Petroleum, Chemical, and Gas Industry Services*.[40]

Centrifugal and Rotary Compressors. A check valve should be installed in the discharge line from any centrifugal or rotary compressor discharge into a system from which the fluid may flow backward through the compressor. The check valve should be located as close as possible to the compressor.

When a compressor takes suction from a header, the suction lateral should preferably be connected to the top of the header. However, if the lateral is at least one pipe size smaller than the header, it is permissible to make a centerline connection to the side of the header. Temporary screens should be provided for initial compressor start-up and should be located as close as possible to the compressor unless permanent screens or filters are installed immediately adjacent to the compressor.

The flow characteristics of centrifugal compressors should be investigated to determine whether devices are required to prevent surging during start-up. Knockout drums should be provided upstream of all compressors except those which handle gases with no possibility of condensate being formed. That is, most air and nitrogen compressors do not require knockdown drums. Compressor suction lines between the knockdown drum and the compressor should be as short as possible, without pockets, horizontal, and sloped toward the compressor. Also, for wet gas compressors, this portion of the suction line should be insulated. It may require auxiliary heating in the form of heat tracing to prevent condensation. Where the line between the knockdown drum and the compressor is long, low points in compressor suction lines should be provided with drains to remove any possible accumulation of liquid. If the suction line normally operates under vacuum conditions, all drains between the knockdown drum and the compressor should discharge into the knockdown drum.

Compressor discharge piping should be analyzed for flexibility under thermal load resulting from the heat of compression. Flexibility analyses will be needed for all centrifugal compressors to confirm the acceptability of the combined loads imposed on the compressor nozzles in accordance with the requirements of API 617, *Centrifugal Compressors for Petroleum, Chemical and Gas Industry Services*.[41] This standard also provides acceptance criteria for axial compressor piping.

The fabrication of suction and discharge piping requires stringent flange alignment tolerances at the compressor nozzle connections to avoid excessive loads imposed on the machine. Maximum permissible flange rotations and lateral translation tolerances of 1⁄64 in (0.4 mm) is not uncommon for this purpose, which can represent a challenge for relatively large [equal to or greater than NPS 12 (DN 300)] suction and discharge piping.

Pump Piping

Permanent strainers should be provided upstream of pumps handling streams which are likely to contain foreign material such as sand and scale. Temporary strainers, preferably of the cone type, should be provided for initial unit start-up where permanent strainers are not provided, and should be located as close as possible to the pump suction nozzle. A block valve should be provided in the suction line of each pump and located upstream of the strainer. For dirty streams, where two or more pumps take suction from a single header, the block valves should be located as close as is practical to the header to minimize the collection of dirt upstream of the valve.

A block valve should be provided in the discharge line of each pump. A check valve should be installed in the discharge line of each centrifugal or rotary pump unless there is no possibility of a reversal of flow or pressure surge under any condition. The check valve should be located between the pump and the block valve with a drain between the block and the check valve.

Pump Piping Layout Considerations. Most pump installations in process plants have spare units to assure continuous operations by switching to a standby pump if required for maintenance. Pump piping, especially for high temperature service, generally represents one of the more difficult systems to design for thermal flexibility.

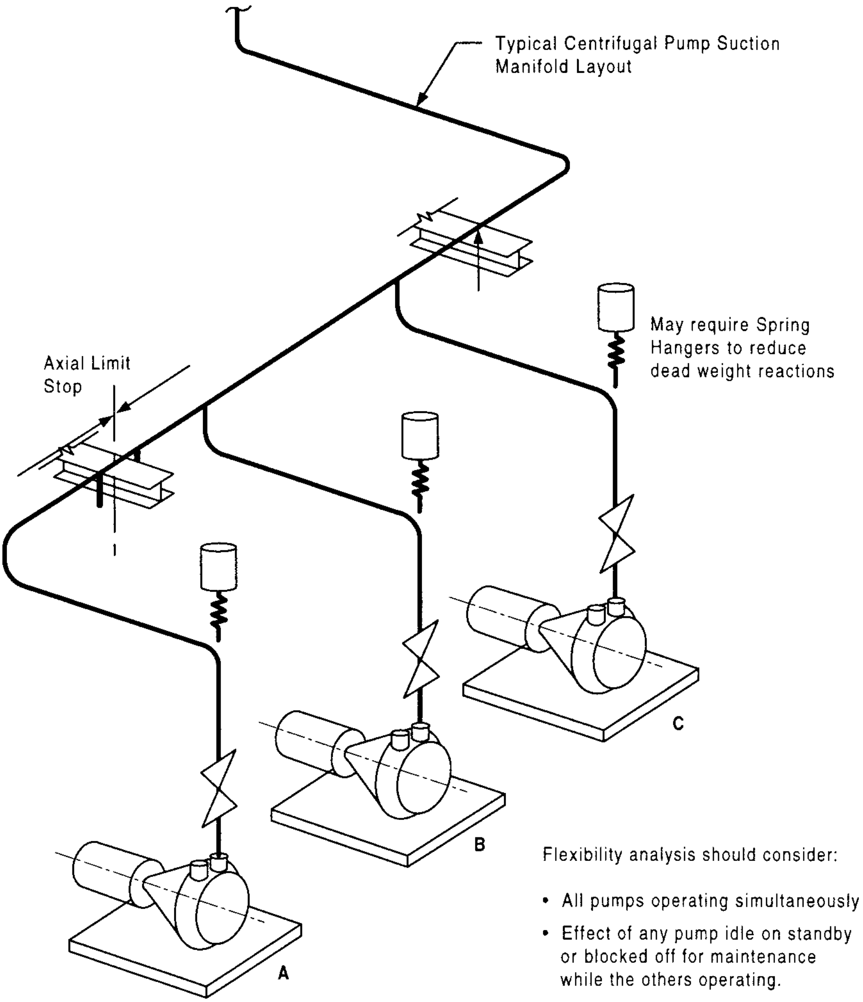


FIGURE C7.17 Typical piping layout for spared pump service.

A typical piping layout for the suction of a 3 centrifugal pump system is shown in Fig. C7.17. The piping design needs to consider the various operating scenarios possible between operating and idle pumps, along with all pumps operating simultaneously. Thermal flexibility analyses of this system will need to consider all of these operating cases to confirm the acceptability of the worst scenario reaction loads imposed on the pumps. This needs to consider simultaneously acting operating or standby temperatures for each of the pump piping branches.

Nozzle load limits must be satisfied for combined thermal, dead weight, and friction loads. Spring supports are often needed near the pumps to reduce the dead weight loads on the nozzle connections. Directional restraints (e.g., axial limit stops and lateral guides) are also typically needed to prevent excessive thermal and friction loads on the pumps to control thermal expansion loads imposed on the pumps. Recommended acceptance criteria for nozzle reaction loads imposed on centrifugal pumps is covered by API Standard 610, *Centrifugal Pumps for Petroleum, Heavy Duty Chemical, and Gas Industry Service*.[42] And, in the case of reciprocating pumps, acceptance criteria is provided by API Standard 674, *Positive Displacement Pumps—Reciprocating*.[43]

As in the case of compressors, flange alignment between mating pump nozzle and piping flanges is very important and must be achieved to close tolerances to avoid excessive loads imposed on the pump. Concerns in this regard can lead to coupling misalignments between the pump and its driver, which can result in operating and subsequent maintenance problems.

Warm-up of Standby Pumps. Pumps that may be idle during plant operations and need to be started quickly should be provided with warm-up lines if pump design temperature exceeds 450°F (232°C), or if the process fluid will solidify at ambient temperature. The purpose of these warm-up lines is to eliminate undesirable thermal effects on lines and equipment and plugging of idle pump and piping materials. A typical warm-up line consists of an NPS ¾ (DN 20) valved bypass around the pump discharge block and check valves. The standby pump should be kept near to operating temperatures by opening the warm-up lines and by providing a suitable bypass around the discharge block and check valves to permit a small flow back through the idle pumps.

If the process fluid will solidify at ambient temperature, and the suction and discharge lines are not heated and insulated, an additional NPS ¾ (DN 20) valved bypass should be provided from the discharge lateral to the suction lateral and the header side of the valves. When the pump is removed from service, these laterals should be kept at operating temperature by opening this bypass valve to permit a small flow. The above warm-up lines should be heat-traced if the process fluid will solidify at atmospheric temperature. Pump systems with warm-up lines should be checked for adequate flexibility for the differential expansion between the pump discharge line and the warm-up line.

Low-Flow Protection. When the discharge line contains a quick-closing valve, the necessity for shock-absorbing equipment should be investigated if the closing time of the valve cannot be increased to a safe level. Where a remotely located valve can be closed against the pump and the pump does not shut off automatically or cannot be shut off immediately, a recirculating line should be provided from the pump discharge back to the point of suction. The purpose of recirculating the fluid is to prevent damage to the pump due to overheating. A low-flow protection system should be installed for pumps expected to operate at a flow less than the minimum continuous stable flow or minimum continuous thermal flow as defined by API 610. The minimum size of the recirculating line should be NPS ¾ (DN 20). The line should be equipped with at least one gate valve and an orifice sized to restrict flow to the minimum pumping rate of the pump.

Fired Heater Piping

Piping of interest for fired heaters consists of the inlet feed and outlet transfer lines typically from the radiant section. It also includes piping to and from convection section headers or cross-overs between the convection and radiant sections. Decoking piping systems and burner fuel lines are also of interest.

The design of principal inlet and outlet piping for large heaters usually needs to consider the thermal expansion, and restraints and supporting details, of the main inlet and outlet collection headers for the radiant section tubes. The thermal expansion movements of these components need to be reflected in the thermal flexibility analyses of the connecting piping, or better yet, to incorporate the headers in the analysis of the system. Spring supports are often required for this piping because of the relatively high operating temperatures and resulting thermal expansion.

Steam-Air Decoking. Permanent steam-air decoking methods for cleaning coke buildup from heater tube internal surface connections should be considered on heaters requiring frequent decoking and where installation of a temporary steam air header would necessitate considerable dismantling of the process piping. On heaters with parallel coils (passes), blanks are required to separate the coils for decoking connections. Dropout spools or blanks should be provided for all decoking operations which are also installed for steam out. The alternate to steam air decoking is to provide sufficient flanged fittings for mechanical decoking. Thermal flexibility analyses of furnace transfer lines should consider the decoking line connections if permanently piped and checked for both normal operation and decoking.

Fuel Gas Burner Piping. All fuel gas supplied to heaters should pass through a dry drum which is located as close as practical to the heaters. The supply main, the branch lines, and the distribution headers between the dry drum and the heater should be pitched downward in the direction of flow and be without pockets. If this is not possible, a condensate leg with a valved and plugged drain connection should be provided at the low point. Branch lines should be connected to the top of the header. A remotely controlled or a remotely located block valve should be provided in the supply line of each heater. Wherever heater outlet temperatures are controlled by regulation of the fuel supply, automatic fuel-regulator valves should be provided upstream of the distribution header. Each gas burner should be supplied with a steel shutoff valve installed in a position such that a person operating the valve will not be in close contact with the aspirator.

Fuel Oil Burner Piping. For heaters using fuel oil, the burner oil piping system generally consists of a burner oil storage tank, a burner oil pump and oil supply main with a strainer, branch line to each heater, a distribution header at the heater, and an oil return main back to the storage tank. Circulating fuel oil lines should be sized to carry 200 percent of the maximum design fuel load of the heater. A remotely controlled or a remotely located block valve should be provided in the supply main or in the branch lines to each heater, and shutoff valves should be provided between the firing valves and the headers. Fuel-oil lines should be sloped from the burner shutoff valves toward the burners to provide natural drainage. A pressure-reducing valve should be installed as close to the heater as practical and upstream of the burners to regulate the pressure at the burners. A recirculating bypass should be provided between the branch line to the distribution header and the return branch line from the distribution header.

The atomizing piping system used in conjunction with the burner oil consists of a branch line from a live steam main, and a distribution header around each burner. Branch lines should have a capacity of approximately twice the combined steam requirements of all burners supplied by the branch. Steam traps should be provided on the atomizing steam header where necessary to prevent water from reaching the burners.

Heat Exchanger Piping

Shell and tube, double pipe, plate frame, and air-cooled type heat exchangers are all well utilized in most process plants. Piping systems for these exchangers, especially for air-fin coolers, require particular attention to confirm the acceptability of imposed nozzle loads.

Generally, bypass piping around exchangers is provided for temperature control and to allow cleaning during operation of the rest of the process unit. There may be cases when the increase in operating efficiency resulting from cleaning or repair during the operation of the rest of the process unit would justify the cost of installing a bypass. Block valves need not be provided on the process side of the exchanger except where the valve is needed for flow control or where the exchanger may be bypassed while the unit is running. Typically, streams which are to be heated should enter at the bottom of the exchanger, and streams to be cooled should enter at the top of the exchanger.

Air-Fin Cooler Exchangers. The inlet and outlet piping to air-cooled exchangers can represent a significant design challenge, especially for large multibundle units operating at relatively high temperatures. Figure C7.18 shows two typical approaches for the design of piping manifolds for air-cooled heat exchangers, which use different layouts for the lateral connections (flexible versus stiff lateral designs) between the air-cooled header and the manifold headers. Both approaches need to satisfy the requirements of API Standard 661, *Air-Cooled Heat Exchangers for General Refinery Services*, for imposed reaction loads to the header nozzles.[44]

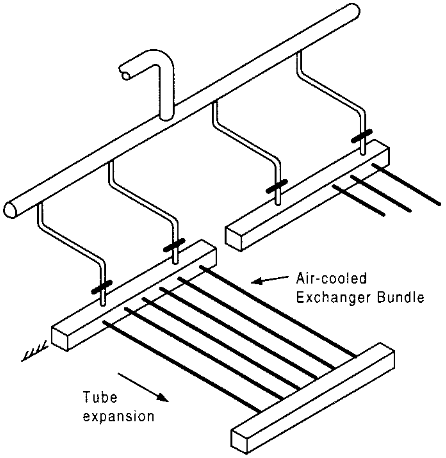
With flexible laterals, the differential thermal expansion between the individual air-cooled heat exchanger bundles and the connecting manifold header is accommodated by providing sufficient flexibility in each of the piping laterals. The thermal movements of the air-cooled exchanger bundles must be considered. The bundles are usually anchored at the inlet header to control the direction of the tube axial expansion.

With stiff laterals, a single manifold has short, stiff connections to the air-cooled exchanger. The bundles are allowed to move laterally to accommodate the axial thermal expansion of the piping manifold header. The lateral nozzle connections must be as short as possible to move the air-cooled bundles without overstressing the nozzles or the manifold connections. The flexibility analysis of this approach is relatively complex since it must consider the restraining effect of friction in attempting to move the bundles laterally. It also must consider the stiffness effects of the exchanger tubes, which resist the free lateral movement of the bundles.

The stiff laterals approach will typically result in lower material costs. However, this approach requires special construction procedures to achieve proper fit and alignment between the header nozzles of all the exchanger bundles. This typically requires the field fabrication of the manifold and the laterals directly off the installed air-cooled exchangers. There also needs to be sufficient clearance between air-cooled headers and side frames to allow for the thermal expansion of the manifold.

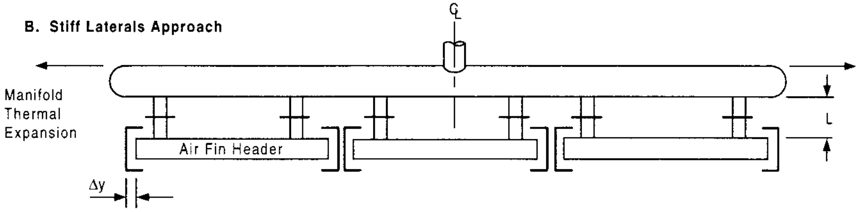
Other Exchangers. A pipe spool, elbow, or some such removable piece (other than the block valve) should be provided adjacent to the channel section of any exchanger which will be opened while the unit is in operation. Lines to condensers

A. Flexible Laterals Approach for Typical Air-Cooled Exchanger Inlet Manifold



- Design permits independent movement between air-cooled exchanger bundle andpiping manifold
- One end of exchanger bundle is typically anchored to control the direction of tube expansion.

B. Stiff Laterals Approach



- Bundles designed to slide in lateral direction to take up thermal expansion of the manifold.
- Make lateral connections, L, as short as possible so relatively stiff to avoid overstress in forcing header movement.
- Check for adequate clearances between the air fin header and side frames.
- Field fabrication of the manifold and laterals is usually required because of the short multiple nozzle connections off the air-cooled exchangers.

FIGURE C7.18 Alternative design layouts for air-cooled exchanger manifiolds.

should be sized to provide sufficient velocity to carry condensed liquids along with the vapors. Pockets must be avoided in these lines.

Heat exchanger lines which enter or leave the exchanger from a bottom nozzle need to be supported in such a way that the vertical expansion of the line between its first support and the exchanger does not overload the nozzle connections. The preferred layout design locates the first line support at about the same elevation as the midpoint of the heat exchanger saddle support. This balances the thermal expansion between the exchanger and the first pipe support.

Storage Tank Piping

The loads transmitted from piping to shell nozzles of large-diameter storage tanks are a major concern for tank designers. The loads which must be considered in the design of principal piping connections to tank nozzles include the following:

- Tank shell radial movements and nozzle rotations while filling and emptying a tank
- Design pressure of the pipe
- Thermal expansion of piping
- Differential settlement between the tank and the piping supports
- Weight of piping, valves, and contents

Stresses in the pipe caused by these load combinations should satisfy the ASME B31.3 Piping Code. Moment loads and resulting local stresses should also be checked in the tank nozzle and its connection to the tank, as covered by API Standard 650 for *Atmospheric Storage Tanks*.[45]

Figure C7.19 provides some examples of typical piping configurations that deal with the load conditions discussed in this section. For most systems, there is an advantage in locating the first horizontal bend of the line as close as possible to the tank nozzle. This provides for tank shell nozzle rotation through torsion in the leg of horizontal piping after this first bend. Depending on the level of predicted tank settlement, which can approach 12 in (305 mm) or greater over the life of the tank, spring hangers may be required for the supports nearest to the tank.

Process unit feed tanks should have separate filling and discharge piping systems to avoid sending slugs of water to the process units. Separate discharge and suction connections are specifically required if it is necessary to have facilities for recirculation or blending and there is no mixer in the tank. Block valves should be provided on all nozzle connections below the tank liquid level. Filling lines for tanks containing flammable fluids should discharge near the bottom of the tank without free fall because of the danger of static electricity being created.

Rack Piping

A *pipeway* is the space allocated for routing several parallel adjacent pipelines within process plants. A *pipe rack* (see Fig. C7.20) is the structure employed for carrying the pipelines and electrical and instrument trays. The pipe rack is usually constructed of steel or concrete frames called *bents*, on top of which the pipeline rests.

Pipe racks are necessary for arranging the process and service pipelines throughout the plant, and they are used in secondary ways; principally to provide a protected location for auxiliary equipment, pumps, utility stations, manifolds, and fire fighting and first-aid stations. Lighting and other fixtures can be fitted to the pipe rack columns. Air-cooled heat exchangers are often supported above pipe racks for economy of plot space.

Some other considerations when arranging piping on pipe racks are:

- Place utility and service piping on upper level of double-deck pipe racks.
- Do not run piping over columns as this will prevent adding another level.
- Locate large liquid-filled pipelines near columns to reduce bending stresses on pipe rack beams.
- Allow space for future piping systems; usually about 25 percent of final width.
- Electrical and instrument trays are best placed on outriggers or brackets to prevent interference with pipes leaving the pipe rack.
- Adjust elevation (up or down) of horizontal lines when making a change in direction. This will avoid blocking space for future lines.

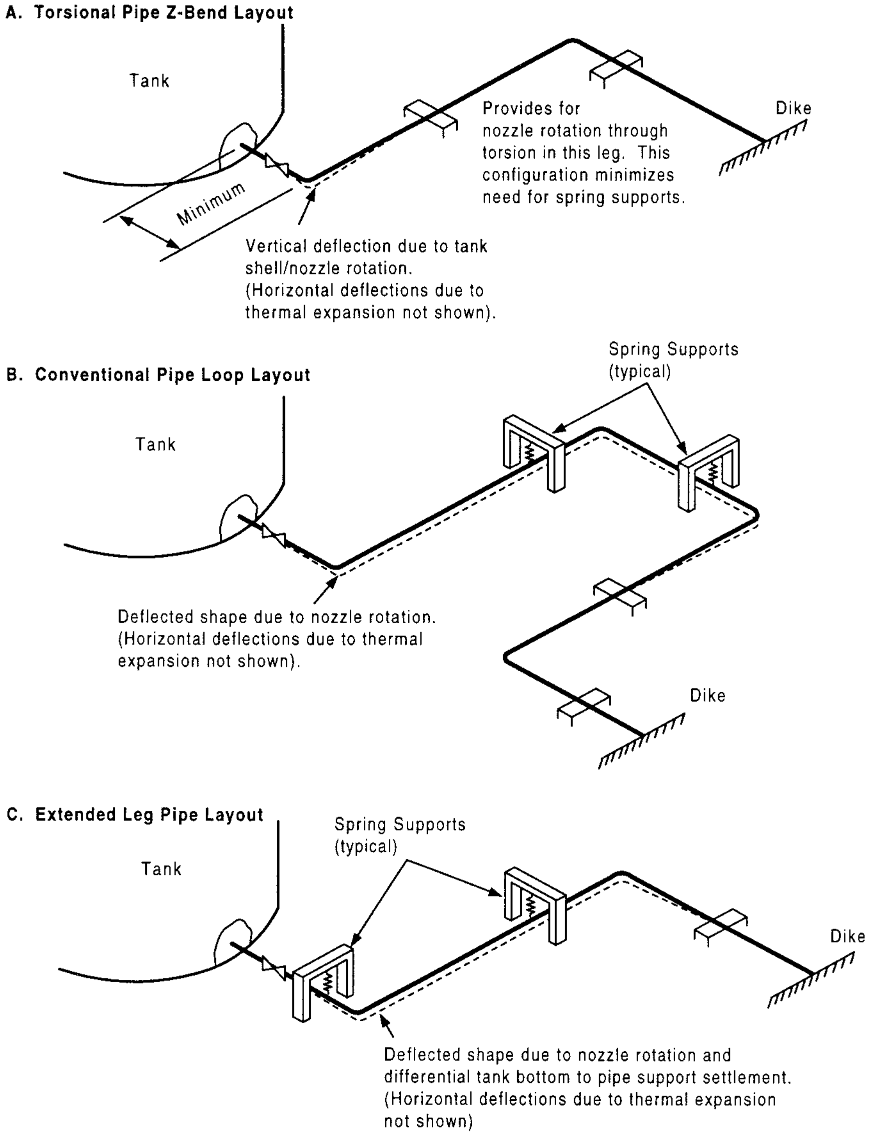


FIGURE C7.19 Tank piping layout considerations.

- Piping can be supported on sleepers at grade if roads or walkways will not be required over the pipeway at a later date. Bottom of pipe elevations must allow for clearance under line drain valves.
- Minimum clearance under the pipe rack is a function of the available mobile lifting equipment requiring access and the minimum vertical clearance determined by the basic plant design parameters.

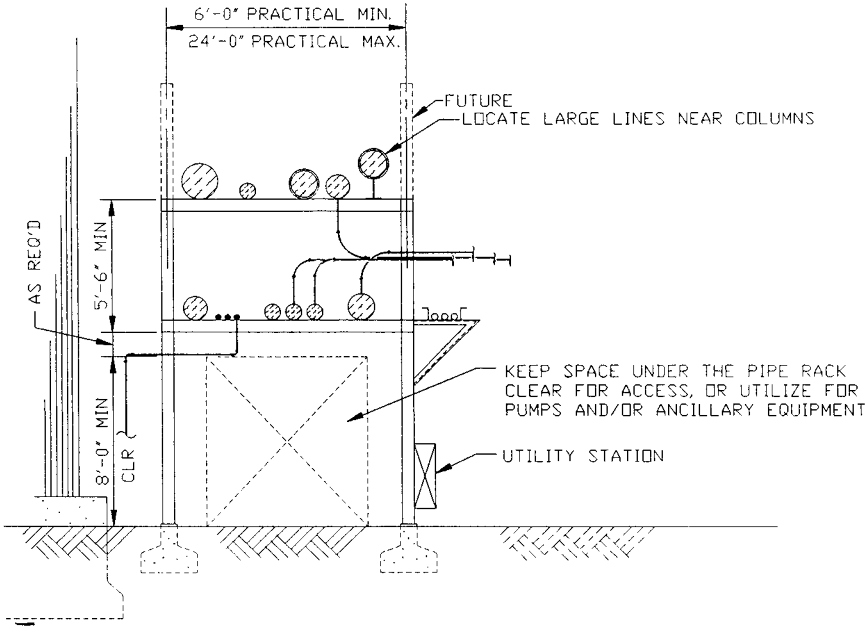


FIGURE C7.20 Typical pipe rack cross section.

An important aspect of rack piping design is the strategic location of line stops or anchors and guides to control the thermal expansion of the piping. Directional line stops also help to distribute expansion forces and support friction loads. Pipe expansion loops may be required for long lengths of rack piping, especially in elevated temperature service. The structural design of the rack bents must consider the combined loads imposed by the simultaneous operation of the piping it supports. Some percentage, usually 25 percent, of all the lines supported off a bent are assumed to simultaneously load the rack, since it is highly unlikely that all lines will be subjected to thermal expansion at the same moment in time.

Axial thrust loads in long horizontal runs, which are typical of rack piping and lines outside of process units, will be significant due to static friction resistance to thermal expansion at the support points. These thrust loads should not exceed the critical buckling load of the line involved. Lateral guides are usually necessary to give stability to the line.

Relief Valve and Flare Header Piping

Relief valve piping in a process plant should be in accordance with API RP 520, *Recommended Practice for the Design and Construction of Pressure Relieving Systems* and API RP 521, *Guide for Pressure Relief and Depressuring Systems*.[46,47] Piping for relief valves protecting pressure vessels should be in accordance with the applicable requirements of Section VIII of the ASME Boiler and Pressure Vessel Code.

The discharge of all pressure relief valves should be piped to a safe place for disposal. Liquid and readily condensable hydrocarbons are usually discharged to a closed system. Pressure relief valves discharging light hydrocarbons which are not likely to condense or accumulate at grade can frequently be safely vented to the atmosphere from the tops of tall towers. Discharging to the atmosphere reduces the size and cost of closed piping systems otherwise required and is the preferred method where it does not create a hazard and where recovery facilities are not necessary. The term *closed system* refers to the typical pressure relief valve collecting system at a process unit, wherein the discharge of pressure relief valves is collected in a piping system for disposal at a safe location. A *blowdown drum*, which may be integral with a vent stack, is usually provided for separating the vapors and collecting liquids. Vapors are typically vented to the atmosphere through a *flare stack* to safely ignite the combustible gas. Frequently this system is combined with any required facilities for emergency blowdown or depressurizing of equipment.

Pressure Relief Valve Piping Design

Block valves are usually provided upstream (and downstream if discharging into a closed system) of pressure relief valves where necessary to permit onstream isolation and maintenance of the PR devices without interrupting process unit operations. Where block valves are used, the installation should conform to the requirements of Section VIII of the ASME Boiler and Pressure Vessel Code when protecting an unfired pressure vessel. These valves are typically installed so that they are car-sealed open (CSO). Mechanical interlocks or key systems are usually required for spared PR valve installations to help ensure continuous safety protection of the system.

Generally, the most difficult and important feature associated with sizing relief valve discharge lines and headers is the determination of the maximum probable flow. The flow is based on the number of valves which may discharge simultaneously owing to a fire or to abnormal process conditions. To do this, the layout of the unit must be considered along with many possible abnormal operation conditions.

The permissible back pressure must also be determined. Generally, the back pressure should not exceed 10 percent of the set pressure for unbalanced safety valves. Balanced pressure-relief valves will operate satisfactorily at higher back pressures (approximately 30 percent of the set pressure), and consequently their use will sometimes result in a more economical relieving system.

Pressure relief valve discharge piping should be sized so that any back pressure that may exist or develop will not reduce the capacity of the pressure relief valve below that required to protect the equipment. Regardless, the discharge piping for each pressure relief valve should not be smaller than the nominal pipe size of the pressure relief valve outlet.

For gas, vapor, or flashing liquid service the inlet piping pressure drop at design flow should not exceed 3 percent of the safety relief valve set pressure. Nor should the inlet piping to a pressure valve be smaller than the valve inlet nominal pipe size. The inlet piping includes all piping between the protected equipment and the inlet flange of the valve. Excessive pressure drop in the inlet piping will cause *valve chatter* (extremely rapid opening and closing of the valve) which may lower the valve capacity and damage valve seating surfaces.

Pressure relief valves should be located so that the inlet piping is short and direct and self-draining with no pockets. However, on installations where pressure pulsations or turbulence are likely to effect the pressure relief valve (e.g., discharge

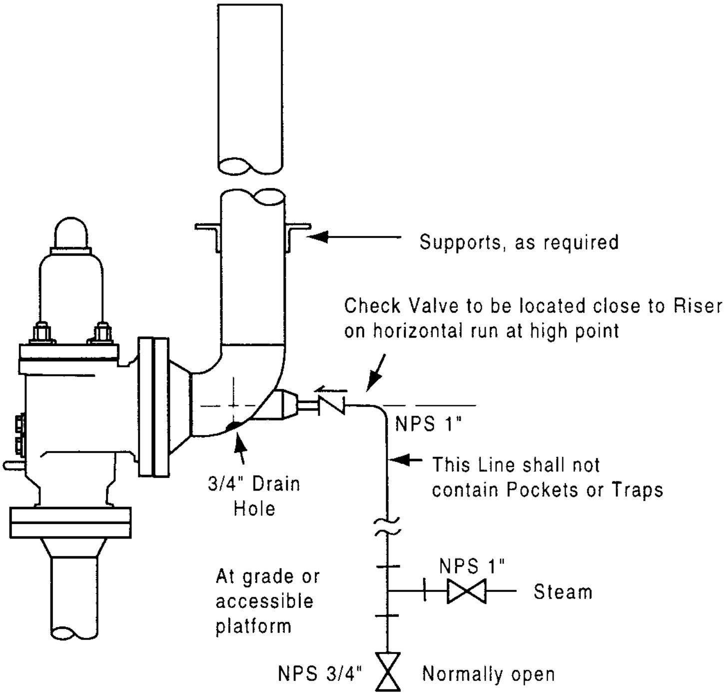


FIGURE C7.21 Snuffing steam to pressure-relief atmospheric vent.

side of reciprocating compressors and pumps), it may be desirable to locate the valve farther from the source in a more stable pressure region. The differential between operating and valve set pressures is also important when the operating pressure is not steady. A large differential will tend to reduce valve maintenance costs.

On certain vessels, pressure relief valve leakage and consequent premature shutting down of the process unit can be anticipated. These vessels should be provided with a sufficient number of pressure relief valves (and accompanying block valves) so that in the event of pressure relief valve leakage it will be possible to shut off any one defective valve and replace it while the vessel is in service and still retain full calculated relieving capacity.

Pressure Outlet Piping Discharge to Atmosphere

Outlet piping for pressure relief valves discharging flammable vapors directly to the atmosphere should normally be equipped with steam and drain connections controlled from grade, as shown by Fig. C7.21. Outlet piping from pressure relief valves should be equipped with drains or otherwise suitably piped to prevent accumulation of liquids at the valve outlet. Pressure relief valve outlet piping for water or other liquids should be self-draining.

Separate pressure relief valve lines should be provided for each valve discharging directly to the atmosphere. On towers, the pressure-relief valve vent piping should be extended at least 10 ft (3 m) above the nearest working platform within a radius of 40 ft (12 m). Outlet piping should be arranged so that the pressure-relief valve discharge will not impinge on any equipment.

Closed Discharge Piping to Flare Header System

Pressure relief valve discharge piping connecting to a closed system should be self-draining to the blowdown drum, vent stack, or other means for liquid/vapor separation and disposal. The main headers are frequently sloped to assure drainage. A continuous purging connection should be considered for closed system piping to prevent flammable mixtures resulting from possible pressure relief valve leakage. Where necessary or desirable to detect leaking pressure relief valves, a NPS ¾ (DN 20) valved and plugged drain connection should be provided at the outlet of each valve.

The sudden initiation of relief valve outflow can cause severe stresses in attached equipment and structures. Consequently, such factors as the high- and low-temperature properties of material, thermal expansion, vibration, and fatigue must be considered in designing pressure relief valve discharge piping. Vibration is particularly a concern for liquid service relief valves, where flashing and valve chatter are possible, which can lead to loosening of flange and valve bolting, and subsequent leaks. The use of conical spring washers or other nut-locking devices should be considered in these relief valve services to minimize the possibility of inadvertent loosening of flange bolting.

Discharges into closed flare header systems also represent significant challenges to the piping designer. Flare headers often represent one of the more difficult piping systems to route along pipe racks from the process units to the offsite blowdown and flare stack facilities. The piping tends to be of relatively large diameter, and it normally must be designed for large variations in operating temperatures. This includes the possibility of severe longitudinal bowing of the line if liquid at either relatively high or low temperatures discharges into the flare header, resulting in mixed-phase flow, with a vapor layer above a liquid stream.

Vent and Drain Piping

Provisions for low-point drains and high-point vents are typically needed for pressure testing, start-up, chemical cleaning, and for decommissioning of process plant piping. Valved drain and vent connections are also provided for most types of process equipment. These drains and vents should be located on the equipment if practical, but they may be located in connected piping where there are no valves or blocks between the drain or vent connections and the equipment.

Piping from drain connections should be arranged to drain the equipment and the connected piping to the appropriate process drainage system. The alternate to complete drainage is a start-up procedure for water removal, such as (1) displacement by circulation, (2) gradual heating during start-up, (3) dry gas purging, or (4) high-velocity gas purging. Multistage pumps, furnace headers, control valves, and horizontal pipe that deflects between supports are typical locations where it is usually impractical to provide complete drainage.

Generally, drain connections to closed drainage systems may require double block valves and with a bleed connection between the block valves.

Drains, vents, and pump outs for piping and equipment in vacuum service should be blinded or plugged during operation of the unit to prevent the entrance of air. There are, however, drain and vent connections which need not be connected to a closed drainage system. Examples are connections which are not hazardous if left open, connections for checking water accumulations, and vessel vents which are not needed during operation. These drains and vents should be provided with a block valve and blind flange, plug, or cap. Valved vents may not be required for high-point vents used to bleed air for system pressure testing only. These connections should be plugged and seal welded after pressure testing.

In lines containing hazardous fluids, a drain should be provided between block and check valves where fluids could be trapped. Where check and block valves separate a hazardous fluid from process piping or other process equipment, the block valve should be located between the check valve and the process piping or equipment.

Water drainage from vessels in light-ends service can be complicated by the refrigeration effect of light hydrocarbons that vaporize at atmospheric pressure. An ice plug formed by this refrigeration effect can prevent proper valve closure, and hazardous vapors will be released when the ice melts. In most cases heat tracing or other means of heating drain lines and valves will prevent freezing.

Means should be available for removing the operating liquid contents from all vessels and heat exchanger units and the connected piping. Although process lines and pumps should be used for this purpose, an auxiliary pumping-out system may be needed. A permissible alternate is to use steam or inert gas to remove the contents of the equipment by pressure. On pressure vessels, pumpout connections should be provided for side drawoffs as well as at the bottom of the vessel.

The recommended minimum size for pipeline drains and vents is NPS ½ (DN 15). The recommended minimum size of drains and vents is NPS 1 (DN 25) for vessels and NPS ¾ (DN 20) for all other equipment. However, the size of vent and drain connections should be such that the water used for hydrostatic test or flushing may be drained off without pulling a vacuum. On some small pumps, compressors, and turbine and steam engine drives, NPS ¾ (DN 20) or larger drain and vent connections are not economical. In such cases, NPS ½ (DN 15) drains and vents are acceptable.

Instrument Piping/Sample Connections

The term *instrument systems*, as used here, includes piping associated with field instrument installations and associated systems to connect air or hydraulically operated instrument control apparatus. It does not include instruments or permanently sealed fluid-filled tubing systems furnished with sampling transport systems associated with process stream analyzers.

Instrument Piping. Instrument piping must meet all the applicable requirements of the associated principal piping systems, and the following:

- The design pressure and temperature for instrument piping should be determined with consideration of short-time conditions. If it presents a more severe condition, the temperature of the piping during periodic operation of the blowdown valve should be considered a short-time condition.
- Consideration must be given to the mechanical strength, including the fatigue resistance, of small instrument connections or apparatus.

- Instrument piping containing fluids which are normally static and subject to freezing must be protected by heat tracing or other heating methods.
- When it is necessary to blow down or bleed instrument piping systems containing hazardous fluids, consideration must be given to the safe disposal of such fluids.

All instruments, including thermocouples, should be accessible for maintenance. Instrument process connections that require maintenance should also be accessible, including accessories such as rod-out connections, condensate pots, and seal connections. The overall piping design needs to consider the intended location of required instruments to locate appropriate take-off connections that allow good accessibility. During pipe layout, consideration should be given to routing process piping adjacent to platforms or to pipe and instrument grouping such that one platform will provide access to several instruments.

A block (usually gate) valve is typically installed in each instrument take-off connection. It should be located as close to the vessel or line as possible, consistent with the manual opening and closing of the valve. Take-off connections, including the first valve, should be in accordance with the line service classification. The use of elbows between the take-off point and the valve should also be avoided.

Sample Connections. On a process unit, sample connections are typically provided on feed and product streams and on such intermediate streams as are necessary for control and testing. Sample piping should be as short as possible and be adequately braced to enable it to resist unexpected external loads and to protect it from damage when valves are operated. If the piping is carefully supported and anchored, it is permissible to use an equipment drain for sample purposes.

As a general rule, sample connections should not be installed directly on pumps, compressors, or other equipment subject to vibration if other locations where samples might be taken are available. A likely location for sample connections is often combined with the installation of pressure gages. It is suggested that the minimum size of the first nipple attached to the piping or equipment from which the sample is taken be NPS ¾ (DN 20). A block valve of the same size as the nipple should be installed at the end of the nipple. A second valve should be installed in the sample line as close to the sampling point as practicable. A sample cooler will sometimes be necessary to assure safe handling of the stream being sampled.

Utility Piping

Air, steam, or water connections to process piping or process equipment should be temporary unless they serve as part of the process. Temporary connections should consist of a block valve, a check valve, and a blind flange. The block valve should be located between the check valve and the process piping or equipment. Both valves should conform to the specification of the more severe service.

When a permanent air, steam, or water connection to process piping or process equipment is needed, a check valve, a NPS ¾ (DN 20) bleed, and a blank should be provided in addition to the block valve. The block valve should be located between the check valve and the process piping or equipment, and the bleed should be located between the two valves. There must be a block valve in the utility line, upstream of the check valve to permit installation of the blank. A second bleed valve is recommended between these valves to test for back-flow through the check valve. All valves downstream of the blank should conform to the specification of the more severe service.

Utility and drain connections at the bottom of the equipment may be manifolded into a single header in order to simplify piping connections to the vessel, except that steam connections should not be in the same manifold as the drain and pump-out connections.

Service outlets for steam, water, and air hose connections are typically NPS 1 (DN 25) size. Outlets should be located so that working areas and process equipment can be reached with a single 50 ft (15 m) length of hose.

Water Service Piping. Process plants have several water systems. These may include high pressure (for fire fighting), low pressure (for cooling and use in the process), potable water, and different types of process water systems. One of the most severe design problems for many locations is to protect water systems from freezing. One obvious way to do this is to place the piping underground and below the frost lines. However, in a process unit much of the water piping must be above grade. If the piping is out of doors and in intermittent or standby service, it should be heat traced and insulated. In cold climates, heat tracing and insulating should be considered for water lines with low continuous flow rates. An alternative to heat tracing and insulating is to provide a bypass to a drain so that flow in the water line is continuous and at a high enough rate to prevent freezing. On water mains, the high-point vent between block valves should be protected from mechanical damage as well as from freezing.

Drains should be provided on any water line located above the frost line so that it can be drained when it is shut down. Such drain connections and valves should generally be located underground, and drains should, where practicable, connect to a sewer. Drainage facilities should also be provided for the water side of heat exchangers.

Water injected into a process stream normally is taken from the low-pressure water system. However, where salt water is used for the cooling-water and fire-water systems, water for process purposes is usually taken from the potable water system.

Each cooling water exchanger that may be removed from service during operation of the unit should have a block valve in both the inlet and outlet piping. Multiple shells or exchanger in series, which cannot operate independently of each other, should be considered as a single exchanger.

The water supplied to shell and tube coolers and condensers should pass through a strainer. If a strainer is not provided at the water pump or in the supply main, individual strainers should be provided in the branch line. The necessity for installing an oil separator drum, a gas disengaging drum, or a bypass filter in the cooling-tower water return system should be considered.

Water from exchangers should generally be sent to a clear water sewer or cooling water return system. Sample connections should be provided for detection of process leaks. However, a separate connection need not be provided for this purpose if other connections (e.g., drains and vents) can be used. An NPS ¾ (DN 20) valved and plugged vent should be provided on top of the first horizontal section of the water line downstream of the exchanger. The vent should be plugged during operation of the unit.

For chemical cleaning of exchangers using cooling water, connections should be provided to the inlet and outer nozzles on the water side of each exchanger. The connections should be between any block valve and the exchanger. If there is no block valve, a pair of flanges must be provided nearby so that the piping can be blanked off during cleaning. It is suggested that the chemical cleaning connections be NPS 1½ (DN 40), and they should be equipped with a blind flange.

Sufficient connections to the water system should be provided so that water can be supplied to the pressure vessels on the process unit for washing out or hydrostatic testing. These connections should be from the cooling-water system if the pressure in the system is adequate to supply water to the top of the tallest tower on the unit; otherwise the connections should be to the fire water system.

Normally vessels need not be permanently connected to a source of water. If a permanent connection is made, it should be at the bottom of the vessel and should be blanked off when the vessel is in operation.

Air Piping. Most process plants have a plant air system not only for use in the processes but to operate tools, equipment, and instruments.

Where necessary, the intakes of air compressors should be designed to minimize the noise level. Filters should be provided in the intake piping to reciprocating and rotary air compressors when they take suction from the atmosphere. Filters will sometimes be necessary for centrifugal air compressors. When a filter is not provided for a centrifugal air compressor taking suction from the atmosphere, the intake piping should be provided with a bird screen. Filters preferably should be of the dry, replaceable-cartridge type. Such filters should have an open area not less then three times the area of the intake pipe. The oil-bath-type filter should not be used with centrifugal air compressors.

Low points in the discharge line from an air compressor should be avoided because it is possible for lube oil to be trapped and subsequently ignited. If low points are unavoidable, they should be provided with drains.

When condensed moisture in air lines is undesirable from a process standpoint (which typically is the case for instrument air connections) or the possibility of moisture freezing exists, consideration should be given to providing an air drier drum in the supply line near the process unit. The drum should be located where it will not be exposed to heat from other equipment. Based on estimated future air requirements, the size of the drum should be such that (1) the velocity in the drum does not exceed 15 fpm (0.08 m/s) during shutdown periods when maintenance equipment is being used and (2) the capacity be equal to at least 6 percent of the free air requirements per minute during normal operation.

In climates where freezing is possible, the bottom 18 in (450 mm) of the dry drum should be insulated and heat traced. The drum drain (or blow-off) should also be traced or insulated. All blow-off connections should be installed pointing downward so that any rust or scale blown out will not endanger personnel.

Air piping should slope downward to dry drums or moisture traps, or be horizontal. Branch connections to air headers should be to the top of the pipe. Block valves should be provided in all branch lines.

When an air line is connected to process piping, two block valves, a check valve, and a bleeder should be provided. A second bleed valve should also be provided upstream of the check valve to test for backflow through the check. Consideration should be given to also providing a removable section of line or hose in order to guard against inadvertent operation.

Air for operating instruments is normally a separate system from the plant air system, and backup compression systems are often provided to increase in-service reliability. For process units, a steam-driven compressor should be furnished to supply instrument air in case of failure of the main supply. Where plant air is the primary source, and the possibility of a power failure is remote, electrically driven compressors may be used.

In extensive instrument air systems, the piping should be arranged with header and subheaders, such that groups of instruments may be isolated from the systems without affecting the air supply to all instruments. Block valves should be provided at the instrument air headers in all branch lines to instruments. Leads to individual instruments should be NPS ½ (DN 15) minimum. As a rule of thumb, headers serving from 1 to 25 instruments should be NPS 1 (DN 25) pipe size, and headers serving from 26 to 75 instruments should be NPS 2 (DN 50) pipe size.

Steam and Condensate Piping. Process plants usually have two or more steam systems and an exhaust steam condensate system. One of the steam systems generally operates in the range of 100 to 150 psig (690 to 1035 kPa) (low-pressure steam), and another operates at superheated conditions and significantly higher pressures (high-pressure steam). The exhaust steam system normally operates at a pressure of less than 50 psig (345 kPa). The design problems associated with these systems are not all similar to those encountered in a central power station; consequently a brief discussion on process plant steam piping requirements follows.

The principal concern is to supply clean, dry steam to the equipment using it. In accomplishing this, it is desirable to connect all branch lines (except condensate collection points) to the top of horizontal steam mains. However, if the line to a steam driver is at least one size smaller than the main and the steam has a considerable amount of superheat, it may be permissible to make a centerline connection to the side of the steam main. With other steam conditions it probably will be necessary to install a knockout pot or drum or a steam separator in addition to making the connection to the top of the main. Pockets should be avoided in the line to the turbine.

Connections to exhaust headers should preferably be made to the top of the header so that the condensate in the header does not run back into the driver.

In the steam line to a steam driver, a block valve(s) should be located at the driver and be easily accessible for operating purposes. A single gate valve is needed in the exhaust line from each steam driver that does not exhaust directly to atmosphere or directly into an individual condenser. However, valves need not be provided where two or more drivers, which will never be shut down separately, exhaust to the same condenser. This exhaust gate valve should be installed at the driver so that the position of the gate (i.e., open or closed) will be obvious to the operator whenever he is required to operate the inlet valve.

Wherever steam is exhausted to the atmosphere and could create such personnel hazards as burns, freezing of condensate on walkways, or the blanketing of working area with a heavy fog, the line should be fitted with an exhaust head and a drain to a sewer. The use of a silencer should be considered where noise nuisance is likely.

The flexibility of steam piping should be attained through the use of expansion bends and elbow fittings. The use of expansion joints is discouraged except where the size and arrangement of exhaust lines prevent the use of expansion bends, which may be the case of certain steam exhaust connections to steam condensers. Particular attention should be given to the anchorage and support of the connecting piping.

When required by the service, means should be available for purging process equipment with steam or inert gas. For example, each pressure vessel in hydrocarbon service should be provided with a steam-hose connection near the bottom if not permanently connected to the source of steam. However, where a permanent connection is made, it should be blinded during operation of the unit.

The steam supply for smothering, snuffing, service hoses, space heating, and auxiliary or protective heating should be connected to a source that will not be shut off during unit shutdowns or to a source that will not be shut off when the steam to a piece of equipment such as a turbine is shut off. For fire protection purposes, smothering (or snuffing) steam usually is required for fired heaters and for relief valve discharge lines.

Condensate Removal and Steam Traps. Condensate should preferably be discharged into an oil free drain system, but under no circumstances should it be discharged into a sanitary sewer. Consideration should be given to a condensate collection system in installations which involve a large number of steam traps. When condensate is to be discharged to a cast iron or concrete sewer or a concrete sewer box, the hazard of vaporizing hydrocarbons which may exist in the sewer should be considered. Also, to avoid damage to the concrete, the connection should be below the water level. If there is insufficient quantity of water for quenching, the condensate should be first led to an atmosphere-pressure drain tank.

Steam traps should be provided for the removal of condensate from collection points in live and exhaust steam systems, in particular from condensate drip legs, drains on steam turbines, steam separators, connectors, unit heaters, and terminal ends of companion piping. All low points in steam lines, except steam companion lines and the ends of long headers, should be provided with drip legs. It may also be necessary to install drip legs at intermediate points on headers with long sections at one elevation (i.e., in addition to those low points at the end).

When a valve is installed in steam piping in such a manner that condensate can collect above the valve, a trapped drain should be provided above the valve seat.

Whenever possible, a steam trap should be installed below and close to the equipment pipeline being drained, but the trap should be easily accessible for periodic inspection. Each trap should serve only one collection point. Where large quantities of condensate are expected, either condensate pots or condensate drains should be provided.

Drains from turbine shaft packing glands and from governor valve stem packing glands should preferably be connected to an open drain system. The drain lines and headers should be of sufficient size to prevent a back-pressure buildup. Also, untrapped drains should be provided at the lowest point of the steam end of each reciprocating pump and compressor.

Drains not discharging into a closed drainage system should discharge downward and should be arranged so that rising steam does not create a hazard or condense on equipment, such as a turbine or pump. The condensation of rising steam on such equipment can create lube oil contamination. One thing that can be done to help eliminate this problem is to quench the condensate.

A principal cause of steam traps freezing is improperly designed discharge lines. Steam trap discharge lines should be sloped for drainage where possible. In cases where freezing is likely, no part of the trap discharge header should be at an elevation above that of the trap discharge. Pockets in the discharge lines should be avoided. Long trap-discharge lines, if not in heated enclosures, should be insulated. Trap-discharge lines in heated enclosures need to be insulated only if necessary for burn protection. To decrease further the possibility of freezing, steam trap bodies should not be insulated unless the following circumstances make doing so advisable:

- The trap is installed downstream of automatic steam controls that could shut the steam off for long periods of time.
- The trap is installed in a location where operators might be burned by the bare metal surfaces.
- The trap is part of a heat recovery system where retention of heat is important.

- The trap is installed to handle exhaust steam condensate that contains quantities of cylinder oil.

Inverted-bucket and thermodynamic steam traps, which are commonly used in process plants, are generally installed without strainers. Steam traps should be selected for a *continuous discharge rate*, which is the actual condensate rate multiplied by a safety factor. A safety factor of at least 3 should be used for inverted bucket type traps and thermodynamic traps. A larger safety factor is needed for traps draining jacketed equipment, and trap manufacturers should be consulted. In borderline cases offering a choice between two traps sizes, the smaller trap is usually preferred.

Steam Companion Piping for Auxiliary Heating. The most commonly encountered situations requiring auxiliary heating are as follows:

1. Piping in which the fluid temperature could drop below the pour point or freezing point, and piping in which the fluid is subject to coagulation, excessive viscosity, or salting out
2. Hydrocarbon vapor and gas piping where condensate formation and icing will affect the safety and operation of the equipment, such as might be caused by the reduction in pressure that takes place through a control, throttle, or relief valve and
3. Lube and seal-oil systems for compressors and turbines

Auxiliary heating is normally not needed for freeze prevention and viscosity maintenance on equipment in intermittent service if the equipment is drained, flushed, blown, or steamed out when there is no flowing stream, or if the equipment is far enough underground to prevent freezing. When required, auxiliary heating is usually furnished by external steam companion piping (steam tracing). Other acceptable methods of heating piping and other equipment are internal steam tracing, steam jacketing, hot-water tracing and jacketing, and electric tracing. Details of various heat tracing techniques are covered in detail in Chap. B6 of this handbook.

It is desirable that each steam companion line be continuous from the header to a trap at the end of the line without any vents, drains, branches, or dead-end extensions at intermediate points. Each companion line should have a block valve at the upstream end and be arranged so that flow is generally downward, avoiding pockets as much as possible and leaving no section of the companion line at a greater elevation than the companion header. Live steam is preferred for steam companion piping in colder climates unless a lower temperature is required.

In the design of the companion piping system, provisions should be made for the differential expansion between the traced line and the tracer. When the piece of equipment which is to be kept hot is irregular in shape (such as traps, strainers, valves, and pumps), tubing must be used. The item should be spirally wrapped, starting at the top and working toward the bottom. Several lines to be traced may be grouped inside a single covering of insulation if they are to be maintained at the same temperature.

CASE HISTORIES: CHALLENGES/SOLUTIONS

Process plants offer the piping designer some unique challenges not found elsewhere. The combinations of demanding service requirements and mechanical needs will necessitate innovative designs and solutions. Included herein are a few practical approaches to problem resolution:

Challenge

Installed Type 304L stainless steel piping and mating vessel nozzle NPS 8 (DN 200) Class 300 flanges were found to be inadequate for the specified 750°F (400°C) design temperature and 440 psig (2760 kPa) design pressure hydrofining reactor service. The reactor shell material and its other principal nozzles were constructed from low-alloy material weld overlayed with Type 304L stainless steel. The reactor flanges were all specified with Class 300 flanges, which is acceptable for the low-alloy flanges but not for the solid alloy Type 304L flanges. ASME B16.5 maximum working pressure for Type 304L SS Class 300 flanges is only 335 psig at 750°F (2310 kPa at 400°C) and clearly inadequate for the specified reactor design pressure.

Solution

ASME B16.5 downrates flanges in Type 304L material in elevated temperature service in comparison to the low-chrome reactor flanges and other non-low temperature grades of stainless steel. Attempts to rerate the installed Class 300 flange based on the provisions of B31.3 for 10 percent metal design temperature reductions for uninsulated flanges and the design procedures of ASME BP&V Code Sec. VIII, Division 1 proved to be unsuccessful. It was ultimately decided to replace the existing Type 304L flanges with Type 347 stainless steel Class 300 flanges, which permit a maximum working pressure of 490 psig (3380 kPa), and as such, clearly acceptable for the specified system design pressure.

Challenge

Two recent experiences with installed spiral-wound gaskets with flexible graphite filler have led to different but related instability problems with these gaskets, which raised questions about the standard ASME B16.20 covering these gaskets. The first experience involved Class 1500 and 2500 spiral-wound (SW) gaskets fitted with inner retaining rings that suffered severe inward buckling at initial boltup. The second experience pertains to the gross inward buckling of the inner spirals of Class 600 and lower rating gaskets supplied without inner rings. Events led to the ultimate removal of some 2000 gaskets supplied by 3 different manufacturers, which revealed that severe inward buckling had occurred on about 12 percent of installed gaskets across a wide range of sizes.

Solution

Gaskets supplied in both cases complied fully with ASME B16.20 requirements, which highlighted inadequacies in this standard for spiral wound gaskets. Efforts have been initiated to work with manufacturers in their assessment of fundamental design considerations and with appropriate code committees to address apparent deficiencies discovered with this type of gasket. The buckling in both experiences had occurred during the initial compression of the gasket, before the flanges were put into service.

While the root cause of the problem has yet to be identified, the buckling phenomenon is clearly related to the incompressible properties of the flexible graphite and the tightness of the spiral windings. The experiences have also revealed that the inner ring widths specified by ASME B16.20 for many gasket sizes are inadequate to effectively resist buckling. Interim measures have been adopted by ASME B16.20, and it is recommended that users specify inner rings for all NPS 6 (DN 150) and larger SW gaskets with flexible graphite filler until more definitive measures are identified to resolve the root cause of the buckling phenomena. Reference 17 provides more information on this industrywide concern and overall considerations for gasket performance testing protocols.

Challenge

Severe acoustically induced piping vibrations generated by high-capacity pressure-letdown valves have led to fatigue failures at downstream piping branch connections within days of their initial operation. One such experience involved a safety letdown control valve within an LNG treat gas unit to a flare header system. The initial operation of this system led to cracks at an NPS 10 (DN 250) branch connection to an NPS 28 (DN 700) flare header. The failure occurred after about 5 to 10 hours of its initial startup and eventually led to the branch connection completely breaking away from the run header. The letdown valve was designed for a mass flow rate of about 383,000 lb/hr (175,000 kg/hr), with an upstream pressure of 620 psia (4278 kPa) letting down to 30 psia (207 kPa) flare header back-pressure.

This and other experiences in the gas production, petrochemical, and other industries have demonstrated that acoustic energy in high-capacity, gas pressure-reducing systems can cause severe piping vibrations that in extreme cases have led to piping fatigue failures within a few hours of commencing operation.

Solution

Based on a statistical approach, criteria were generated to reflect maximum levels of acoustic power generated by the pressure letdown valve before fatigue failure was experienced (see Ref. 5). The ultimate solution involved the replacement of the installed pressure letdown valves with low-noise producing valves with labyrinth multistaged pressure reducing trim to avoid choked sonic flow conditions generated by the valve.

Challenge

Severe vibrations were found with the initial start-up of an NPS 2 (DN 50) nitrogen utility line connected to an NPS 10 (DN 250) suction line of a reciprocating compressor in make-gas service. The nitrogen line was relatively flexible, and had long lengths of supported piping. Detailed acoustical analyses were conducted with the main suction and discharge piping of this reciprocating compressor, but this did not include the subject utility connection.

Solution

Additional pipe supports were installed to the nitrogen line, changing the natural frequency of the piping geometry and reducing the response to the compressor pressure pulsation excitations.

Challenge

An erosive slurry was causing material loss at changes of direction in a conventionally constructed piping system with elbows and tees. Space constraints did not allow for long-sweep turns.

Solution

Dead-end tees were installed where the solids filled the impact area of the tee. The abrasive solids then wore on themselves, thereby protecting the pressure boundary.

Challenge

A heater outlet line was expected to operate at about 1500°F (816°C). The attendant expansion and stress analysis difficulties were magnified, since the process piping material was well into the creep range. Premature failure was expected.

Solution

The hot metal heater line was transitioned into an internally refractory-lined system near the heater outlet. The lower shell temperature eliminated the probability of creep rupture failure, simplified the expansion and stress analysis problems, and reduced system maintenance.

The previous discussion only touches on the multitude of challenges/solutions encountered in the area of process piping. Reference literature has documented some of the many valuable experiences encountered in this regard.

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