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Liquid Process Piping

Part 2: Metallic Piping Design

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Chapter 4 Metallic Piping Systems

4-1. General

The metallic materials that are commonly used in liquid process piping systems can be categorized as ferrous (ductile iron, carbon steel, stainless steel and alloys with iron as the principal component) and non-ferrous alloys of nickel, aluminum, copper and lead. Metallic piping systems other than those addressed in this chapter are available (e.g. zirconium, 416 SS). Such materials may be used if cost and technical criteria are met. Applicable design principles from this manual are applied to use these materials.

4-2. Corrosion

When metallic components are used, corrosion of some type(s) will occur. USACE policy requires that all underground ferrous piping be cathodically protected. Chapter 12, TM 5-811-7 and MIL-HDBK-1004/10 contain guidance pertaining to cathodic protection of underground pipelines. Conditions which promote corrosion are:

- contact between dissimilar metals which may become immersed in a conductive medium;
- exposure of piping to corrosive soils or water;
- high temperatures;
- low-velocity, stagnant-type flow conditions;
- abrasive effects that may cause the surfaces of metals to be eroded;
- application of tensile stresses within a corrosive environment;
- highly acidic solutions combined with holes near metal-to-metal surfaces or near sealing surfaces; and
- any metals close to sources of atomic hydrogen.

a. Theory of Corrosion

Corrosion occurs by an electrochemical process. The phenomenon is similar to that which takes place when a carbon-zinc "dry" cell generates a direct current. Basically, an anode (negative electrode), a cathode (positive electrode), electrolyte (corrosive environment), and a metallic circuit connecting the anode and the cathode are required for corrosion to occur. Dissolution

of metal occurs at the anode where the corrosion current enters the electrolyte and flows to the cathode. The general reaction which occurs at the anode is the dissolution of metal as ions:



where:

M = metal involved

n = valence of the corroding metal species

e⁻ = represents the loss of electrons from the anode.

Examination of this basic reaction reveals that a loss of electrons, or oxidation, occurs at the anode. Electrons lost at the anode flow through the metallic circuit to the cathode and permit a cathodic reaction (or reactions) to occur.

Practically all corrosion problems and failures encountered in service can be associated with one or more of the following basic forms of corrosion. These are: general corrosion, galvanic corrosion, concentration cell (crevice) corrosion, pitting attack, intergranular corrosion, stress-corrosion cracking (environmentally-induced-delayed failure), dealloying (dezincification and graphitic corrosion), and erosion corrosion.

Corrosion control and avoidance is a highly specialized field. All pre-design surveys, Cathodic Protection (CP) designs, and acceptance surveys must be performed by a "corrosion expert." A "corrosion expert" is a person who, by reason of thorough knowledge of the physical sciences and the principles of engineering and mathematics acquired by a professional education and related practical experience, is qualified to engage in the practice of corrosion control of buried or submerged metallic piping and tank systems. Such a person must be accredited or certified by the National Association of Corrosion Engineers (NACE) as a NACE Accredited Corrosion Specialist or a NACE certified CP Specialist or be a registered professional engineer who has certification or licensing that includes education and experience in corrosion control of buried or submerged metallic piping and tank systems. USACE Construction Engineering Research Laboratories (CECER) provides corrosion expertise on request.

For information on metallic piping system material compatibility with various chemicals, see appendix B. Material compatibility considers the type and concentration of chemical in the liquid, liquid temperature and total stress of the piping system. The selection of construction materials is made by an engineer experienced in corrosion. See Appendix A, paragraph A-4 - Other Sources of Information, for additional sources of corrosion data.

b. General Corrosion

General corrosion is sometimes referred to as uniform attack. When this form of corrosion occurs, anodic dissolution is uniformly distributed over the entire metallic surface. The corrosion rate is nearly constant at all locations. Microscopic anodes and cathodes, which are continuously changing their electrochemical behavior from anode to cathode and cathode to anode, are believed to provide the corrosion cells for uniform attack.

Readily obtained from weight-loss and electrochemical tests, the general corrosion rates for many metals and alloys in a wide variety of environments are known. When a metal or alloy is exposed to an environment where the corrosion rate is known, equipment-life expectancy can be estimated (providing general corrosion is the only form of corrosion which will occur). It is common practice to select materials having general corrosion rates which are acceptable for the application involved.

Time-to-failure should not be the only corrosion criteria used for materials selection. Quite often, even trace amounts of metal which are introduced into the environment by very low corrosion rates are, or should be, unacceptable. For example, relatively non-corrosive domestic waters can dissolve sufficient amounts of certain metals, such as lead and copper, from the piping to create a health hazard. Corrosion-produced trace elements which are considered toxic and frequently found in the domestic waters of buildings include cadmium and antimony (from solder) and lead (an impurity in hot-dip, galvanized coatings).

One of the environments where general corrosion can occur is soil. Steel is especially susceptible to general corrosion when exposed to soils having resistivities less than about 10,000 ohm-cm. Even galvanized-steel can

be expected to fail in these aggressive environments. As the resistivity of the soil decreases, the magnitude of the corrosion damage increases.

c. Galvanic Corrosion

Galvanic corrosion can occur when two electrochemically-dissimilar metals or alloys (see Table 4-1) are metallically connected and exposed to a corrosive environment. The less noble material (anode) suffers accelerated attack and the more noble material (cathode) is protected by the galvanic current.

| Table 4-1 Galvanic Series (Partial Listing) | |
|--|--|
| Wasting End (anodic or least noble) | |
| Magnesium alloys Zinc Galvanized steel Aluminum Aluminum alloys Carbon steel Cast iron Stainless steel (active state) Lead Nickel (active state) Brass Copper Bronze Nickel alloys Nickel (passive state) Stainless steel (passive state) Titanium Graphite Platinum | |
| Protected End (cathodic or most noble) | |
| Sources: Schweitzer, <u>Corrosion-Resistant Piping Systems</u> , p. 264 (courtesy of Marcel Dekker, Inc.). SAIC, 1998. | |

One common galvanic corrosion problem clearly illustrates the "area and distance effects". For example, consider a building where a copper water service line and

a coated carbon steel natural gas service line are laid in the same ditch. Assuming soil in the area has low resistivity, it is easily recognized that a cathode (copper tube), an anode (steel pipe), and an electrolyte (soil) exist. In order to have a galvanic cell, only a metallic path for electron flow is needed; this is provided when the two dissimilar materials are metallicity connected through the hot-water heater. Because the cathodic area is large (bare copper tube) and the anodic area is small (steel exposed at locations where "holidays", or defects, exist in the coating), corrosion produced leaks in the natural gas line can occur in relatively short times. (Generally, natural gas leaks occur first in soil near the foundations of buildings where fertilizing and watering have lowered the resistivity of the native soil.) The fact that the two service lines were laid only inches apart and in the same ditch is also a factor in this corrosion problem. Had the lines been located in separate ditches, the distance between them may have been sufficient to prevent the flow of galvanic current.

Severe galvanic corrosion is a problem in many potable-water systems. Providing the water is sufficiently aggressive, connecting steel or galvanized steel (the zinc coating is generally destroyed by threading) to copper or copper-base alloys will cause galvanic attack of the steel. Similarly, connecting aluminum and its alloys to copper-base materials exposed to corrosive potable waters generally accelerates attack of the aluminum. However, there are many waters where dissimilar metals and alloys can be directly connected without accelerated attack of the less noble material. In general, waters of high pH and low carbon dioxide, or those capable of producing a thin continuous layer of calcareous scale on the metal surface, do not promote galvanic attack.

Galvanic corrosion is also an important cause of rapid deterioration to underground aluminum-alloy structures. For example, in aircraft refueling areas, it is common practice to use aluminum-alloy pipe between the filter-meter pit and the hydrant outlets. Steel pipe is usually used between the filter meter pit and the fuel storage area. For safety, convenience, and aesthetic reasons, all of the pipe is underground. When the two dissimilar pipe materials (see Table 4-1) are metallicity connected (for example, flanged at a filter meter pit) and exposed to a highly conductive, chloride containing soil, galvanic corrosion can be expected to occur. In these environments, galvanic corrosion of the aluminum alloy

is generally characterized in a appearance by severe pitting attack. Cases are known where galvanic corrosion has perforated 7.6 mm (0.3 in) thick, aluminum-alloy pipe in two (2) years.

A number of methods and practices are available which will either prevent or minimize galvanic corrosion. These include: the use of materials which are electrochemically similar (that is, close together in the galvanic series); avoiding unfavorable (large) cathode-to-anode area ratios; breaking the metallic circuit by the proper use of insulators (for example, isolating flanges and insulating unions); the use of inhibitors (preferably cathodic inhibitors, or a sufficient amount of anodic inhibitor to insure that the anodic reaction will be completely stifled); keeping the dissimilar metals or alloys physically distant from each other; avoiding the use of threaded joints between dissimilar metals; cathodic protection; applying protective coatings to both dissimilar metals; and possibly increasing the resistivity of the environment.

d. Concentration Cell Corrosion

Electrochemical attack of a metal or alloy because of differences in the environment is called concentration cell corrosion. This form of corrosion is sometimes referred to as "crevice corrosion", "gasket corrosion", and "deposit corrosion" because it commonly occurs in localized areas where small volumes of stagnant solution exist. Normal mechanical construction can create crevices at sharp corners, spot welds, lap joints, fasteners, flanged fittings, couplings, threaded joints, and tube-sheet supports. Deposits which promote concentration cell corrosion can come from a number of sources; other sites for crevice attack can be established when electrolyte-absorbing materials are used for gaskets and the sealing of threaded joints.

There are at least five types of concentration cells. Of these, the "oxygen" and "metal ion" cell are most commonly considered in the technical literature. The "hydrogen ion", "neutral salt", and "inhibitor" cells must be considered in any discussion of concentration cell corrosion.

It is known that areas on a surface in contact with electrolyte having a high oxygen content will generally be cathodic relative to those areas where less oxygen is present. Oxygen can function as a cathodic depolarizer;

in neutral and alkaline environments, regions of high oxygen would be preferred cathodic sites where the reduction of oxygen can occur. This is the commonly referred to as an "oxygen concentration cell," see Figure 4-1.

A mechanism is proposed wherein the dissolution of metal (anodic process) and reduction of oxygen (cathodic process) initially occur uniformly over the entire surface, including the interior of the crevice. In time, the oxygen within the crevice is consumed and the localized (oxygen reduction) cathodic process stops in this area. The overall rate of oxygen reduction, however, remains essentially unaltered because the area within the crevice is quite small compared to the area outside of the crevice. The rate of corrosion within and outside the crevice remains equal.

Concentration cell corrosion can occur at threaded joints of pipe used to convey aggressive, liquids. When the joints are improperly sealed, rapid crevice attack occurs in the threaded area where stagnant, low-oxygen-content fluids exist. Since the wall thickness of the pipe is reduced by threading, failures due to concentration cell corrosion can be a frequent and common occurrence at threaded joints. Threaded joints sealed with liquid-absorbing materials (for example, string or hemp) can fail in times as short as nine months. Similarly, transport deposits of solids can be a major cause of concentration cell corrosion.

Some of the methods to reduce concentration cell corrosion damage include: using butt welds instead of riveted, spot-welded, and bolted joints; caulking, welding and soldering existing lap joints; avoiding the use of fluid absorbing materials for gaskets and threaded-joint sealants; providing a more uniform environment, for example, placing homogeneous sand around underground steel structures; removing suspended solids from solution; periodic cleaning to remove deposits from the surface; improving the design, for example, providing adequate slope on the inside bottoms of underground storage tanks so accumulated liquid will flow to the sump; cathodic protection; and protective coatings, especially on the interior surfaces of storage tanks and carbon steel piping.

e. Pitting Corrosion

Pitting corrosion is a randomly occurring, highly localized form of attack on a metal surface. In general, it is characterized by the observation that the depth of penetration is much greater than the diameter of the area affected. Pitting is similar to concentration cell-corrosion in many respects. The two should be distinguished, however, because crevices, deposits, or threaded joints are not requisites for pit initiation. Further, concentration cell corrosion can occur in environments where the metal or alloy is immune to pitting attack.

Pitting attack appears to occur in two distinct stages. First, there is an incubation period during which the pits are initiated; second, there is a propagation period during which the pits develop and penetrate into the metal. It is generally agreed that a sufficient concentration of an aggressive anion (generally chloride, but also bromide, iodide, and perchlorate) and an oxidizing agent (dissolved oxygen, Fe^{+++} , H_2O_2 , Cu^{++} , and certain others) must be present in the electrolyte. A stagnant volume of liquid must exist in the pit or pitting will not occur. In addition, for a given metal/electrolyte system, the redox potential must be more noble than a certain critical value. It is also agreed that the corrosion processes within the pit produce conditions of low pH and high chloride ion content; these keep the localized anodic areas electrochemically active.

Many grades of stainless steel are particularly susceptible to pitting corrosion when exposed to saline environments. Alloying elements in a stainless steel, however, greatly affect its resistance to pitting attack; the tendency to pit decreases as the content in nickel, chromium and molybdenum increases. In sea water, austenitic stainless steels containing 18% chromium and a 2-3% molybdenum addition (e.g., Type 316 stainless steel) exhibit much better pitting-corrosion resistance than similar alloys which contain no molybdenum (e.g., Type 302 stainless steel). For certain grades of ferritic stainless steel, relatively low chloride content waters can cause severe pitting corrosion. For example, Type 430, ferritic grade, stainless steel (16% Cr) tubes failed by pitting corrosion and pinhole leaks when they were used to convey cooling water containing only a small amount of chlorides.

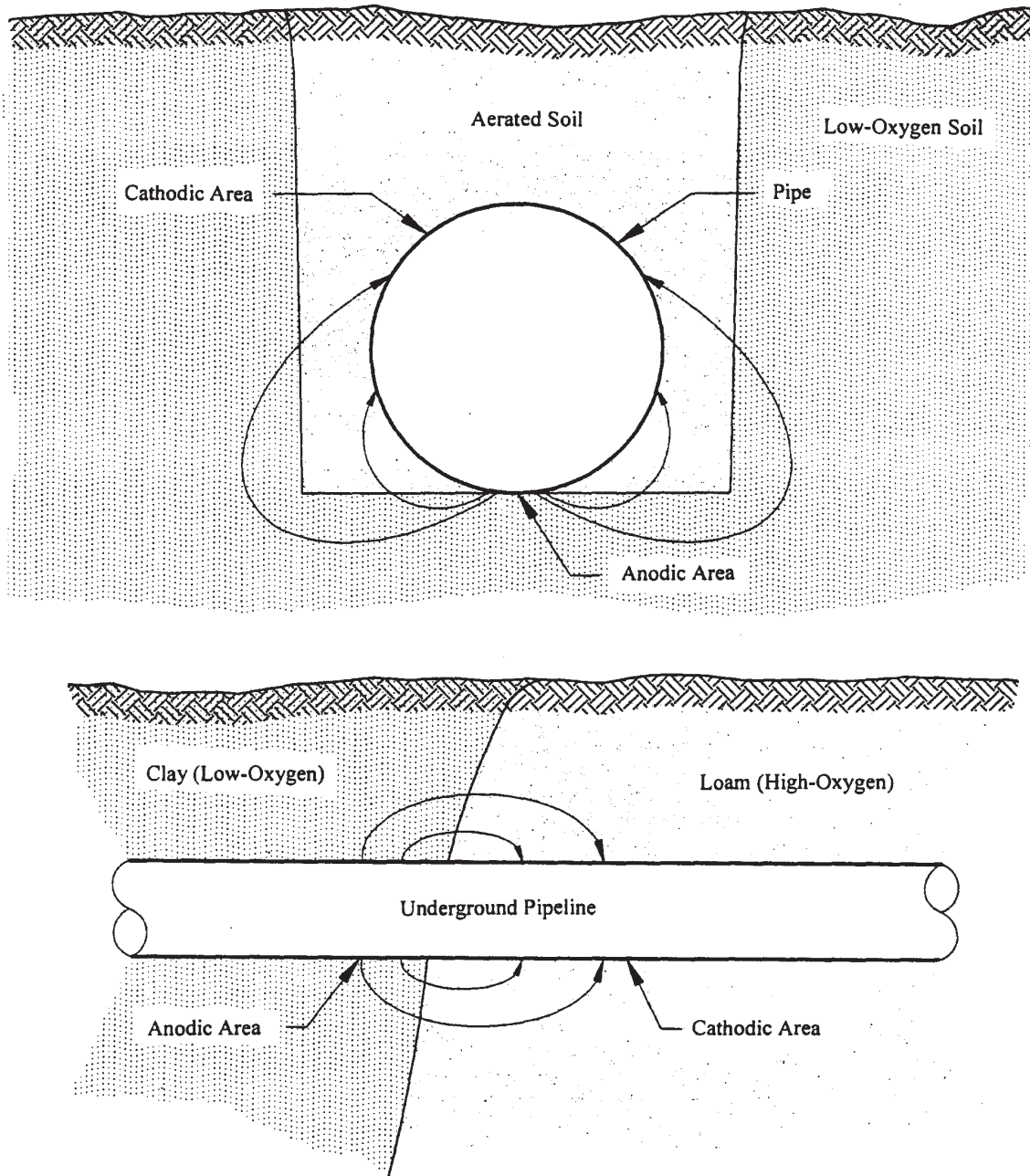


Figure 4-1. Concentration-Cell Corrosion of Underground Pipeline
(Source: USACE CECER, 1998.)

In many cases, methods which minimize concentration cell corrosion can be used to successfully mitigate pitting attack. Widely-used practices and procedures for reducing damage by pitting corrosion include: keeping the fluid uniformly aerated; keeping the fluid at a low and uniform temperature; improving the homogeneity of the metal's surface by polishing, heat treating, or passivation; using inhibitors; implementing cathodic protection; reducing the concentration of aggressive ions in the electrolyte; selecting materials which have good pitting corrosion resistance; and using anodic protection by controlling the metal or alloy's potential in the passive range at a value more negative than the critical potential for pitting.

f. Intergranular Corrosion

Intergranular corrosion is the localized attack which occurs at or in narrow zones immediately adjacent to the grain boundaries of an alloy. Severe intergranular attack usually occurs without appreciable corrosion of the grains; eventually, the alloy disintegrates or loses a significant amount of its load-bearing capability. Although a number of alloy systems are susceptible to intergranular attack, most of the problems encountered in service involve austenitic stainless steels and the 2xxx and 7xxx series aluminum alloys. Welding, stress-relief annealing, improper heat treating, or overheating in service generally establish the microscopic, compositional inhomogeneities which make a material susceptible to intergranular corrosion.

Several grades of austenitic stainless steels (for example, Type 304, which contains about 0.08% carbon) are susceptible to intergranular corrosion after they have been heated into the temperature range of about 425°C to 790°C (800°F to 1450°F). Provided the time in this temperature range is sufficiently long, but not extended, the stainless steel becomes sensitized. Intergranular corrosion will occur if the alloy is subsequently exposed to certain environments.

Some of the environments which reportedly cause intergranular corrosion in sensitized, austenitic stainless steels are listed in Table 4-2. Examination of this table reveals that intergranular corrosion can occur in many environments where austenitic stainless steels normally exhibit excellent corrosion resistance.

| Table 4-2 Environments Which Cause Intergranular Corrosion in Sensitized Austenitic Stainless Steels | |
|---|------------------------|
| Acetic Acid | Phosphoric Acid |
| Ammonium Nitrate | Phthalic Acid |
| Beet Juice | Salt Spray |
| Chromic Acid | Sea Water |
| Copper Sulfate | Sodium Bisulfate |
| Crude Oil | Sulfite Cooking Liquor |
| Fatty Acids | Sulfite Digestor Acid |
| Lactic Acid | Sulfamic Acid |
| Maleic Acid | Sulfur Dioxide (wet) |
| Nitric Acid | Sulfuric Acid |
| Oxalic Acid | Sulfurous Acid |
| Source: USACE CECER, 1998. | |

The use of extra-low carbon grades of stainless steel, for example, Type 304L, essentially eliminates the intergranular corrosion problem. These alloys are immune to sensitization because of their low carbon content. It is well known that sensitization can occur only if the carbon content of the alloy exceeds about 0.02 to 0.03%. The control of carbon to a maximum of 0.03%, by blowing oxygen through the melt and using low-carbon ferrochrome, has permitted steel manufacturers to produce alloys which can be welded, stress-relief annealed, and used in corrosive environments without major concern for intergranular attack.

g. Stress-Corrosion Cracking

Stress-corrosion cracking (environmentally-induced-delayed failure) describes the deleterious phenomena which can occur when many alloys are subjected to static, surface tensile stresses and exposed to certain corrosive environments. Cracks are initiated and propagated by the combined effect of a surface tensile stress and the environment. When stress-corrosion cracking occurs, the tensile stress involved is often much less than the yield strength of the material; the environment is generally one in which the material exhibits good resistance to general corrosion. For example, various steels have good general

corrosion resistance to anhydrous liquid ammonia. Steel tanks are widely and successfully used for the storage and transport of this liquified gas. Stress-corrosion cracking failures have occurred in some large-diameter liquid ammonia tanks, however, probably because the high residual tensile stresses introduced during fabrication were not removed by stress-relief annealing. Several of the alloy/susceptible environment combinations where stress-corrosion cracking can occur are given in Table 4-3.

h. Dealloying

Dealloying, sometimes referred to as parting or selective leaching, is a corrosion process wherein one element is preferentially removed from an alloy. The process is unique in that corrosion occurs without appreciable change in the size or shape of the component being attacked. The affected areas become brittle, weak, and porous but the overall dimensions of the component do not change appreciably.

| Table 4-3 Alloy/Susceptible Environment Combinations for Stress-Corrosion Cracking (Partial Listing) | | |
|---|---|--|
| Alloy System | Environment | Type of Cracking |
| Mild Steel | OH ⁻ NO ₃ ⁻ | Intergranular Intergranular |
| Alpha Brass (70 Cu- 30 Zn) | NH ₄ ⁺ | Transgranular at high pH; intergranular in neutral solutions |
| Austenitic Stainless Steel | Cl ⁻ | Transgranular |
| 2XXX - Series Al Alloys | Cl ⁻ | Adjacent to grain boundaries |
| 7XXX - Series Al Alloys | Cl ⁻ | Intergranular |
| Cu-P Alloys | NH ₄ ⁺ | Intergranular |
| Titanium Alloys* | Cl ⁻ | Transgranular or intergranular |
| Mg-Al Alloys | Cl ⁻ | Intergranular; sometimes transgranular |
| Beta Brass | Cl ⁻ NH ₄ ⁺ | Transgranular Intergranular |
| Martensitic Low-Alloy | Cl ⁻ | Along prior-austenite grain boundaries |
| 18 Ni Maraging Steel | Cl ⁻ | Along prior-austenite grain boundaries |
| Note: *Includes Ti-8Al-1Mo-1V, Ti-6Al-4V and Ti-5Al-2.5Sn alloys. Source: USACE CECER, 1998. | | |

The two most important examples of dealloying are the preferential removal of zinc from copper-zinc alloys (dezincification) and the preferential removal of iron from gray-cast iron (graphitic corrosion). Other cases of dealloying include the preferential removal of aluminum, nickel, and tin from copper-base alloys and cobalt from a Co-W-Cr alloy.

Dezincification commonly occurs when yellow brass (67Cu-33Zn) is exposed to waters having a high chloride content, low temporary hardness, and pH above approximately 8. Other alloys which are susceptible to dezincification in many waters include Muntz metal (60Cu-40Zn) and non-inhibited aluminum brass (76Cu-22Zn-2Al). Generally, higher zinc content brasses are more susceptible to dezincification than alloys containing smaller amounts of the solute element.

Dezincification problems are generally solved by changing alloys. This includes the use of low-zinc-content alloys such as red brass (85Cu-15Zn) and specially-alloyed materials such as arsenical Admiralty Metal (70Cu-29Zn-1Sn-0.05As) and arsenical aluminum brass (76Cu-22Zn-2Al-0.05As). For severe applications, it may be necessary to use cupro-nickel alloys, for example, 90Cu-10Ni, which contain a small amount of iron. In some process streams, dezincification can be eliminated by changing the fluid chemistry, but this should be done with caution and not without expert advice.

i. Erosion Corrosion

Most metals and alloys depend upon a protective surface-film for corrosion resistance. When the protective film or corrosion products have poor adherence, an acceleration or increase in the rate of localized corrosion can occur because of relative movement between the liquid and the metal. Generally, movement of the liquid is quite rapid and mechanical wear effects or abrasion (due to suspended solids and entrained gases in the environment) can be involved. Repetitive formation (a corrosion process) and destruction (a mechanical erosion process) of the surface films is referred to as erosion corrosion. The term includes impingement attack, a special form of erosion corrosion is cavitation.

Many metallic materials are susceptible to erosion corrosion at sufficiently high flow rates or excessive turbulence. Some of the equipment and components where erosion-corrosion damage frequently occurs include: piping systems (particularly at elbows, tees, and bends), pump impellers, valves, propellers, orifices of measuring devices, nozzles, heat-exchanger tubes, and turbine blades. Erosion corrosion is characterized in appearance by the presence of waves, valleys, deep grooves, and gullies on the metal surface. An absence of residual corrosion products and a clean metal appearance in the area of attack also suggest that the destructive process is erosion corrosion. For copper, the effected area is usually bright and shiny, resembling that of a new penny.

Some of the other material/environmental combinations where erosion corrosion can occur include: red brass (85Cu-15Zn) in potable hot waters; hard lead (92Pb-8Sb) in heated, dilute sulfuric acid solutions; carbon steel in heated, acidified distilled waters; austenitic stainless steels in heated sulfuric acid-ferrous sulfate slurries; and cupro-nickel alloys in heated sea water. It is important to appreciate that none of these environments would appreciably corrode the respective materials under static or low-flow conditions. For example, hard lead corrodes at a negligible rate in stagnant 10% sulfuric acid at 90°C (194°F). When the same sulfuric acid solution is circulated at 11.8 m/s (39 ft/s), the erosion-corrosion penetration rate of hard lead is about 1000 microns/y (40 mils/y).

A number of techniques are available for minimizing erosion corrosion. Velocities in a system must be considered before materials are selected and used. Materials which are susceptible to erosion corrosion should not be used when the environment is going to be circulated at high velocities. For this reason, copper tubing is not recommended for conveying aggressive, potable hot waters at temperatures above 60°C (140°F); 90-10 cupro-nickel should be used when high-temperature, potable waters must be circulated at high flow rates. Similarly, use of Monel can generally eliminate the "wire drawing" which occurs in brass valve seats.

Cavitation corrosion is a special form of erosion corrosion. The process is basically the result of gas bubbles forming at low pressure and collapsing under high pressure at or near the liquid-metal interface. Bubble collapse, which produces very high localized pressures (shock waves), destroys the metal's protective film. Repetitive formation and destruction of the film on a localized basis results in severe damage. Cavitation corrosion damaged surfaces are characterized by their deeply pitted and "spongy" appearance.

j. Microbially Induced Corrosion

Microbiological activity can induce corrosion as a result of byproducts such as carbon dioxide, hydrogen sulfide, ammonia and acids. In some instances microorganisms may also consume metal. Biological activity can be reduced through the use of biocides and/or occasional pH variations.

4-3. Design Pressure

In addition to the requirements of Paragraph 3-2, a key consideration when specifying metal pipe and components is compliance with established pressure and temperature rating of applicable codes and standards.

a. Maximum Steady Pressure

When using ASME B31.3 as the governing code, the following pressure and temperature rating issues must be addressed for the metal pipe to be specified:

- (1) For listed components having established rating, utilization of materials falling within the acceptable service ratings are listed in the codes and standards contained in Table 326.1 of ASME B31.3.
- (2) For listed components not having established ratings, utilization of components of the same materials with the same allowable stress as material specified in the codes and standards contained in Table 326.1, if the service ratings are based on straight seamless pipe and the pipe components to be utilized are not manufactured from straight seamless pipe. Because of this deviation from the listed rating, the pipe components should be rated using not more than 87.5% of the nominal wall thickness of the listed pipe less allowances applied to the pipe.

- (3) Unlisted components, components not listed in ASME B31.3 but conforming to other published standards, may be utilized if the requirements of the published standard are comparable to ASME B31.3 requirements and if the pressure design satisfies the ASME B31.3 pressure design of components.

b. Pressure Transients

Most design codes for metal pipe provide allowances for short duration transient conditions which do not increase the design pressure and temperature. When following ASME B31.3 or similar codes, the limitations of using these allowances without increasing the design conditions are typically specified within the code. Before finalizing the system design pressure and temperature, allowances for transient conditions within the applicable design code are reviewed and the anticipated conditions that would be covered by the allowances in the code are fully evaluated.

4-4. Piping Supports for Metallic Piping Systems

Specific metallic piping materials have particular requirements for the design of piping supports. Care should be taken to minimize stress in the pipe that may induce corrosion. Concentrated loads, such as valves, meters, and other fittings, should be independently supported. As a rule of thumb, spans for insulated lines should be reduced by approximately 30% from those for uninsulated pipes.

Tables 4-4 through 4-7 present support spacing examples for various metals. Calculations should be performed for each application since material strength varies by temper and manufacturing method. Table 4-4 summarizes support spacing for carbon and stainless steel pipe.

Support of nickel pipe should follow similar principles of other metallic piping systems. Table 4-5 summarizes support spacing for nickel 200 and nickel 201. Nickel 200 is pure wrought nickel. Nickel 201 is a low-carbon alloy of nickel 200, for higher temperature applications.

When designing aluminum pipe system supports, either aluminum or padded pipe supports should be specified. Aluminum will corrode when exposed to other metals. Contact with metals such as copper, brass, nickel, and carbon steel should be avoided. The support spacing for aluminum alloy 6063 pipe is summarized in Table 4-6.

| Table 4-4 Support Spacing for Steel Pipe | | | | | |
|---|--|--------------------|-------------------|-------------------|------------------|
| Nominal Pipe Size, mm (in) | Maximum Support Spacing, m (ft) | | | | |
| | SS, Sch 5S | SS, Sch 10S | CS, Sch 40 | SS Sch 40S | CS Sch 80 |
| 15 (0.5) | 2.9 (9.4) | 2.9 (9.6) | 2.1 (7.0)* | 2.9 (9.6) | 2.5 (8.3) |
| 20 (0.75) | 3.2 (10.3) | 3.2 (10.6) | 2.1 (7.0)* | 3.3 (10.7) | 2.9 (9.4) |
| 25 (1) | 3.4 (11.2) | 3.6 (11.9) | 2.1 (7.0)* | 3.6 (12.0) | 3.2 (10.5) |
| 40 (1.5) | 3.8 (12.6) | 4.2 (13.8) | 2.7 (9.0)* | 4.3 (14.2) | 3.9 (12.7) |
| 50 (2) | 4.1 (13.4) | 4.5 (14.9) | 3.0 (10.0)* | 4.8 (15.6) | 4.3 (14.1) |
| 80 (3) | 4.8 (15.7) | 5.2 (17.1) | 3.7 (12.0)* | 5.8 (18.9) | 5.2 (17.1) |
| 100 (4) | 5.0 (16.5) | 5.6 (18.3) | 4.3 (14.0)* | 6.4 (21.0) | 5.8 (19.2) |
| 150 (6) | 5.9 (19.4) | 6.3 (20.6) | 5.2 (17.0)* | 7.5 (24.6) | 7.0 (23.0) |
| 200 (8) | 6.2 (20.2) | 6.8 (22.4) | 5.8 (19.0)* | 8.3 (27.4) | 7.9 (25.8) |
| 250 (10) | 7.1 (23.3) | 7.4 (24.1) | 6.1 (22.0)* | 9.1 (30.0) | 8.7 (28.7) |
| 300 (12) | 7.4 (24.3) | 7.8 (25.6) | 7.0 (23.0)* | 9.8 (32.2) | 9.5 (31.1) |

Notes:
 CS - electric resistance welded carbon steel ASTM A 53, grade A.
 SS - seamless stainless steel ASTM A 312, TP316L.
 Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).
 *Maximum horizontal spacing based on MSS SP-69 (std. wt. steel pipe, water service)
 Source: Calculations by SAIC, 1998

**Table 4-5
Support Spacing for Nickel Pipe**

| Nominal Pipe Size, mm (in) | Maximum Support Spacing, m (ft) | | | | | |
|----------------------------------|---------------------------------|------------------|-------------------|-------------------|-------------------|-------------------|
| | Ni 200, Sch 5 | Ni 201, Sch 5 | Ni 200, Sch 10 | Ni 201, Sch 10 | Ni 200, Sch 40 | Ni 201, Sch 40 |
| 15 (0.5) | 2.4 (7.8) | 2.1 (6.9) | 2.4 (7.9) | 2.1 (6.9) | 2.4 (7.9) | 2.1 (6.9) |
| 20 (0.75) | 2.6 (8.6) | 2.3 (7.5) | 2.7 (8.8) | 2.3 (7.7) | 2.7 (8.8) | 2.4 (7.8) |
| 25 (1) | 2.9 (9.4) | 2.5 (8.2) | 3.0 (9.8) | 2.6 (8.6) | 3.0 (9.9) | 2.6 (8.7) |
| 40 (1.5) | 3.2 (10.6) | 2.8 (9.3) | 3.5 (11.5) | 3.1 (10.1) | 3.6 (11.8) | 3.1 (10.3) |
| 50 (2) | 3.4 (11.3) | 3.0 (9.9) | 3.8 (12.5) | 3.3 (10.9) | 4.0 (13.0) | 3.5 (11.4) |
| 80 (3) | 4.0 (13.2) | 3.5 (11.6) | 4.4 (14.4) | 3.8 (12.6) | 4.8 (15.7) | 4.2 (13.8) |
| 100 (4) | 4.3 (14.0) | 3.7 (12.3) | 4.7 (15.4) | 4.1 (13.6) | 5.3 (17.5) | 4.7 (15.3) |
| 150 (6) | 4.5 (14.7) | 4.0 (13.2) | 4.8 (15.6) | 4.3 (14.0) | 5.6 (18.4) | 5.0 (16.4) |
| 200 (8) | 4.7 (15.4) | 4.2 (13.8) | 5.2 (17.0) | 4.6 (15.2) | 6.3 (20.5) | 5.6 (18.4) |
| 250 (10) | 5.4 (17.8) | 4.8 (15.9) | 5.6 (18.3) | 5.0 (16.4) | 6.9 (22.5) | 6.1 (20.1) |
| 300 (12) | 5.7 (18.5) | 5.1 (16.6) | 5.9 (19.4) | 5.3 (17.4) | 7.4 (24.2) | 6.6 (21.6) |

Notes:
 Ni 200 = seamless nickel ASTM B 161, alloy N02200, annealed.
 Ni 201 = seamless nickel ASTM B 161, alloy N02201, annealed.
 Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).
 Source: Calculations by SAIC, 1998.

**Table 4-6
Support Spacing for Aluminum Pipe**

| Nominal Pipe Size, mm (in) | Maximum Support Spacing, m (ft) | | | |
|----------------------------|---------------------------------|-----------------|-----------------|-----------------|
| | Al 6063, Sch 5 | Al 6063, Sch 10 | Al 6063, Sch 40 | Al 6063, Sch 80 |
| 15 (0.5) | 2.3 (7.6) | 2.4 (8.0) | 2.5 (8.3) | 2.6 (8.5) |
| 20 (0.75) | 2.5 (8.1) | 2.6 (8.6) | 2.8 (9.1) | 2.9 (9.4) |
| 25 (1) | 2.6 (8.5) | 3.0 (9.7) | 3.1 (10.1) | 3.2 (10.5) |
| 40 (1.5) | 2.7 (9.0) | 3.2 (10.6) | 3.6 (11.4) | 3.7 (12.2) |
| 50 (2) | 2.8 (9.3) | 3.4 (11.1) | 3.7 (12.3) | 4.0 (13.3) |
| 80 (3) | 3.2 (10.7) | 3.7 (12.2) | 4.5 (14.7) | 4.8 (15.9) |
| 100 (4) | 3.3 (10.9) | 3.9 (12.6) | 4.9 (16.0) | 5.3 (17.5) |
| 150 (6) | 3.8 (12.6) | 4.2 (13.8) | 5.5 (18.1) | 6.3 (20.5) |
| 200 (8) | 3.9 (12.9) | 4.5 (14.7) | 6.0 (19.8) | 6.9 (22.7) |
| 250 (10) | 4.5 (14.8) | 4.8 (15.6) | 6.5 (21.4) | 7.6 (25.0) |
| 300 (12) | 4.7 (15.4) | 5.0 (16.4) | 6.9 (22.7) | 8.2 (27.1) |

Notes:
 Al 6063 = seamless aluminum ASTM B 241 A96063, type T6 with welded joints.
 Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).
 Source: Calculations by SAIC, 1998.

Design of copper pipe support follows principles similar to those for other metallic piping systems. Galvanic action between pipe supports and copper piping must be considered when specifying support materials. Table 4-7 summarizes support spacing for copper pipe.

4-5. Joining

Common methods for the joining of metallic pipe for liquid process systems include utilization of welded, flanged, threaded and mechanical joints including flared, flareless, compression, caulked, brazed and soldered joints. The application requirements and material specifications for these fittings are typically found in accompanying sections of the codes and standards used for the specification of the metallic pipe. The most common sources for application requirements and material specifications can be found in ASME, MSS and

API standards. Table 4-8 presents applicable sections of relevant codes and standards for the metallic fittings. In selecting a joining method for liquid process piping systems, the advantages and disadvantages of each method must be evaluated.

4-6. Thermal Expansion

Thermal expansion can impact the design of the piping system in the following critical areas: excessive stress related to thermal loads on the liquid being contained by the piping system, reduction of allowable stress due to elevated material temperature and stresses caused by elongation of the metal pipe; excessive thrust loads or bending moments at connected equipment due to thermal expansion of the metal pipe; and leaking at pipe joints due to thermal expansion of the metal pipe.

**Table 4-7
Support Spacing for Copper Pipe**

| Nominal Pipe Size, mm (in) | Maximum Support Spacing, m (ft) | | |
|----------------------------|---------------------------------|-----------------|------------------|
| | Cu Light Wall | Cu Regular Wall | Cu X-Strong Wall |
| 15 (0.5) | 1.5 (5.0)* | 1.5 (5.0)* | 1.5 (5.0)* |
| 20 (0.75) | 1.5 (5.0)* | 1.5 (5.0)* | 1.5 (5.0)* |
| 25 (1) | 1.8 (6.0)* | 1.8 (6.0)* | 1.8 (6.0)* |
| 40 (1.5) | 2.2 (7.3) | 2.4 (8.0)* | 2.4 (8.0)* |
| 50 (2) | 2.4 (7.8) | 2.4 (8.0)* | 2.4 (8.0)* |
| 80 (3) | 2.8 (9.2) | 3.0 (10.0)* | 3.0 (10.0)* |
| 100 (4) | 3.2 (10.4) | 3.7 (12.0)* | 3.7 (12.0)* |
| 150 (6) | 3.8 (12.6) | 4.2 (13.9) | 4.3 (14.0)* |
| 200 (8) | 4.5 (14.6) | 4.8 (15.8) | 4.9 (16.0)* |
| 250 (10) | 4.9 (16.1) | 5.3 (17.4) | 5.5 (18.0)* |
| 300 (12) | 5.4 (17.6) | 5.9 (19.4) | -- |

Notes:
 Cu = seamless copper ASTM B 42, allow C 12200, drawn with brazed fittings.
 Span lengths are based on a piping system that is a simple single span pipe run, is not insulated, has a full flow condition that is essentially water and is subject to a maximum operating condition of 93 °C (200 °F).
 *Maximum horizontal spacing based on MSS SP-69 (copper tube, water service).
 Source: Calculations by SAIC, 1998.

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| Table 4-8 Applicable Codes for Metallic Fittings | |
|---|--|
| Reference Standard | Key Aspects of Standard |
| API 605 | Large Diameter Carbon Steel Flanges |
| ASME B16.1 | Cast Iron Pipe Flanges and Flanged Fittings, Classes 25, 125, 250, and 800 |
| ASME B16.5 | Pipe Flanges and Flanged Fittings |
| ASME B16.9 | Factory Made, Wrought Steel Butt-Welding Fittings |
| ASME B16.11 | Forged Steel Fittings, Socket Welding and Threaded |
| ASME B16.24 | Bronze Pipe Flanges and Flanged Fittings, Classes 150 and 300 |
| ASME B16.25 | Butt-Welding Ends |
| ASME B16.31 | Non-Ferrous Pipe Flanges |
| ASME B31.3 | Chemical Plant and Petroleum Refinery Piping - Chapter II Design Parts 3 and 4, Chapter III, Chapter IV, and Chapter V |
| ASME B16.42 | Ductile Iron Pipe Flanges and Flanged Fittings, Classes 150 and 300 |
| ASME B16.47 | Large Diameter Steel Flanges |
| MSS SP-43 | Wrought Stainless Steel Butt-welding Fittings |
| MSS SP-44 | Steel Pipeline Flanges |
| MSS SP-51 | Class 150 LW Corrosion Resistant Cost Flanges and Flanged Fittings |
| MSS SP-73 | Brazing Joints for Wrought and Cast Copper Alloy Solder Joint Pressure Fittings |
| MSS SP-104 | Wrought Copper Solder Joint Pressure Fittings |
| MSS SP-106 | Cast Copper Alloy Flanges and Flanged Fittings, Class 125, 150 and 300 |
| MSS SP-114 | Corrosion Resistant Pipe Fittings Threaded and Socket Welding, Class 150 and 1000 |
| MSS SP-119 | Belled End Socket Welding Fittings, Stainless Steel and Copper Nickel |
| Source: Compiled by SAIC, 1998. | |

When designing a piping system subject to thermal expansion due to anticipated operating temperatures and in which the piping is restrained at supports, anchors, equipment nozzles and penetrations, thermal stresses and loads may be large and must be analyzed and accounted for within the design. The system PFDs and P&IDs are analyzed to determine the thermal conditions or modes to which the piping system will be subjected to during operation. Based on this analysis, the design and material specification requirements are followed as an applicable standard.

The need for detailed thermal stress analysis is assessed for piping systems. An approach for this as-

essment is to first identify the operating conditions that will expose the piping to the most severe thermal loading conditions.

Once these conditions have been established, a free or unrestrained thermal analysis of the piping is performed. This analysis is performed by assuming no intermediate pipe supports, only terminal connections to anchors, equipment nozzles, and equipment penetrations. If, based on this analysis, the stress resulting from thermal expansion is less than 68.9 MPa (10 ksi), the pipe section analyzed has sufficient flexibility to accommodate the thermal expansion and rigid supports can be utilized. The terminal loadings on

equipment determined from this analysis can then be used to assess the equipment capabilities for withstanding the loading from the piping system. It should also be noted that this analysis at equipment and anchor terminations should consider the movement and stress impacts of the “cold” condition.

If the initial free thermal analysis indicates that the resulting stresses will require the piping system to be designed to accommodate thermal expansion, the design should conform to applicable codes and standards.

A basic approach to assess the need for additional thermal stress analysis for piping systems includes identifying operating conditions that will expose the piping to the most severe thermal loading conditions. Once these conditions have been established, a thermal analysis of the piping can be performed to establish location, sizing, and arrangement of expansion loops, or expansion joints (generally, bellows or slip types).

If the application requires the use of a bellow or piston joint, the manufacturer of the joint should be consulted to determine design and installation requirements. An alternative is an expansion loop. Expansion loops can be used in vertical or horizontal planes. If an expansion loop is to be required, the following formula can be used. This formula is based on guided-cantilever-beam theory in which both ends are fixed and limited pipe rotation is assumed. The loop is also geometrically similar (as depicted in Figure 2-3d) with the middle parallel leg equal to 1/2 of each of the tangential legs.

$$L = X + 2Y = (\Delta DE / C_1 S_A)^{0.5} \quad (\text{Metric Units})^1$$

or

$$L = X + 2Y = (3\Delta DE / (144 \text{ in.}^2/\text{ft}^2) S_A)^{0.5} \quad (\text{English Units})^2$$

where:

L = loop length to accommodate the thermal expansion, mm (ft)

X = parallel leg of loop, mm (ft)

$Y = 2X$ = tangential leg of loop, mm (ft)

D = actual outside pipe diameter, mm (in.)

¹ 1988 ASHRAE Handbook, EQUIPMENT

² 2000 ASHRAE Handbook, Heating, Ventilating, and Air-Conditioning, SYSTEMS AND EQUIPMENT

E = modulus of elasticity at the working temperature, kPa (psi)

S_A = maximum allowable stress at the working temperature, kPa (psi)

Δ = change in length due to temperature change, mm (in.)

C_1 = constant, 0.3333

ASHRAE states that for the commonly used A53 Grade B seamless or electric resistance welded (ERW) pipe, an allowable stress S_A of 155 MPa (22,500 psi) can be used without overstressing the pipe. However, this may result in very high end reactions and anchor forces, especially with large-diameter pipe. Designing to a stress range $S_A = 103$ MPa (15,000 psi) and assuming $E = 1.92 \times 10^5$ MPa (27.9×10^6 psi), the above equation reduces to:

$$L = 74.7(\Delta D)^{0.5} \quad (\text{Metric Units})$$

$$L = 6.225(\Delta D)^{0.5} \quad (\text{English Units})$$

This provides reasonably low end reactions without requiring too much extra pipe. In addition, this equation may be used with A53 butt-welded pipe and B88 drawn copper tubing.

When welded fittings are used in expansion loops rather than pipe bends, another important consideration is the effects of bending on the fittings used to install the expansion loop. The loop should be installed in consultation with the fitting manufacturer to ensure that specified fittings are capable of withstanding the anticipated loading conditions, constant and cyclic, at the design temperatures of the system. Terminal loadings on equipment determined from this analysis can then be used to assess the equipment capabilities for withstanding the loading from the piping system. It should also be noted that this termination analysis at equipment and anchor terminations should consider the movement and stress impacts of the “cold” condition.

Example Problem 7:

A 145-m-long (475-ft-long) steel, 200-mm (8-in.) diameter liquid process pipe operates at 90°C (194°F) and 1.55 MPa (225 psig). The expansion caused by the process stream must be absorbed using U-bends without damage to the pipe.

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Solution:

Step 1. Establish a temperature differential (ΔT). Assume an installation temperature of 4.4°C (40°F). This would be a conservative, yet reasonable, assumption. Therefore, the temperature differential would be 90°C – 4.4°C, or 85.6°C (194°F – 40°F, or 154°F).

Step 2. Determine the thermal expansion (Δ).

$$\Delta = \alpha L_0 (\Delta T)$$

where:

Δ = thermal expansion of pipe run, mm (in.)
 α = coefficient of thermal expansion, 11.7×10^{-6} mm/(mm °C), $(6.5 \times 10^{-6}$ in./[in. °F])³
 L_0 = original length of pipe run, mm (in.)
 ΔT = temperature differential

$$\begin{aligned} \Delta &= 11.7 \times 10^{-6} \text{ mm/(mm } ^\circ\text{C)} \times 145,000 \text{ mm} \times 85.6^\circ\text{C} \\ &= (6.5 \times 10^{-6} \text{ in./[in. } ^\circ\text{F)} \times 5700 \text{ in} \times 154^\circ\text{F)} \\ \Delta &= 145.2 \text{ mm} \\ &= (5.71 \text{ in.}) \end{aligned}$$

Step 3. Determine dimensions of expansion loop. The expansion loop is centered between anchored supports as schematically shown in Figure 2- 3d.

$$L = X + 2Y = 74.7(\Delta D)^{0.5} \quad 6.225(\Delta D)^{0.5}$$

and

$$Y = 2X$$

So

$$\begin{aligned} L &= 5X = 74.7(145.2 \text{ mm} \times 220 \text{ mm})^{0.5} \\ &= 6.225 (5.71 \text{ in.} \times 8.625 \text{ in.})^{0.5} \\ L &= 5X = 13,351 \text{ mm} \quad (43.7 \text{ ft}) \\ X &= 2670 \text{ mm} \quad (8.74 \text{ ft}) \\ Y &= 2(2670 \text{ mm}) = 5340 \text{ mm} \quad (17.5 \text{ ft}) \end{aligned}$$

The length of the parallel leg of the expansion loop is 2670 mm (8.74 ft), and the length of each of the two tangential legs of the expansion loop is 5340 mm (17.5 ft).

4-7. Ductile Iron

³ Design of Machine Elements, 5th Edition, Spotts, M.F., Tables 2-1, 2-1A, Prentice Hall, 1978.

Ductile iron is a hard, nonmalleable ferrous metal that must be molded into the various component shapes. It is used for those piping applications requiring strength, shock resistance, and machinability. It has good resistance to general corrosion, but reacts readily with hydrogen sulfide.

a. Ductile Iron Specifications

Due to the long use of ductile iron in water service, ductile iron piping is most commonly specified pursuant to AWWA standards. As noted in Paragraph 3-5, care must be taken when joining AWWA piping systems to ASME piping systems.

4-8. Carbon Steel

Carbon steel is a hot-rolled, all-purpose material. It is the most common and economical metal used in industry. It will readily rust (corrode) in ambient atmospheres, and therefore casting applications should be considered. It will also become embrittled with prolonged contact with alkaline or strong caustic fluids and contact with acid accelerates corrosion. It may react directly with hydrogen sulfide gas. The material/fluid matrix in Appendix B should be consulted for each application.

a. Carbon Steel Pipe Specifications

A wide variety of mechanical properties is available by varying the carbon content and heat treatments. The most commonly specified carbon steel piping is manufactured to meet ASTM A 53. The type and grade of the pipe must be specified: type F (furnace-butt-welded), grade A; type E (electric-resistance welded), grade A or B; or type S (seamless), grade A or B. Type F should not be used if flanging is required, and grade A is preferred if cold-bending is to occur. Options that can be specified pursuant to ASTM A 53 include hot-dip galvanizing, threaded ends and dimensions, schedule 40, 80, 160 and others that may be available depending on pipe diameter.

Many other options exist. For example, ASTM A 587 specifies an electric-resistance welded carbon steel pipe intended for use in the chemical industry. The material is low-carbon and can also be specified for galvanizing; either of these factors will reduce corrosion effects. The pipe is available in two nominal wall thicknesses from 15 mm (½ in.) to 250 mm (10 in.) in diameter. Another carbon steel pipe standard is ASTM A 106 which specifies seamless carbon steel pipe for high temperature service, but

graphitization at prolonged high temperature may still occur. Additional manufacturing standards for specialized carbon steel piping include, but are not limited to: ASTM A 135, schedule 10 electric-resistance welded carbon steel pipe; ASTM A 333, seamless or welded carbon steel (and low-alloy steel) pipe for low temperature service; and ASTM A 691, 405 mm (16 in.) and larger diameter electric-fusion welded carbon steel (and low-alloy steel) pipe for high pressure service at high temperatures. ASTM standards are reviewed for unusual process conditions or requirements to select the material most compatible to the application.

b. Carbon Steel Fittings

Fittings for carbon steel piping can be threaded, welded or flanged; all are commonly used. Fitting materials can be cast malleable iron, forged carbon steel and low-carbon or other specialized steel. In non-corrosive applications with threaded fittings, malleable iron conforming to ASTM A 47 is typically used. However, as the process dictates, forged carbon steel threaded fittings pursuant to ASTM A 105 are applicable for ambient to high temperature service, and low-carbon steel threaded fittings pursuant to ASTM A 858 are applicable for ambient to low temperature or corrosive service. Welded fittings can be butt-welded or socket welded with ASTM A 105 or ASTM A 858 conforming materials. Malleable iron is not welded. Other ASTM materials may also be appropriate; select a material and fitting that are compatible to the application.

Due to the relative inexpense of carbon steel flanges, carbon steel piping is usually flanged at connections to equipment and appurtenances such as valves or other items that may have to be removed or replaced. Common flange material is ASTM A 105 forged carbon steel for ambient to high temperature and ASTM A 727 forged carbon steel for temperatures between -30EC (-20EF) and 345EC (650EF).

In addition to fittings described above, carbon steel piping may be joined by mechanical couplings. The pipe sections must, however, be specified with grooved ends. Most of the manufacturers that produce mechanical couplings for ductile iron piping also produce them for carbon steel piping.

4-9. Stainless Steel

Stainless steel is the product of steel alloyed with chromium and, to a lesser extent, nickel. Other elements such as molybdenum, copper, manganese and

silicon may also be included as part of the alloy for various steel types. Chromium is the primary additive that makes steel “stainless”; stainless steels are actually a very broad range of highly corrosion-resistant alloys that have a variety of trace elements.

a. Stainless Steel Types

The most common types of stainless steel used for liquid process applications are 304 and 316. One caution: stainless steel is not totally corrosion resistant. Chemicals such as sodium bisulfide, ferric chloride, ozone and hydrochloric acid can attack stainless steel successfully. Check the material/fluid matrix in Appendix B for compatibility with the application. The most commonly used series for corrosion resistance are discussed below.

Types 304 and 304L are austenitic stainless steels that provide outstanding resistance to bases such as lime and sodium hydroxide. They are highly resistant to many acids, including hot or cold nitric. Types 316 and 316L are stainless steel types that exhibit better resistance to sulfides and chlorides than 304 and 304L, and will provide adequate resistance to corrosion from sulfuric acid. Otherwise, 316 and 316L provide the same outstanding resistance to acids and bases as 304 and 304L. The “L” designation indicates alloys developed to minimize post-welding intergranular corrosion, and these alloys are strongly recommended whenever welding is involved. In general, the “L” stainless steels provide more resistance to sulfuric acid/nitric acid mixed solutions than non-low carbon steels.

Austenitic stainless steel piping is commonly specified to conform to ASTM A 312, ASTM A 813 or ASTM A 814. All three of these standards address austenitic stainless steel pipe intended for general corrosive and/or high temperature service. ASTM A 312 specifies seamless and straight-seam welded pipe; ASTM A 813 covers straight-seam single- or double-welded pipe that is of fit-up and alignment quality; and ASTM A 814 addresses flanged and cold-bending quality (cold worked) straight-seam single- or double-welded pipe.

Austenitic stainless steel fittings may be threaded, welded or flanged. The materials should match the associated pipe. For example, WP316L fittings or F316L flanges should be used with type 316L pipe. Welding fittings are typically specified under ASTM A 403. Class WP welding fittings are standard use as they conform to ASME B16.9 and ASME B16.11. Class CR welding fittings are light weight and con-

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form to MSS SP-43. Threaded and flanged fittings are commonly specified under ASTM A 182.

Ferritic and martensitic stainless steels are used less commonly than austenitic. Unlike austenitic steels, ferritic stainless steels do not contain nickel and do not resist reducing chemicals such as hydrochloric acids. Ferritic stainless steels have excellent resistance to chloride attack and organic acids.⁴ A commonly used ferritic stainless steel is type 430. Martensitic stainless steels, however, may contain nickel because their chromium content is limited. Typically, martensitic steels exhibit less corrosion resistance than austenitic steels.

Ferritic and martensitic stainless steel piping should conform to ASTM A 731, which addresses both seamless and welded pipe intended for general corrosive and high-temperature service. Welding fittings are typically specified under ASTM A 815 as Class WP or CR similar to austenitic stainless steel fittings. Threaded and flanged fittings are specified in accordance with ASTM A 182.

b. Stainless Steel Pipe Construction

Standard nominal pipe sizes are 15 through 300 mm (½ through 12 in.) commonly available in schedules 5S, 10S, 40S and 80S. Schedule 5S and 10S piping can not be threaded due to wall thickness constraints.

4-10. Nickel and Nickel Alloys

Nickel is used for its strong resistance to certain corrosive chemicals.

a. Common Alloys

Refer to the corrosion compatibility tables for specific applications of these alloys. Although other nickel alloys are used for specialty applications, these are the more commonly prescribed.

Alloy 200 is commercially pure wrought nickel, and 201 is a low-carbon version of 200 that is used for applications above 315EC (600EF). Corrosion resistances are the same for both alloys. They are resistant to caustic soda and most alkalis (key exception: ammonium hydroxide). They are not subject to stress corrosion in chloride salts. They are excellent for dry handling of chlorine and hydrogen chloride at elevated temperatures.

⁴ Schweitzer, Corrosion-Resistant Piping Systems, p. 234.

Nickel alloy 200 and 201 pipe can be specified seamless or welded. Cold-worked seamless pipe is readily available in nominal pipe sizes 6 mm (1/8 in.) to 200 mm (8 in.), dimensioned as schedule 5, 10, 40, or 80, pursuant to ASTM B 161 and ASTM B 829. Welded pipe, intended for corrosive service, is manufactured in accordance with ASTM B 725 and B 775, and is readily available in nominal pipe sizes 6 mm (1/8 in.) to 750 mm (30 in.), dimensioned as schedule 5S, 10S, and 40S. The material condition must be specified for both seamless and welded pipe as annealed or stress relieved. The latter conditioning provides more tensile strength. For example, the tensile strength for a seamless alloy 200 pipe is 380 MPa (55,000 psi) annealed and 450 MPa (65,000 psi) stress relieved.

Hastelloy, a nickel-molybdenum-chromium alloy, offers excellent resistance to wet chlorine, hypochlorite bleach, ferric chloride and nitric acid. Hastelloy, and related alloys, can be seamless or welded. Seamless pipe is manufactured pursuant to ASTM B 622 and ASTM B 829, and is readily available in nominal pipe sizes 8 mm (1/4 in.) to 80 mm (3 in.), dimensioned to schedule 10, 40, or 80. Welded pipe is readily available in nominal pipe sizes 6 mm (1/8 in.) to 200 mm (8 in.), dimensioned to 5S, 10S, 40S, and 80S, pursuant to ASTM B 619 and ASTM B 775. The material class is specified as class 1 or 2. Class 1 pipe is welded and solution annealed, and class 2 is welded, cold-worked and then solution annealed. Class 1 pipe may have sunken welds up to 15% of the wall thickness, while class 2 pipe does not have sunken welds.

Monel, a nickel-copper alloy, combines high strength with high ductility (usually a tradeoff in metals selection), as well as excellent general corrosion resistance. It is specified particularly where seawater or industrial chemicals may be accompanied by high temperatures. It must not be exposed, when hot, to sulfur or molten metals.

Monel can also be provided either seamless or welded. Seamless, cold-worked pipe is available in nominal pipe sizes 6 mm (1/8 in.) to 200 mm (8 in.), dimensioned to schedule 5, 10, 40, or 80, pursuant to ASTM B 165 and ASTM B 829. Welded Monel, intended for general corrosive service, is manufactured in accordance with ASTM B 725 and ASTM B 775, and is readily available in nominal pipe sizes 6 mm (1/8 in.) to 750 mm (30 in.), dimensioned as schedules 5S, 10S, and 40S. The pipe material conditioning, either annealed or stress relieved, should be specified.

Inconel, a nickel-chromium-iron alloy, is noted for having high temperature strength, while maintaining excellent corrosion resistance. Similar to all the nickel and nickel alloy piping systems, Inconel pipe can be provided either seamless or welded. Seamless Inconel pipe is available in nominal pipe sizes 8 mm (1/4 in.) to 150 mm (6 in.), dimensioned to schedule 5, 10, 40 or 80. It is manufactured pursuant to ASTM B 167 and ASTM B 829. The material conditioning should be specified; hot-worked, hot-worked annealed or cold-worked annealed. The conditioning determines tensile strength; for example, the tensile strength of a 150 mm (6 in.) seamless Inconel pipe is 515 MPa (75,000 psi) for hot-worked and hot-worked annealed tempering and is 550 MPa (80,000 psi) for cold-worked annealed tempering. Welded Inconel pipe, intended for general corrosive and heat resisting applications, is produced in accordance with ASTM B 517 and ASTM B 775. Manufacturers will have to be contacted to confirm available sizes and schedules.

b. Nickel and Nickel Alloy Fittings

Welding and threaded fittings for nickel and nickel alloy piping systems are manufactured in conformance with ASTM B 366. Threaded fittings meet ASME B 16.11. Welding fittings can be class WP, which conforms to ASME B 16.9, ASME B 16.11 and ASME B 16.28, or class CR which are light weight and conform to MSS SP-43. Flanges are commonly specified to ASTM B 564 (and ASTM B 160 for nickel alloys 200 and 201), annealed temper only. Fitting dimensions and ratings are specified pursuant to ASME standards.

4-11. Aluminum

Aluminum is highly ductile. Although it has relatively low strength, its high strength-to-weight ratio results in the extensive use of aluminum alloys where that feature is required.

a. Aluminum Pipe Use

Alloys 1060, 3003, 5052, 6061, and 6063 are the most common compositions of its aluminum pipe. Alloy 6063 is most widely used due to cost, good corrosion resistance, and mechanical properties. Alloys 3003 and 5052 are best used for extremely low temperatures. Alloy 5052 has the best corrosion resistance for slightly alkali solutions.⁵

⁵ Schweitzer, *Corrosion-Resistant Piping Systems*, p. 253.

Aluminum piping resists corrosion well by forming a protective aluminum oxide film. Refer to the fluid/material matrix in Appendix B for compatibility applications. It is very resistant to sulfur compounds and most organics, including halogenated organic compounds. Aluminum should not, however, directly contact concrete because alkalis in the concrete will attack the aluminum. One note of caution is that resistance of aluminum to some combinations of compounds is poor, even though aluminum may be strongly resistant to each compound in the mixture. An example would be strong resistance to either carbon tetrachloride or methyl alcohol separately, but poor resistance to a mixture of the two. Also, aluminum has poor resistance to contaminants such as halide ions (like chloride) and reducible metals (like copper) contained in commercial chemical grades of some chemicals. Aluminum piping is not compatible with most inorganic acids, bases and salts outside a pH range of approximately 4 to 9. In addition, nearly all dry acids, alcohols and phenols near their boiling points can cause excessive aluminum corrosion.⁶

b. Aluminum Pipe Construction

All alloys are available in nominal pipe sizes from 15 mm (½ in.) to 300 mm (12 in.), in schedules 5, 10, 40 and 80. The preferred method for joining aluminum pipe to handle corrosives is welding; however, welding reduces tensile strength. Only schedule 40 and 80 pipe can be threaded. Threading is not recommended for aluminum piping systems that handle corrosives. Flanges are not normally used to join pipe sections and should be limited to connecting aluminum pipe to equipment such as pumps and process vessels.

Aluminum piping materials are most commonly specified using ASTM B 241. This standard covers seamless pipe intended for pressure applications and includes many aluminum alloys and tempering options. The temper required to obtain the proper tensile strength must be specified. For example, temper T6 is the strongest tensile strength for alloy 6063—206.8 MPa (30,000 psi). As an option, pipe lengths specified by ASTM B 241 may also have threaded ends.

Aluminum piping materials may also be specified to meet ASTM B 345 which covers seamless pipe for internal pressure applications. The number of alloys and tempers available under this standard is less than ASTM B 241. However, additional options for pipe

⁶ *Ibid.*, p. 254.

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length ends exist, including threaded, beveled, grooved, or specialty end configurations such as the V-groove or modified Vee. If used with end configurations for mechanical coupling, the burden of mating the end configuration with the mechanical coupling used should be placed on the coupling supplier in the specifications.

Welding fittings are addressed in ASTM B 361, and threaded or flanged fittings materials are forged in accordance with ASTM B 247. Dimensions and configurations for the fittings should reference the appropriate ASME standard(s).

4-12. Copper

Copper is very ductile and malleable metal and does not corrode easily in normal wet/dry environments. Being a noble metal, it does not normally displace hydrogen from a solution containing hydrogen ions. However, copper corrodes rapidly when exposed to oxidizing agents such as chlorine, ozone, hydrogen sulfide, nitric acid and chromic acid. It is very susceptible to galvanic action, and this demands that padded pipe hangers are used and that attention is paid to contact with dissimilar metals.

a. Copper Pipe Construction

Seamless copper pipe is specified pursuant to ASME B 42. Various alloys and tempers may be selected. The copper alloys vary based upon the oxygen and phosphorus contents, and temper is selected based on required tensile strength. Nominal pipe sizes range from 6 mm (1/8 in.) to 300 mm (12 in.), in three wall thicknesses: light, regular, and extra strong.

Other options for copper based piping exist. For example, ASTM B 608 provides copper alloys that contain nickel for brackish or sea water applications with nominal pipe sizes from 100 mm (4 in.) to 1,200 mm (48 in.). In addition, aluminum-bronze, copper-nickel and red brass piping materials are also available.

b. Copper and Copper Alloy Fittings

Flanges and fittings for copper piping systems are component casted. The material is typically produced in accordance with ASTM B 61 for high-grade metal (used in limited steam applications) and for valve-bronze alloys, or with ASTM B 62 for a lesser grade alloy. Configuration and pressure ratings must be specified pursuant to ASME standards.