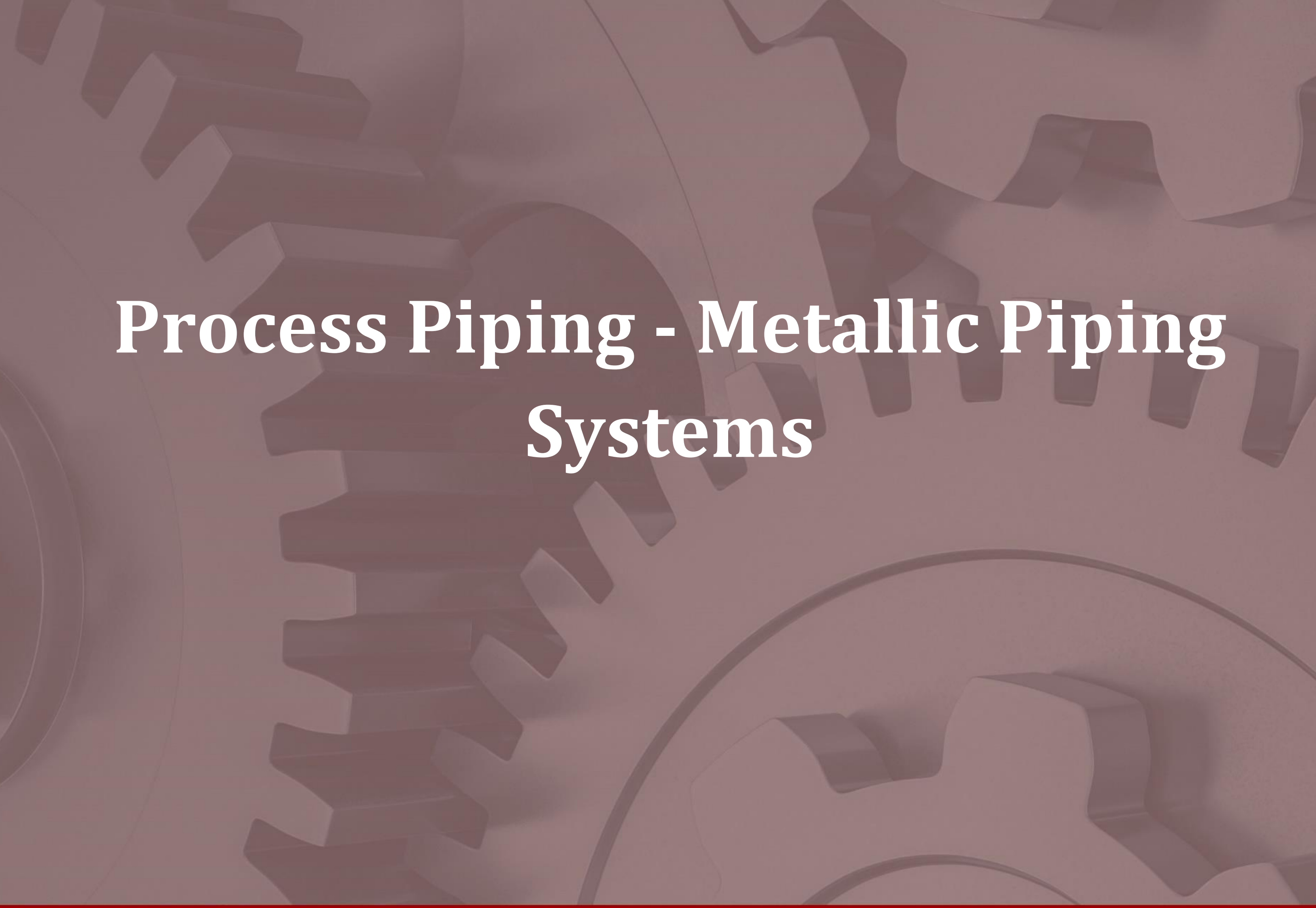


Process Piping - Metallic Piping Systems

An Online Continuing Education Course for Engineers

Course Number: M-2051

Credit: 2 Hours / 2 PDH / 2 CPD

Process Piping: Metallic Piping Systems

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.

2. Corrosion

When metallic components are used, corrosion of some type(s) will occur. 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:

$$\mathrm{M} \rightarrow \mathrm{M}^{+n} + \mathrm{n}\, e^{-}$$

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.

For information on metallic piping system material compatibility with various chemicals, see Appendix A. 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 should be made by an engineer experienced in corrosion.

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.

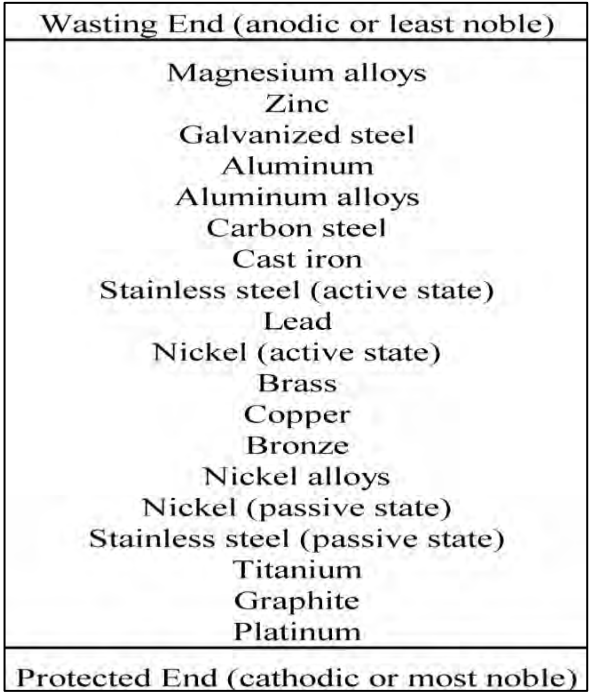
Time-to-failure should not be the only corrosion criteria used for materials selection. Quite often, even trace amounts of metal which are introduced into the environment by very low corrosion rates are, or should be, unacceptable. For example, relatively non-corrosive domestic waters can dissolve sufficient 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 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 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)

Source: Philip A. Schweitzer, Corrosion-Resistant Piping Systems.

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 metallically 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 1) are metallically 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 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 commonly referred to as an "oxygen concentration cell," see Figure 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 corrosio
environments where
immune to pitting att

Pitting attack appears
stages. First, there is
during which the pits
there is a propagation
the pits develop and pe
It is generally agree
concentration of an
(generally chloride, but
and perchlorate) and
(dissolved oxygen, Fe^{+}
certain others) must
electrolyte. A stagnant vo
exist in the pit or pitting
addition, for a given
system, the redox poten

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.
nts in a stainless steel,
affect its resistance to
tendency to pit decreases
n nickel, chromium and
reases. In sea water,
steels containing 18%
3% molybdenum addition
nless steel) exhibit much
osion resistance than
contain no molybdenum
less steel). For certain
inless steel, relatively
vaters can cause severe
example, Type 430,
steel (16% Cr) tubes
ion and pinhole leaks
to convey cooling
a small amount of