Corrosion Control for Buried Water Mains

Pocket Field Guide

Andrew E. Romer and
Bayard Bosserman II

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WHAT IS CORROSION?

Corrosion occurs when a substance is deteriorated by its environment. A common example is when iron rusts. There are many types of corrosion. This guide focuses on the process of corrosion of buried water mains.

Mechanism of Corrosion

Corrosion occurs by an electrochemical process. An anode (negative electrode), a cathode (positive electrode), electrolyte (corrosive environment, such as certain soils and waters), 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 current enters the electrolyte and flows to the cathode (Figure 1).

The three basic forms of corrosion that commonly occur on underground ferrous metal pipelines are (1) general corrosion (uniform attack); (2) galvanic corrosion (dissimilar-metal corrosion); and (3) concentration cell corrosion. In addition to these "normal" forms of deterioration, stray current corrosion can also occur on an underground ferrous metal structure. This form of corrosion is related to uncontrolled direct

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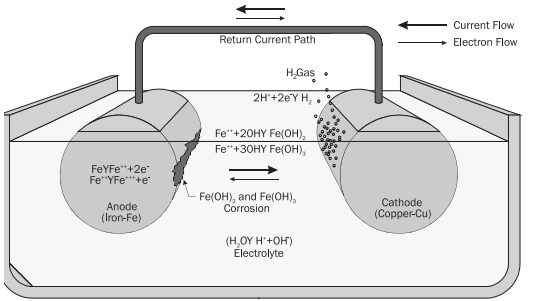


Figure 1 Galvanic corrosion cell (adapted from Figure 2-2 AWWA M27)

currents flowing in the earth. The currents flow onto the underground ferrous metal structures at certain locations, causing no detrimental effect. Similarly, the currents cause no damage while they are flowing along the structure. Eventually, however, the currents must leave the structure, return to the earth, and flow to their source of generation. It is where the currents leave the pipeline that serious corrosion damage occurs. Stray current corrosion and normal corrosion activity are similar in that corrosion always occurs at the anodic areas. The basic difference between the two is that an external current causes stray current corrosion; the current is generated by the

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corrosion cell when normal corrosion activity takes place.

General uniform corrosion is the uniform anodic dissolution of metal over the entire exposed surface area. The corrosion rate is nearly constant at all locations. Underground uncoated ferrous metal pipelines can be expected to deteriorate by general corrosion at reasonably rapid rates when they are exposed to low resistivity, aggressive soils. For example, uncoated ferrous metal pipelines exposed to soils having resistivities less than 1,000 ohm-cm can be expected to develop corrosion leaks in as short as five years.

Galvanic corrosion will generally occur if two electrochemically dissimilar metals or alloys are metallically connected and exposed to a common electrolyte. Oxidation occurs at the anode. Reduction occurs at the cathode. There is no net electrical discharge. (See Table 1.) Anodic materials are at the top of the list, progressing down to cathodic materials. The less noble material (anode) suffers accelerated attack, and the more noble metal/alloy is cathodically protected by the galvanic current. Any material in Table 1 will act as an anode to materials listed below it. For example, accelerated corrosion of the steel would

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be expected to occur if brass and steel are metallically connected and exposed to an aggressive soil. Similarly, underground steel pipelines that are connected to large copper grounds would be expected to deteriorate by galvanic action if the soil has a relatively low resistivity.

Electrochemical attack of a metal or alloy because of differences in the environment is called *concentration cell corrosion*. At least five types of concentration cells exist. Of these, the differential aeration or oxygen concentration cell is the one generally responsible for corrosion of underground steel structures. Areas on a pipeline surface in contact with electrolyte having a high oxygen content are generally cathodic to those areas in contact with electrolyte having a lower oxygen content.

On cross-country electrically continuous underground pipelines, concentration cell corrosion can occur over relatively long distances. This is caused by what are often referred to as *long-line* corrosion currents. For example, ferrous metal pipe exposed to a loam generally will be cathodic to areas where the pipeline is in contact with clay. Pipe buried under a river will be anodic to aerated soil adjacent to the stream.

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TABLE 1 Practical galvanic series of commonly produced metals

Anodic	Metal	Volts*
	Commercially pure magnesium	–1.75
	Magnesium alloy (6% Al, 3% Zn, 0.15% Mn)	–1.55
	Zinc	–1.15
	Aluminum alloy (5% zinc)	–1.05
	Mild steel (clean and shiny)	–0.5 to –0.7
	Mild steel (rusted)	–0.2 to –0.5
	Cast and ductile iron	–0.5
	Tape-coated steel	–0.5
	Lead	–0.5
	Stainless steel, AISI 316	–0.25
	Mild steel in concrete	–0.2
	Copper, brass, bronze	–0.2
	Cast iron–high silicon	–0.2
	Mill scale on steel	–0.2
	Stainless steel, AISI 304	–0.15
Cathodic	Graphite	+0.3

*Reference to a copper–copper sulfate reference cell.

Localized soil differences can also be involved in the concentration cell corrosion of underground pipelines. For example, ferrous metal in contact with undisturbed, low oxygen content soil will generally be anodic to ferrous metal in contact with the aerated backfill. Corrosion damage to the underside of the pipeline is accelerated by the large cathode-to-anode area ratio that exists. Similarly, ferrous metal in contact with lumps of clay will be anodic to nearby ferrous metal if the major backfill material is a

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sandy loam. Localized concentration cell corrosion is believed to be a major cause of corrosion leaks in underground pipelines. New pipelines act as anodes and protect old pipelines; of course, this increases the corrosion on the new pipeline. Concentration cells also develop between highly stressed surfaces such as under bolt heads.

Materials Susceptible to Corrosion

Do not bury copper lines next to uncoated ferrous metal lines in low resistivity soils. The ferrous metal pipe will act as an anode and will rapidly corrode. To protect the ferrous metal line, the following items should be done in decreasing order of preference: (1) do not use copper piping, use PVC or ferrous metal; (2) coat the copper line with hot- or cold-applied coal-tar tape or polyethylene wrap and install in an insulating coupling between the copper and ferrous metal line at the point of connection; and (3) coat the ferrous metal line for a distance of at least 50 pipe diameters on both sides of the connection to the copper line with cement mortar, coal-tar enamel, or hot- or cold-applied coal-tar tape. It is best to perform both (2) and (3).

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What is a Corrosive Soil?

One of the important factors affecting corrosion activity along an underground pipeline is the resistivity of the soil. Corrosiveness of the environment is generally an inverse function of resistivity. Low resistivity favors the flow of current and increases the probability of anodic dissolution; corrosion may not be a problem in very high resistivity electrolytes. The effect of soil resistivity on the anticipated corrosion activity for steel can be predicted using the information given in the Table 2. These data, however, should not be used as an absolute criterion for corrosivity. Often, severe corrosion damage occurs in soils having relatively high resistivities. This is especially true in heterogeneous soils (e.g., an environment consisting of lumps of clay mixed with sand).

TABLE 2 Soil resistivity v. corrosion activity

Resistivity range (ohm-cm)	Corrosion activity
0 to 2,000	Severe
2,000 to 10,000	Moderate
10,000 to 30,000	Mild
Greater than 30,000	Limited

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The latter should be considered when widely varying, high resistivities are measured along a pipeline.

In addition to the mineral content, moisture greatly affects a soil's resistivity. Resistivity decreases with an increase in moisture content up to a point near saturation. For example, a typical clay containing about 5 percent moisture can have a resistivity approaching 1,000,000 ohm-cm; the soil can have a resistivity as low as 7,000 ohm-cm if the moisture content is increased to about 20 percent. This suggests that corrosion activity should be most severe during the rainy season. For this reason, resistivities should not be measured when the soil is abnormally dry.

The pH of nearly all soils and groundwaters vary within the range of 3.5 to 10. The majority of these environments, however, have a pH in the range of 6.5 to 7.5; that is, most are essentially neutral. Alkaline soils having a pH in the range of 7.5 to 10 (e.g., alkaline loams and alkaline salt marshes), and acidic soils having a pH in the range of 3.5 to 6 (e.g., cinder fills and muck) also exist.

Although the exact influence of pH and the other interrelated factors that affect the corrosion

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