External Corrosion Control for Infrastructure Sustainability

Third Edition

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Importance of Controlling External Corrosion

Corrosion is the deterioration of a material or its properties because of a reaction with its environment. Deterioration of pipelines, valves, pumps, and associated equipment due to external corrosion is an important concern for many water utilities. At one time, corrosion was accepted as inevitable in many soils, and extra thickness for metal piping was often specified to extend the piping’s useful life. Today, a variety of techniques are available to eliminate or significantly reduce external corrosion. Determining the need for such corrosion-control measures and selecting the most appropriate techniques are the primary topics of this manual. Corrosion is generally defined as deterioration of a metal or an alloy by reaction with its environment. For the purposes of this manual, corrosion also includes the dissolving of other water system materials through contact with water or soil.

This chapter first presents a brief introduction to the science and terminology of corrosion and then discusses economic implications and managerial responsibility for external corrosion-control programs.

After completing this chapter, the reader should be able to

- Define corrosion.
- Recognize certain environmental conditions and items of water supply equipment that are often associated with external corrosion problems.
- Understand the cost to remedy and the extent of the corrosion problem.
- Recognize potential hazards to public health and safety that may result from corrosion.
• Understand the basic economic questions that must be asked when selecting measures for corrosion control.
• Recognize the responsibilities for a corrosion-control effort that must be assumed by various utility personnel.

CORROSION: OCCURRENCE AND IMPLICATIONS

Corrosion is a natural phenomenon. Metals are normally found in their stable, oxidized (corroded) form in nature. Iron ores, for example, are found as iron oxides. These oxides are chemically reduced in the refining process to produce useful metal, with the iron atoms in the elemental (unoxidized) form. In the presence of oxygen and water, or under certain soil and electrical conditions, refined iron tends to return to its more stable form, iron oxide (rust). Some waters and some soils are especially favorable to corrosion. The US Federal Highway Administration (FHWA 2002) performed a two-year study on the direct costs associated with metallic corrosion in nearly every US industry sector, from infrastructure and transportation to production and manufacturing. The study provides current cost estimates and identifies national strategies to minimize the effect of corrosion. Results of the study show that the total annual estimated direct cost of corrosion in the United States is $276 billion ($36 billion for drinking water and sewer systems).

Potentially Corrosive Conditions

Several conditions increase the likelihood that corrosion will occur in a water utility system:

• Dissimilar metals or alloys in contact with each other and with a common media, such as water or soil.
• Great variances in soil in contact with metal or alloys.
• Naturally occurring corrosive soil.
• Atmospheric corrosion.
• Environmental contamination of soil with chemical waste, cinders, mine wastes, salts, or other refuse.
• Stray current corrosion, including exposure to stray direct-current earth currents from transit systems.
• Microbiologically influenced corrosion.

These conditions, discussed briefly in the following sections, are examined in detail in chapters 2 through 4 of this manual. Where such conditions occur, the water utility staff should be especially alert to the selection of materials and preventive measures that will minimize the effects of corrosion.

Dissimilar metals. Iron and copper are among the metals used in water system piping, valves, pumps, and other equipment. For each application, the manufacturer selects a metal with appropriate properties. There is no single ideal metal or alloy that can satisfy the many requirements of water system equipment.

Unfortunately, whenever two dissimilar metals are immersed in a common corrosive medium (soil or water) and then placed in contact with each other, the likelihood of corrosion significantly increases. The extent of corrosion depends on the characteristics of the corrosive medium and the metals involved. Figures 1-1 through 1-3 illustrate common...
uses of dissimilar metals and alloys in water systems. Each of these situations, among many others, poses a potential condition for corrosion.

Soil variances. The composition of soil can vary from point to point and with changing soil depth. In many cases, a single metallic unit (pipe, well casing, valve, etc.) may be in contact with two or more completely different soil types. Whenever this situation occurs, the likelihood of corrosion increases. The severity of the corrosion will depend on the soils and the metal involved.

Naturally corrosive soils. As noted, some soils tend to promote corrosion. As a general rule, swamps, bogs, peat, and soils with high salt content are corrosive. Low, poorly drained soils are more likely to be corrosive than soils in well-drained areas. The corrosivity (also called aggressiveness) of a given soil can be determined by sampling, testing, and analysis.

Atmospheric corrosion. Equipment and facilities may experience corrosion due to exposure to the atmosphere, brought on by acid rain, salt spray, industrial chemicals, and other factors.

Figure 1-1  Metals used in a typical gate valve
Environmental contamination. In many urban areas, the history of street surfacing may offer clues concerning potential corrosion of underground water system materials. Older streets were often surfaced with cinders and later paved. Cinders are aggressive to most pipe and valve materials, and their presence is a warning that serious corrosion may occur.

Coal bottom ash has been used as an aggregate material in flowable fill mixes. Bottom ash (and boiler slag) is composed principally of silica, alumina, and iron, with smaller percentages of calcium, magnesium, sulfates, and other compounds. The composition of
the bottom ash or boiler slag particles is controlled primarily by the source of the coal and
not by the type of furnace. Due to the salt content and, in some cases, the low pH of bottom
ash and boiler slag, these materials could exhibit corrosive properties. When using bottom
ash or boiler slag in an embankment, backfill, subbase, or pipe base course, the potential
for corrosion of metal that may come in contact with the material is of concern and should
be investigated prior to use.

The presence of chloride salts can create corrosive soils. Steel reinforcement in con-
crete, iron, copper, brass, and many other materials in common use may be subject to
attack if elevated concentrations of chlorides are present in the environment. Heavy use
of deicing salts and chemicals on streets and highways can also be a potential source of
corrosion.

Finally, sites where chemical contamination has occurred, such as refuse dumps,
landfills, and mine or industrial waste disposal areas, may cause deterioration of water
utility materials. Such locations should be avoided if possible. However, if alternative loca-
tions are not feasible, the potential for corrosion must be considered.

**Stray current corrosion.** ASTM G15, Standard Terminology Relating to Corrosion
and Corrosion Testing, defines *stray current corrosion* as “corrosion caused by electric cur-
rent from a source external to the intended electrical circuit, for example, extraneous
current in the earth.” Although stray current corrosion may sometimes be caused by alter-
nating current in areas with a very high alternating-current density, it is normally associ-
ated with direct current.

Stray current corrosion is normally localized and will occur at locations on the struc-
ture where the direct current is discharged back into the earth. In areas of stray current
influences, electrically continuous pipelines accumulate a greater magnitude of stray
current flow than electrically discontinuous pipelines. Sources of stray direct current
normally include cathodic protection systems, direct (DC) powered streetcars or trains,
welding equipment, and mine/industrial equipment.

A more detailed discussion of stray current corrosion is given in chapter 3 (Evaluat-
ing the Potential for Corrosion).

**Microbiologically influenced corrosion (MIC).** ASTM G15 defined *microbiologically
influenced corrosion* as “corrosion inhibited or accelerated by the presence or activity, or
both, of microorganisms.” MIC-related corrosion normally takes the form of pitting, as
compared with generalized corrosion. Four primary forms and mechanisms of MIC have
been proposed and published (Pope and Morris 1995).

1. One is in instances where a biofilm, a film composed of families of low-nutrient
bacteria, forms on the metal surface, creating a differential aeration cell.
2. Another occurs when various mutually beneficial bacteria create a colony housed
in a biodome, thereby setting up a corrosion cell by cathodic depolarization.
3. Still another condition may exist in which the biological waste material from these
bacteria within the biodome presents a strong acid concentration, which can rap-
idly perforate the metal substrate.
4. Lastly, conditions can occur that provide for iron-reducing bacteria to flourish. In
this instance, bacteria that respire iron (Fe), or utilize Fe in their electron recep-
tor for energy, become citizens of the colony represented in a particular biodome.

To date, there is no widely accepted field method without laboratory analysis to posi-
tively identify MIC responsible for, or contributing to, corrosion. MIC continues to be
studied and defined to develop reliable field test methods and also to allow more defini-
tive control mechanisms to be developed. A more detailed discussion on MIC is given in
chapter 3.
Implications of Corrosion

Aside from the 2002 FHWA report, information is limited that details costs incurred by the public water supply industry due to corrosion-produced losses. Given the extent and wide variety of materials used in water systems, the amount is certainly substantial.

In addition to the financial impact of repair, replacement, labor, and equipment, other more important costs impact the public as a result of corrosion. The health of water consumers may be threatened whenever extensive corrosion breaches the sanitary integrity of the water system. The ever-present danger of backflow of contaminated liquid into the drinking water system is further increased when water pressure is interrupted to facilitate repairs on corroded wells, pumps, treatment equipment, pipes, valves, and services.

Another concern is that public safety depends heavily on an adequate supply of pressurized water for fire control. Low pressures and insufficient water can result in the growth of small fires into disasters that cause injury, death, and destruction of property. Uncontrolled corrosion can be a major contributor to the problems of unreliable or inadequate fire-control systems.

Controlling corrosion in water utility systems can contribute greatly to cost savings, public health protection, and public safety.

ECONOMICS OF CORROSION CONTROL

Two primary considerations are involved in any decision regarding corrosion control. The first and more important is the protection of public health and safety. The second is economics. Both private and governmental utilities must operate effectively and efficiently.

In either case, faced with decisions regarding the best corrosion-control programs to implement, water utility staff must determine which actions will produce the lowest overall cost and the highest return on capital. The staff must decide which alternative is preferable: (1) minimize initial costs and accept higher maintenance costs and shorter equipment life or (2) marginally increase initial investment by specifying corrosion-control procedures that will reduce maintenance and extend the life of components.

Economic evaluations are commonly the province of the design engineer and utility management. Determining a reasonable estimate for the anticipated life of alternative installations requires considerable engineering expertise and experience. However, much of the required data is empirical and depends on knowledge of the system and local environmental conditions.

REFERENCES
