

# Water Treatment Corrosion: Causes and Prevention

It has been estimated that in the United States alone, corrosion accounts for over \$150 billion per year. Of this more than \$50 billion could be saved through preventive action. By their nature, water treatment facilities of all kinds—treatment plants, distribution systems, etc.—are highly subject to corrosion and its results. In this, Part 1 of a six-part series, the fundamentals of the corrosion process and its remedies are reviewed.

**T**he corrosion of metals has been defined as the direct chemical or electrochemical reaction of metals with the environment, resulting in their deterioration from a metallic to a non-metallic state by combination with, or in solution in, the surrounding substances. In most cases this will be the oxidation of iron or copper in the presence of water. We are all familiar with the deterioration of iron to form rust, another word for iron oxide. Similarly, we have all seen the attractive blue green patina formed on copper roofs or on the Statue of Liberty. This would be the oxide form of copper. In the case of water, the excessive oxidation of iron results in red water while the excessive oxidation of copper results in blue water. Such characteristics can be readily observed by the blue or brown-red stains sometimes found on porcelain sinks or bathtubs. This discussion will mainly address the corrosion of iron, although similar principles apply to the corrosion of other metals.

## Theory

For corrosion to occur, four components must be present:

**ANODE.** This is the site at which the corrosion process is occurring and the metal undergoes oxidation to its ionic

state. In the case of iron corrosion, this is where ferrous ions enter solution. A stationary anode will be the site of a pit commonly observed in some corrosion coupon test specimens. It is also at this site where the release of electrons occurs.

**CATHODE.** This is the site to which the electrons travel upon release from the anode. This acceptance of electrons can result in the neutralization of positive hydrogen ions or the formation of negative ions. In hydrogen ion neutralization, H<sub>2</sub> gas is formed, causing gas bubbles. This can be readily observed in the rapid corrosion of certain metals in strong acidic solutions where tiny gas bubbles are released at the cathodic areas. The anodic and cathodic reactions must go on at the same time and at equivalent rates, but corrosion only occurs at the anodic sites.

**CONDUCTOR.** This is the metal itself, which allows for the transfer of electrons from the anode to the cathode. Where two metals are insulated from one another, an anode on one metal could not transfer electrons to the cathode of the other metal—but only to other cathodes on itself.

**ELECTROLYTE.** This is the component that actually forms the corrosive environment, in our case the water. Its role is to serve as a transferring medium for metal ions that have released an electron allowing the formation of anodes and

cathodes to occur. If there was no conversion and release of metal to the ionic state from anodic areas to the electrolyte, an equilibrium would be established and the corrosion process would cease.

The electron transfer mechanism just discussed is also the same mechanism taking place in an automobile battery with a flow of electrons occurring from anodic areas (-) to cathodic areas (+). In a corrosive environment, electrons are generated at the anode by the oxidation (corrosion) of iron, flowing through the conductor (metal pipe) to the cathode. At the cathode surface the electrons would meet hydrogen ions from the solution. One hydrogen ion would accept one electron and become a hydrogen atom. In most cases this hydrogen atom would combine with another hydrogen atom to form hydrogen gas, which would either cling to or be released from the cathodic surface. It is important to note that the term “oxidation” is not necessarily associated with oxygen, but rather the giving up of electrons and corresponding change of valence of the associated metal ion.

## Factors Affecting Corrosion

**DISSOLVED OXYGEN.** Having an affinity for electrons, dissolved oxygen plays an active role in the corrosion

cathodic areas to the environment is often the limiting factor in a corrosion rate. The faster this transfer, the higher the corrosion rate. A water saturated in dissolved oxygen will corrode at a faster rate because of dissolved oxygen's ability to accept electrons at the cathodes. If there were no transfer of electrons from the cathode to the surrounding environment, i.e., water, an equilibrium would be reached between the anode and the cathode and the corrosion process would cease.

**TEMPERATURE.** The corrosion process is accelerated when water temperatures increase. This may be due in part to a number of factors including increased brownian movement at higher water temperatures allowing for a more rapid transfer of ions in the cathodic and anodic areas.

**DEPOSITS AND SCALE.** If a uniform, durable, tenacious deposit could be formed on the surface of a water conduit it would serve as a corrosion inhibitor. The problem is that most water formed deposits do not meet these criteria. Most deposits formed on the surface of pipe tend to be spotty, or covered with microscopic fissures and cracks. Such conditions can be readily examined under microscopic observation of calcium carbonate scale. Areas protected by such scales tend to become anodic to areas that are not protected. This phenomenon can be explained by the fact that areas covered by scale exist under anaerobic conditions where there is a low concentration of dissolved oxygen relative to the surrounding areas. Areas of higher dissolved oxygen become cathodic to areas of lower dissolved oxygen concentration. Thus the scale covered area becomes an anode and the corrosion process begins to occur.

**METAL STRESS.** In areas where a metal has been stressed due to tapping or drilling, the corrosion rate is normally greater. This condition is related to increased corrosion rates under scales and deposits. Stressed metal is found to be full of microscopic fractures and cracks. Such areas tend to exist under anaerobic conditions and a differential of dissolved oxygen concentration sets up an anode/cathode formation. This can be observed in corrosion test

coupons where a relatively high corrosion rate can be seen near the coupon mounting areas where the metal has been drilled.

**WATER CHEMISTRY.** It is not unusual to find two waters with the same laboratory analysis to act differently in their corrosive characteristics. Such discrepancies can be explained by the absence or presence of undetected, naturally occurring inhibitors or promoters present in the water supply.

**pH.** Some metals tend to enter their ionic state more rapidly when the pH of the surrounding electrolyte is within a certain range. Such is the case of copper in a pH of less than 6.8.

**CORROSION BYPRODUCTS.** The corrosion process itself yields various byproducts that either inhibit or promote the corrosion process. In most cases, the formation of these byproducts, i.e., iron oxide inhibits corrosion, but promotes biological activity by shielding bacteria from chlorine.

**GALVANIC EFFECTS.** Certain metals, when joined, become cathodic and anodic to one another. In such cases the two dissimilar metals should be electrically insulated from one another or rapid corrosion will occur. Charts illustrating the galvanic series are available from a multitude of sources. Generally, the further apart two metals appear on the galvanic series, the more reactive they are with one another.

## Types of Corrosion

What follows are some of the more common types of corrosion observed in a water distribution system.

**GENERAL ATTACK.** This is a condition where there is a uniform loss of metal over the entire surface of the affected metal.

**LOCAL ATTACK.** This is a condition where there is a localized loss of metal on the corroding surface. Pitting is a common form of localized attack where there is a concentrated loss of metal in a small area. Recognized to be the most severe form of corrosion, pitting can cause the perforation of a pipe wall within a short time period. It is generally characterized by small pock marks or holes in the surface of the corroding material.

**GRAPHITIZATION.** This is a condition specific to cast iron pipe where the iron matrix corrodes leaving the carbon matrix behind. The pipe remains intact, but becomes brittle and apt to crack under stress.

**GALVANIC CORROSION.** Galvanic corrosion is caused by the coupling of two dissimilar metals in a corrosive environment. It can be eliminated by electrically insulating the two metals from one another.

## Physical and Chemical Alternatives

Fortunately, the effects of corrosion can be minimized, reducing customer complaints, generating a better quality finished water, and prolonging the life of the distribution system.

**MATERIALS SELECTION.** The most cost-effective long-term solution to minimize corrosion problems is through intelligent materials selection. Replacement of an existing distribution system with non-corrosive materials will eliminate the need for any further treatment. However, it is seldom practical for a district to completely replace an entire distribution system over a short period, so interim actions must be taken. However, as replacement of sections of existing distribution systems become necessary, some thought should be given to the selection of non-corrodible materials.

**COATINGS.** It is seldom practical to physically apply coatings to the entire interior surface of the existing distribution system. This could be practical in cases of new installations or in the periodic maintenance of valves, pumps, or other frequently serviced items.

**pH ADJUSTMENT.** This method remains one of the most prevalent means of corrosion control practiced today. These methods rely upon depositing a calcium carbonate scale. The process is monitored by various indexes to indicate whether or not a water is laying down a scale.

**SODIUM SILICATE.** This inhibitor has been found to be cost-effective in areas of low-hardness waters. In theory, the sodium silicate lays down a monomolecular film on the surface of the pipe inhibiting anode/cathode formation. It

would appear that there is some mechanism in harder waters that inhibits the formation of this film, rendering it an unsuitable choice under these conditions. Silicates exhibit some sequestering capabilities suggesting their use in areas where iron or manganese are prevalent in raw water supplies.

**PHOSPHATES.** There are two main groups of phosphates: polyphosphates and orthophosphates. Polyphosphates, like silicates, work better under low hardness conditions. Like silicates they can also be used as sequestering agents on certain waters where iron and manganese are prevalent. Polyphosphates have a tendency to revert to orthophosphate with time.

**ORTHOPHOSPHATES.** Zinc orthophosphates are the principal form of orthophosphates used in water treatment. Like silicates, zinc orthophosphates deposit a monomolecular film on the surface of the pipe. There is often some form of complexing occurring on the surface of the pipe with respect to the zinc. A reaction takes place between the negatively charged cathodic sites and the positively charged zinc ions. This results in a rapid formation of zinc compounds forming films over the cathodic

site. Such films quickly interrupt the corrosion process because the cathode is shielded. Electron transfer between the cathode and the environment is halted and the corrosion process is stifled. It has been shown that small dosages of zinc orthophosphate can inhibit the release of asbestos fibers from AC pipe because of an observed hardening of the pipe surface. While zinc alone has been shown to have corrosion reduction capabilities, evidence has clearly indicated that a relatively small amount of orthophosphate greatly improves the corrosion resistant properties of the inhibitor. In the majority of cases the most effective ratio of zinc to phosphate would be 2:1 zinc to phosphate or greater. Care must be given to minimize phosphate concentrations as phosphates cause the eutrophication of potable water and are a pollutant to the environment. The highest zinc to phosphate ratio available that achieves corrosion protection should be considered superior since less phosphate is introduced to the water supply. Recent evidence suggests that in the case of lead solders or surfaces, the phosphate ion plays a more important role. If the protection of lead is an important consideration, a ratio of

1:1 zinc to phosphate or greater should be considered. This would provide for additional lead protection while minimizing phosphate concentrations overall as compared to other high phosphate low zinc inhibitors.

**ORTHO-POLYPHOSPHATES.** Over the past ten years or so a "new" group of phosphates has emerged and found widespread use known as orthopolyphosphates. On a chemical level these products are really nothing new at all but essentially a blend of the same ortho and polyphosphates noted above. Most all of the orthophosphates used in these blends are derived from either mono- or di-sodium salts of orthophosphoric acid while the polyphosphates can come from a number of both sodium and potassium based polyphosphate salts. The main advantage to these products is their ability to both sequester troublesome cations in solution such as iron and manganese while also providing corrosion protection largely through the presence of the orthophosphate ion. GE

*The preceding is courtesy of Sweetwater Technologies, [www.sweetwatertech.com](http://www.sweetwatertech.com). Part 2 of this series will discuss how to conduct a corrosion study.*

## Determining the Condition of Critical Water Assets

Denver Water serves a population in excess of 1.1 million people in the Metro Denver area and operates over 2,600 miles of water transmission mains. Denver Water was among the first utilities to implement a Condition Based Asset Management program for its prestressed concrete cylinder pipe (PCCP) pipelines. To date, Denver Water has inspected 23 miles of PCCP using the Pressure Pipe Inspection Company's (PPIC, [www.pplic.com](http://www.pplic.com)) patented Remote Field Eddy Current/Transformer Coupling (RFEC/TC) technology to establish the baseline condition of some of its more critical PCCP assets.

Denver Water has limited capacity in parts of its water transmission system. One such pipeline is Conduit No. 30. This pipeline provides load shifting between Denver Water's Moffat and Marston treatment plants. Moffat is higher in elevation than Marston, therefore the load shifting from Marston to Moffat has to be pumped.

Due to a need to move additional water from the Marston Treatment Plant to the Moffat Treatment Plant, John H. Bambei Jr., chief of engineering for Denver Water, was interested in determining if it was safe to raise the hydraulic gradient in Conduit No. 30 by 20 to 30 psi. "Our choices are raising the pressure in this line, or building a new one," said Bambei. "For budgetary control purposes, we'd obviously prefer to raise the pressure in the line. However, before doing so, we needed to determine its structural condition. RFEC/TC provides data on the structural integrity of PCCP. Only with accurate data can we assess the risk that this pressure increase will have on individual pipe."

Conduit No. 30 is a 60-in. diameter PCCP pipeline that was manufactured in 1963 and does not contain shorting straps. Consequently, on August 17, 2005, PPIC conducted a non-destructive evaluation of Conduit No. 30

using its RFEC/TC technology. The inspection was performed between STA 5+32 and STA 60+61, and between STA 63+02 and STA 64+82, spanning an overall distance of 1.08 miles and a total of 366 pipes. Analysis of the data obtained during this inspection determined that only seven pipes (two percent) in this portion of Conduit No. 30 contained broken prestressing wires.

"This inspection provided Denver Water with the baseline condition information that we needed to move our stress analysis program forward," concluded Bambei.



PPIC personnel prepare to enter Conduit No. 30 and assemble PipeRider—a self-propelled RFEC/TC inspection tool.