Corrosion

Corrosion causes gradual decay and deterioration of pipes, both internally and externally. It can reduce the life of a pipe by eating away at the wall thickness. Under certain conditions, the time for the decay to cause the pipe to fail is as short as five years. Corrosion can also result in encrustation inside the pipe, reducing the carrying capacity of the pipe to a point that it has to be replaced to provide the flow needed.

In the past, a variety of materials were used in the construction of water systems. Terra-cotta, wood, and lead were among the materials commonly used. Today, the materials are more likely to be cast iron, ductile iron, asbestos cement, steel, copper, galvanized iron, and plastic.

In some cities, cast-iron water mains have been in continuous service for more than 100 years. Ductile iron, which has normally replaced cast iron in newer installations, contains alloys of several metals. This tends to reduce the brittleness of the pipe. Both materials are typically lined to protect the metal from the water. Linings are normally cement mortar or a bituminous seal coat. Steel has been used in large diameter pipes in which additional flexibility is needed. These pipes must be lined to protect the pipe from any corrosive action of the water.

Because of its flexibility and durability, lead was once used in the construction of service lines and interior plumbing. Its longevity is due to its low corrosion rate and its resistance to encrustation. Many utilities have used lead service pig tails at the connection to the water main itself. This practice disappeared when copper was introduced to the construction field in the early 1950*s*. In addition, health concerns surfaced regarding the lead materials dissolving into the water. As a result, copper and plastic pipes have gradually replaced the other types of piping materials in residential construction.

All of the materials just mentioned are subject to corrosion when they are used in water systems. Whether the corrosion attacks from the exterior or the interior, the result is the same: the pipe will eventually fail.

EXTERNAL CORROSION

The best indication of whether or not the outside of a pipe will corrode is the soil resistivity, which can be measured by one of several types of meters. The four-point type is used most often because it can measure the average resistivity of the soil down to the pipeline. Some water systems use soil resistivity to determine the type of pipe to install. If the soils resistivity is greater than 5,000 ohms per centimeter (cm), serious corrosion is unlikely; ductile iron or steel pipe could be used in these situations. If the resistivity is less than 500 ohms/cm, however, the potential for corrosion is greater. In these cases, non-metallic pipe such as asbestos cement or PVC should be used. Ductile iron, if used in soil with low resistivity, should be wrapped to prevent contact with the soil.

The reactions involved in corrosion are electrochemical in nature. With external corrosion, the current paths are not continued to the inside surfaces of the pipe; therefore, galvanic corrosion electrolysis is relatively more important and cathodic protection is usually practical.

Electrolysis is the decomposition of a substance by the passage of an exterior source of direct electrical current (D. C.). When a D. C. current flows from a metal to soil, most metals are corroded.

Alternating current (A. C.) electrolysis will also corrode metals, but the possible effect is considered to be only one percent of what would be caused by the same flow of direct current.

PROTECTION FROM EXTERNAL CORROSION

Several approaches are used to protect pipes from external corrosion. They include:

Wrapping

Encasing the pipe in a plastic wrap to prevent contact with the soil is performed extensively with ductile iron pipe. In addition, the pipe can be bedded in material other than the normal backfill found on the construction site. Both these methods have been used with varying degrees of success.

Cathodic Protection

The natural-gas industry has had great success with this method, which involves attaching cathodes (negatively charged metals) or anodes (positively charged metals) to the pipe. These charged metals will corrode instead of the pipe. The anodes or cathodes introduce a current to the pipe. This changes the current flow from the pipe and causes it to flow from the anode to the cathode. This method of protection has also been used with some success on water piping.

Pipe Replacement

This involves the use of piping material that is resistant to the corrosion. Originally, such material was asbestos cement, a mixture of cement and asbestos. Disadvantages of this material are its tendency to increase the loss of water that seeps through the pipe and its brittleness.

Plastic pipe was introduced in the 1960s. In many locations, it has replaced asbestos cement. Available in most sizes and resistant to corrosion, plastic has been used successfully in several Minnesota cities.

INTERNAL CORROSION

PROPERTIES OF WATER AFFECTING CORROSION

The property of the water passing through the piping system greatly affects the corrosion rate of the material. These effects can be explained in terms of electrochemical theory. The water properties that affect corrosion include the concentration of dissolved oxygen, the temperature, the velocity of the water, the chlorine residual, and the concentration of the chloride ions.

Dissolved Oxygen

The concentration of dissolved oxygen is one of the most important factors influencing the rate of corrosion for all metals. At ordinary temperatures, the absence of dissolved oxygen will greatly slow corrosion of ferrous metals. Oxygen is a direct participant in the corrosion reaction, acting as a cathode-accepting electron.

The level of oxygen concentration increases as the rate of the electron transport increases. As a result, the rate of corrosion for most metals increases with any increase of dissolved oxygen.

Temperature

Corrosion represents a particular group of chemical reactions. The rate of any particular chemical reaction will increase with a rise in the temperature and decrease with a drop in the temperature.

Changes in temperature can influence the chemical composition and physical properties of the water, the character of any scales formed on the metal, and the nature of the metal itself. Temperature affects the solubility of many gases, such as oxygen, that are important to the rate of corrosion. With any increase in temperature, an increase of corrosion activity is expected.

Velocity

The velocity of the water in the piping system is important to the rate of corrosion. If the water is flowing fast and is also hot and soft, the rate of corrosion of copper can be extremely fast. The critical velocity is considered to be greater than four feet per second. This type of corrosion is called erosion corrosion and involves the removal of dissolved metal ions. It is typically characterized by grooves, gullies, or waves on the inside of the pipe, especially near points of turbulence. Tees and elbows are often the first to fail when excessive velocities occur.

Chlorine

Chlorine is an effective oxidation chemical; therefore, it is assumed that it will take the place of oxygen in any corrosion processes. Free chlorine residuals tend to cause more corrosion than combined residuals.

CORROSION OF COPPER

One of the most common piping materials used in interior plumbing, copper is subject to corrosion by three different ways:

1. A general corrosion attack on copper is most often associated with soft and acidic waters. It usually proceeds at a slow rate and is characterized by a build-up of cupric acids.

   The most important factors influencing the general corrosion rate of copper are the pH of the water, softness, temperature, age of the pipe, and oxygen content of the water. A water that is soft--less than 60 mg/l of hardness--with a pH of less than 6.5 will be aggressive to copper. If the water is heated, the aggressive nature will be greater due to the destruction of the metal-oxide layer on the pipe.

   The impact of general corrosion on copper pipe is more of a nuisance nature. Green water is caused by the dispersion of the copper corrosion into the water. Another problem is the blue or green staining of plumbing fixtures. Water from corroded copper pipes also has a rather unpleasant taste because of the high concentration of dissolved copper.

   The problems of general corrosion can be controlled by adding a material such as lime to raise the pH of the water.

2. Impingement of copper pipe is the result of excessive flow velocities, usually greater than four feet per second. At one time, impingement was thought to be mechanical in nature. This type of corrosion can be aggravated by soft water, high temperature, and low pH.

   Impingement is shown by a rough surface, often accompanied by horseshoe or U-shaped pits. In severe cases, the pipe will be destroyed in as little as six months. The pipe will have severe damage in areas of turbulence downstream from fittings. It is most noticeable in recirculation systems, such as swimming pools.

3. Pitting of copper pipe is most commonly associated with waters that are hard. This type of pitting generally occurs first in the cold-water piping.

   Hard water will create horizontal pitting on the bottom of the pipe. New installations usually show more pitting, with the pipe failing in the first two-to three years. In some cases, the failure may even be in the first few months of service.

CORROSION OF LEAD

Pipes made of lead were first used by the Romans. Lead is soft and pliable; as a result, it can easily be formed to the desired shape. The introduction of galvanized pipe in the early 1900s caused a decline in the use of lead in plumbing, although the material was still common in service-line well into the 20th century and in solder until just a few years ago. Health concerns have now resulted in a virtual elimination of lead in plumbing materials.

Health problems associated with exposure to lead, especially in children, include mental retardation, hypertension, and renal failure. Because of this, the use of lead in plumbing or solder is no longer allowed in Minnesota.

Corrosion of lead, as is the case with other materials, is affected by the pH and temperature of the water. The solubility of the lead increases dramatically with a low pH and high temperature. A pH of 8 and below causes a rapid increase in the lead corrosion by-products. It increases by a magnitude of 2 with each 1-unit drop of pH.

In many systems it appears that elevated levels of lead at the tap are not due to the presence of lead piping, but rather to the use of lead-soldered joints and brass fixtures on the interior plumbing. This raises concerns about the protection of the public health, even for systems that do not have lead services in the water system. Minnesota no longer allows the use of lead solder for potable water sources. One alternative now allowed is 95-5 solder, which consists of tin and antimony.

MICROBIOLOGICAL ASPECTS OF CORROSION

Microorganisms can play a part in the corrosion of pipe materials. Bacteria have the ability to form microzones of high acidity and high concentrations of corrosive ions in a pipe. The most common bacteria involved in the corrosion reaction are sulfate producers, methane producers, nitrate reducers, sulfur bacteria, and iron bacteria. The greatest possibility for this type of reaction occurs in dead ends where the water becomes stagnant. The conditions favorable to bacterial growth could be a decline of the chlorine residual and a lack of scouring velocities in the pipe. This is more common where there pitting action has been started, resulting in additional areas for the organism to become attached to the pipe. This corrosion could cause an increase of the number of main breaks.

CORROSION INDEXES

Corrosion indexes used to date can be divided into two broad-based classes--the calcium carbonate saturation and indexes based on other solution properties expected to influence corrosion rates.

Calcium Carbonate Saturation Index

The most common relationship used in the water industry is the Langelier Index, or the calcium carbonate saturation index. Achieving calcium carbonate saturation is still considered to be the principal means of controlling corrosion in distribution piping containing iron. If a solution is supersaturated with calcium carbonate, the pipe will be coated with an eggshell-like coating that protects the pipe. The basis of the index is the relationship of the pH of saturation and the pH of the water in the system. The Langelier Index is defined as the pH of the saturation minus the pH of the water. If the result of this calculation is positive, the water will likely coat the pipe; if negative, the water will attack or corrode the pipe material.

It is common practice in water operations to add lime or some other material to adjust the Langelier Index to neutral or slightly to the positive side to decrease the corrosion of the pipe material.

Calcium Carbonate Precipitation Index Potential (CCPP)

The CCPP index is used for evaluation the water quality goals that are necessary to provide corrosion-control protection through the formation of calcium carbonate films. The CCPP refers to a theoretical quantity of calcium carbonate that can be precipitated from waters that are supersaturated. CCPP can be determined graphically through the use of Caldwell-Lawrence diagrams and analytically through equilibrium equations or by computer analysis. A treated water CCPP of 4 to 10 mg/l (as $CaCo_3$) is typically required to promote formation of protective calcium carbonate deposits. When applying this corrosion index as a surrogate measure of corrosion-control performance, it is important that the application be supported by additional information, such as distribution system monitoring, in-situ coupon testing, bench-scale studies, and inspection of pipe materials removed from the distribution system during routine maintenance and repair.

TREATMENT ALTERNATIVES

Corrosion of water conduits can cause great economic loss. As a result, several methods have been developed to slow or prevent corrosion. The methods include pH adjustment, use of chemical inhibitors, electrochemical measures, and designing the system so that conditions that encourage corrosion are avoided.

pH Adjustment

The goal of pH adjustment is to form a protective layer on the pipe. This is usually the first method attempted to achieve a positive Langelier Index. In addition to affecting the carbonate system, pH is the key variable in the solubility of pipe materials such as lead, copper, and zinc. pH adjustment can play a major role in the stabilizing of a pipe material.

Water treatment practices used to adjust pH and achieve a positive Langelier Index have typically involved the addition of calcium oxide or calcium hydroxide. These chemicals increase the alkalinity of the water, which then tends to decrease the solubility of the corrosion products. In waters of high alkalinity, however, it becomes more difficult to adjust the pH to above 8 because of the more rapid precipitation of calcium carbonate in the distribution system. This reaction could cause the plugging of the pipe over a period of time.

Addition of Zinc Orthophosphate

Dehydrated sodium phosphate has been used to control corrosion in industrial waters since the 1930s. The use of zinc orthophosphate as a corrosion inhibitor in drinking water is more recent. It is thought that the zinc orthophosphate acts by forming a finely divided colloid in the water that deposits a thin film of insoluble zinc orthophosphate on the surface of the pipe.

A number of utilities have employed zinc orthophosphate successfully at a feed rate of about 0.5 mg/l along with a pH adjustment to 7.0. This has usually resulted in a decrease in the corrosion rate.

Addition of Polyphosphates

The polyphosphates group includes a variety of compounds such as pyrophosphate, metaphosphate, and tripolyphosphate blends. The structure of this group of compounds tends to be indeterminate because of the possibility of conversion of one form to another.

A certain amount of controversy has surrounded the use of polyphosphates for corrosion inhibition. It has been established that polyphosphate can be effective in sequestering (holding in solution) iron and manganese to prevent red water complaints. The conditions under which polyphosphate actually inhibit the corrosion appear to be limited. The mechanism that prevents the corrosion appears to be deposition of polyphosphate films on the pipe materials, preventing the corrosive water from coming in contact with the pipe.

Polyphosphates are ineffective in stagnant waters. Protection increases with turbulence. Studies have shown that higher velocities tend to help in corrosion control. As a result, the use of polyphosphates appears to be most beneficial in controlled situations with flowing water, low pH, and use of high polyphosphate doses, as may be the case for industrial use.

Polyphosphates may be effective only with certain types of water. In some cases the use of polyphosphates in natural water may actually accelerate the corrosion. Another problem with the use of polyphosphates is that they tend to revert to orthophosphates when stored.

Addition of Ortho-polyphosphate Blends

Ortho-polyphosphate blends are being produced specifically to use in water systems when an orthophosphate inhibitor is a viable corrosion-control approach and a polyphosphate is also required to meet other treatment objectives, such as the control red water discoloration from iron. Blended ortho-polyphosphates have the potential to provide corrosion control, finished-water stabilization, and distribution system protection. Testing for both orthophosphates and polyphosphates in the distribution system will assist in determining the correct inhibitor dosage.

Silicate Addition

Use of silicate like polyphosphates to prevent corrosion tends to work for some waters and not for others. The protective mechanism is the formation of colloidal solids that tend to coat the inside of the pipe, isolating the pipe from the corrosive water.

The degree of effectiveness of silicates as corrosion inhibitors depends on the water. Tests indicate that pH controls the silicate dose required for control, with higher dosages needed at a pH lower than 8.5. The concentrations of calcium, magnesium, chloride, and other materials affects the optimal dosage. The presence of calcium may decrease the corrosion while magnesium tends to aggravate it.

Silicates may be the best corrosion inhibitor for copper and galvanized pipe in domestic hot water, especially in recirculating systems used in some commercial buildings. When added at too low a dosage, silicates may actually intensify the corrosion rate while overdosage can affect the taste of the water and cause discoloration of food.