

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, decay can cause the pipe to fail in as soon 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, the most commonly used materials used in water systems were terra-cotta, wood, lead, and cast iron. Today, piping materials are more likely to be ductile iron, asbestos cement, copper, steel, galvanized iron, and plastic piping such as high density polyethylene (HDPE), and polyvinyl chloride (PVC).

Cast iron watermains have been in continuous service for more than 100 years. Ductile iron, which is used in newer installations, contains alloys of several metals, which tends to reduce 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 1950s. 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.

EXTERNAL CORROSION

The best indication that the outside of a pipe will corrode is soil resistivity, which can be measured with the four-point meter (measures the average resistivity of soil at the pipeline). Some water systems use soil resistivity to determine the type of pipe to install.

If soils resistivity is greater than 5,000 ohms/cm (measure of electrical resistance per centimeter), serious corrosion is unlikely, and ductile iron or steel pipe could be used. If resistivity is less than 500 ohms/cm, the potential for corrosion is greater. In these cases, non-metallic pipe such as asbestos cement, HDPE, or PVC piping should be used. Ductile iron, if used in soil with low resistivity, should be wrapped to prevent contact with the soil.



Corrosion reactions are electrochemical in nature. With external corrosion, electrochemical current paths do not reach inside surfaces of the pipe and result in galvanic corrosion electrolysis; therefore it is important to have cathodic protection.

Electrolysis is the decomposition of a substance by passage of an exterior source of direct electrical current (DC). When a DC current flows from a metal to soil, most metals will corrode. Alternating current (AC) electrolysis also corrodes metals, but the effect is considered to be only one percent of what would be caused by the same flow of direct current.

Methods to protect pipes from external corrosion include:

Wrapping

Encasing pipe in a plastic wrap to prevent contact with soil is used extensively with ductile iron pipe. In addition, pipe can be bedded in material other than the normal backfill found on the construction site. Both 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 has also been used with some success on water piping.

Pipe Replacement

Piping material resistant to corrosion, such as asbestos cement (mixture of cement and asbestos), was used for pipe replacement. Disadvantages of this material are its tendency to increase loss of water that seeps through the pipe and its brittleness. Plastic pipe was introduced in the 1960s, and 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

The property of the water passing through the piping system greatly affects the corrosion rate of the material. Water properties that affect corrosion include the concentration of dissolved oxygen, temperature, velocity of the water, chlorine residual, and concentration of 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 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 water, the character of any scales formed on the metal, and the nature of 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 (critical velocity is 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 and 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.



COPPER CORROSION

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

General Corrosion

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. Water that is soft (less than 60 milligrams per liter (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.

Impingement

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.

Pitting

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.



Water Quality

As mentioned earlier, dissolved oxygen is an important factor influencing corrosion. In Minnesota, a large number of water systems using groundwater have faced a copper corrosion problem due to high dissolved oxygen content in finished water, resulting from aeration as part of iron and manganese filtration.

Copper corrosion can also be contributed to ammonia found in groundwater. When a significant amount of ammonia is present, breakpoint chlorination or optimal chloramination may not be feasible. As a result, free (or unreacted) ammonia may end up in the distribution system, and under certain conditions, cause nitrification and localized corrosion.

LEAD CORROSION

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 intellectual disability, 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 pH and temperature of water. The solubility of lead increases dramatically with a low pH and high temperature. pH of 8 and below causes a rapid increase in lead corrosion by-products, and solubility doubles with each 1 unit drop of pH.

In many systems, 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 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.



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 their 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

The most commonly used corrosion indexes are the Langelier Index and the Calcium Carbonate Precipitation Potential Index. These indexes use calcium carbonate saturation to predict the tendency of water to be corrosive.

Langelier Index

The most common relationship used in the water industry is the Langelier Index (LI) or the calcium carbonate saturation index. Achieving calcium carbonate saturation is 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 Langelier Index is the relationship of pH of saturation and pH of the water in the system, and is defined as pH of the saturation minus pH of the water. If the LI is positive, the water will likely coat the pipe, and if negative, the water will attack or corrode the pipe material.

It is common practice 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 Potential Index

The Calcium Carbonate Precipitation Index Potential (CCPP) Index is used to provide corrosion-control protection through the formation of calcium carbonate films. CCPP refers to a theoretical quantity of calcium carbonate that can be precipitated from waters that are supersaturated.

CCPP can be determined graphically using Caldwell-Lawrence diagrams, and analytically through equilibrium equations or by computer analysis. A finished water CCPP of 4-10 mg/l (as CaCO₃) is typically required to form protective calcium carbonate deposits.

When using this corrosion index as a measure of corrosion-control performance, it must 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.



CORROSION CONTROL

Corrosion of water piping can cause great economic loss, and several methods have been developed to slow or prevent corrosion. These methods include pH adjustment, chemical inhibitors, electrochemical measures, and designing the system so 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.

Calcium oxide and calcium hydroxide increase the alkalinity of the water, which then tends to decrease the solubility of the corrosion products. In high alkalinity waters, it becomes more difficult to adjust pH to above 8 because of more rapid precipitation of calcium carbonate in the distribution system. This reaction could cause the plugging of the pipe over a period of time.

Orthophosphate Addition

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 successfully used zinc orthophosphate at a feed rate of about 0.5 mg/l along with a pH adjustment to 7.

Polyphosphate Addition

The polyphosphates group includes a variety of compounds such as pyrophosphate, metaphosphate, and tripolyphosphate blends. These compounds tend to convert from one form of polyphosphate to another.

A certain amount of controversy has surrounded the use of polyphosphates for corrosion inhibition. 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 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, since protection increases with turbulence. Studies have shown that higher velocities tend to help polyphosphates improve 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. Polyphosphates also tend to revert to orthophosphates when stored.

Blended Ortho-polyphosphate Addition

Ortho-polyphosphate is produced specifically for water systems where an orthophosphate inhibitor can control corrosion and a polyphosphate is needed 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 determines the correct dosage.

Silicate Addition

Silicates form 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. Concentrations of calcium, magnesium, chloride, and other materials affect 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.