Controlling Corrosion
Preventing corrosion in WWTPs with cathodic protection

It is estimated that more than $30 billion in corrosion damage occurs in water and wastewater handling systems each year. Much of that estimated dollar amount is due to corrosion damage that occurs in wastewater treatment plants (WWTPs).

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PROBLEMSOLVER

By Laura Bauer & Frederick Frank
These plants process some of the most aggressive and corrosive liquids to travel through any piping system, and the resulting corrosion remains an ongoing problem. The industry has spent, and will continue to spend, millions of dollars on a wide range of corrosion measures.

One of the proven technologies for controlling corrosion is cathodic protection. Although used in numerous applications in WWTPs, there are still many untapped opportunities to apply this technology. Plants using cathodic protection are able to reduce the economic impact of corrosion. The following discussion will focus on the basic applications of cathodic protection in WWTPs and its economic value.

**What is Corrosion?**

Corrosion is defined as the degradation and destruction of a metal by its chemical reaction with the environment. Corrosion reactions, with the exception of some forms of high-temperature corrosion, are electrochemical oxidation/reduction reactions. Figure 1 shows a typical corrosion cell that is formed when small variations in potential occur over the metal’s surface. The corrosion is caused by differences in the shape of things to come.

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Figure 1. A typical corrosion cell, resulting from a metal’s chemical reaction with its environment.

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Cathodic Protection

Cathodic protection is one option for controlling corrosion. In the typical corrosion cell, the metal structure has both anodic (area where the metal is lost) and cathodic (area with no metal loss) regions resulting from electrical potential differences. Even small differences in potential can result in significant metal loss over time. Cathodic protection is accomplished by intentionally substituting the slightly anodic region of the structure with an even more anodic component called an anode.

The anode is intentionally coupled with the protected structure. In a galvanic system, current results from the inherent potential differences between the anode and the cathode. An impressed system, on the other hand, uses a DC power supply. As long as sufficient protective current is maintained, an impressed system can eliminate further corrosion.

Figure 2. A galvanic anode system requires careful selection of the anode material in order to prevent corrosion. There is little room for design error.
Galvanic Systems

The simplest system is the galvanic anode system, as illustrated in Figure 2. With a galvanic system, the potential difference results entirely from the electrical characteristics of the anode versus the structure to be protected. Although this type of system will protect the entire surface, it is important that the correct anode be selected. Some common galvanic anode materials are magnesium, zinc, and aluminum.

Anodes are available in standard sizes weighing from 1 to 48 lb. For example, the 17-lb magnesium prepackaged anode, approximately 30 in. long with a 6-in. diameter, is the most commonly specified anode for many pipeline system applications. The package consists of a solid bar of magnesium alloy connected to an electrical lead that protrudes from a bag filled with a mixture of bentonite and gypsum.

The bentonite and gypsum provide an environment that absorbs and retains moisture while assuring a uniform low resistance around the anode. Prior to installation, the bag is thoroughly wetted and the lead is either welded or mechanically connected to the structure to be protected. Typically, multiple galvanic anodes are strategically located across the entire structure.

Although galvanic systems can be inexpensive, there is little margin for design error. The natural voltage differences are relatively small and fixed. Galvanic systems also do not allow for increased current output when operating conditions or the environment change.

For buried magnesium anodes, the electrical potential between the anode and carbon steel is a nominal -0.85V. The current output is a function of Ohm’s Law (E=IR) and is thus dependent on the resistance of the system.

Spacing, quantity and location of the anodes must be determined during the design process. The rate of consumption of the anodes can be calculated and its design life reasonably predicted.
Sacrificial anodes must be replaced on a regular basis to maintain system performance. Generally, buried or submerged anodes are not removed at the end of their useful life; new anodes are added to the system to maintain the required protection.

**Impressed Current System**

The impressed current system, in contrast to the galvanic system, does not rely on the potential differences between the anode and the structure to be cathodically protected. Instead, an external power source, typically a rectifier converting electric power from AC to DC, is used. This creates a potential difference and helps to transmit the current from the anode through the electrolyte and onto the surface being protected, as shown in Figure 3.

Because the system uses a rectifier to provide the necessary current, the current can be regulated to provide optimum protection. It can also be adapted to changes in the structure, operating conditions or the environment. When this type of system is used, the number of anodes required can be significantly reduced. A single anode is able to transfer more current over greater distances.

Anode materials are selected based on how fast they are consumed—not on their inherent potential difference with the structure to be protected. Many anode materials can be used in impressed current systems, including graphite, high-silicon cast iron, platinum alloys and mixed-metal oxides. The latter two have very low consumption rates, and for this reason they are coated in thin layers onto a substrate of titanium or niobium, giving the active element an inert but conducting base. With consumption rates of milligrams per amp year, impressed current anodes can be designed for long life.

Reference cells tied back to a control loop on the rectifier can be used to regulate the current output of the system. This is required when conditions change or where excessive current must be limited to prevent damage to the system. When designing impressed current systems, the design engineer must take into consideration control points, test stations, instrumentation and other operational and maintenance tools.
WWTP Applications

WWTPs are made up of concrete and metal. As concrete and metal are both subject to corrosion, there are several applications within WWTPs where cathodic protection can be utilized, including reinforced concrete; piping or transfer lines; tanks; waste sludge lines; overflow lines; chill water or closed-loop systems; delivery piping; steam condensate lines; and process equipment.

Steel-in-Concrete

Reinforced concrete is used extensively throughout wastewater treatment facilities in piping, tanks and holding basins. It has a high compressive strength but very limited tensile strength. To increase tensile strength, steel rebar is added to concrete, thus making it an excellent building material. However, the steel rebar also allows the reinforced concrete to be susceptible to corrosion.

Concrete has high alkalinity but over time, contaminants (e.g., chlorides and sulphates) will leech into the material and lower concrete’s normal pH level of 13. When pH drops below 11.5, a natural current will flow through the steel and begin the corrosion cell. When the corrosion cell occurs, the anodic area will oxidize and form rust. As rust accumulates on the surface of the rebar, it will expand the volume of the steel, putting tensile stress on the concrete until it fails (cracking and spalling). Once started, the corrosion process will continue exponentially. Reinforced concrete can be protected only by using coatings and impressed current cathodic protections systems.

Piping

Steel piping within a plant is susceptible to corrosion on both external surfaces (corrosive soil) and internal surfaces (corrosive water). Of the several causes of corrosion, the two most common are galvanic and oxygen-concentration cells. Galvanic corrosion occurs when two metals with different potential are in contact with one another through an electrolyte. The difference in potential causes a natural corrosion cell to occur. Oxygen-concentration cells can result from varied oxygen concentrations in water. Because a WWTP is a closed system, oxygen is unable to disperse evenly along the pipes’ interior surfaces, causing areas of high and low concentrations. This creates an electrical potential between the areas of concentration. Corrosion will occur where there is a low concentration of oxygen (anodic area).

Most steel pipes are coated to protect against corrosion, but due to the highly corrosive nature of wastewater, the coatings will develop small pinholes, cracks and holidays over time. This is when most of the corrosion takes place. Applying a cathodic protection system to the pipes will stop further corrosion.

Tanks

Protecting tanks from corrosion is not only recommended for economic purposes but it is also extremely important for preserving the environment. Today, cathodic protection for new tanks is becoming increasingly common; however, older tanks can be retrofitted with cathodic protection. Corrosion in tanks may occur both externally and internally. External corrosion will occur on the tank bottom, where the steel is exposed to contact with the soil.
Internal coated steel surfaces in water storage tanks can be protected by cathodic protection as well. Whether containing raw water, potable water, drinking water or wastewater, the storage tank is subject to internal corrosion. Anodes can be suspended from the roof of the tank to protect the side walls and bottom.

**Operation & Maintenance**

Cathodic protection systems prevent corrosion of the protected structure only when they function properly. As a result, their design should incorporate sufficient test stations and reference cells to allow plant staff to confirm that the system is operating as intended.

Systems should be thoroughly tested on an annual basis by a National Association of Corrosion Engineers (NACE)-certified specialist. For galvanic systems, testing is done to confirm that the protected structure is polarized properly. In addition, taking potential readings and measuring instant on/off voltages in accordance to NACE standards can confirm that the proper protective current is being supplied. Impressed current systems also require similar performance testing. The rectifiers supplying the power should be checked on a regular basis, and reference cell voltage readings should be taken and compared to the initial baseline readings.

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Economic Considerations

Most WWTPs were originally designed to have a useful life of 25 to 50 years, depending on geography and other conditions. Today, consideration of indefinite useful life and how that can be achieved is being discussed aggressively. Protecting your plant from corrosion may be one of the first steps in achieving an indefinite life.

Before installing a cathodic protection system, an economic evaluation should be conducted weighing the upfront costs of cathodic protection versus the cost associated with the failure of WWTP equipment due to corrosion. Even though the cost of providing cathodic protection is relatively low and easily defined, the cost of WWTP equipment failures resulting from corrosion are more difficult to quantify.

Besides the cost of repairing equipment damaged by corrosion, there are often consequential costs from equipment failures. These can include environmental costs in the event of an underground pipeline or above-ground storage tank failure, lost production from a condenser failure, or equipment failure costs resulting from corrosion failure or safety-related issues.

Corrosion at WWTPs gets very little attention from high-power managers and policymakers, although the individuals who operate and maintain the plants are acutely aware of corrosion problems. In the industry, there have been a number of large corrosion-related failures within WWTPs. These failures have been traced to corrosion and deterioration of concrete and are expected to cost billions of unplanned rehab and replacement dollars. Each year, corrosion damages cause an enormous burden on companies, societies, and taxpayers all over the world.
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On a positive note, plant designers, owners and operators have an arsenal of tools for controlling corrosion. If properly selected and used, these tools can result in significant savings over the long term.

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