

# Material Matters

## Electrochemical Methods to Prevent Pump Corrosion

**Stephen J. Morrow**

Global Manager of Materials Technology  
ITT Industrial Pump Group

### Question:

**What's the difference between anodic and cathodic protection? How do these methods work to reduce corrosion of pumps and other equipment?**

### Introduction

Electrochemical protection methods offer economic opportunities in the struggle to overcome corrosion. Most metals exposed to a corrosive liquid environment can be protected from corrosion by using electrochemical techniques such as anodic protection (AP) or cathodic protection (CP). These methods can eliminate or minimize pump corrosion, reduce replacement costs and equipment weight, and allow for the use of less costly materials.

Three electrochemical technologies are primarily used:

- Galvanic (*sacrificial anode*) cathodic protection
- Impressed current (*potential controlled*) cathodic protection, and
- Impressed current (*potential controlled*) anodic protection

Anodic and cathodic protection are often confused, but the two techniques have fundamental differences. These differences concern which electrode is protected; the cathode is protected with CP, while AP provides protection to the anode. Selecting the proper method depends mainly on the metals involved and the service pumpage. Cathodic protection is widely used, and can be applied to most metals. Anodic protection however, is limited to passivating metals only, and mostly used in the chemical or process industries.

### Some Corrosion Basics

The electrode of an electrolytic or corrosion cell at which oxidation occurs is called the **anode**. Electrons flow away from anodes. The term **anode** is also used to describe that part of a metal surface or electrode where corrosion occurs and from which (positive) current and metal ions leaves the metal to enter the surrounding environment.

The electrode of an electrolytic or corrosion cell at which reduction occurs is called the **cathode**. Electrons flow toward, and are consumed at the cathode. The term **cathode** is also used to describe that portion of a metal surface where current flows from the surrounding environment into the metal and where corrosion does not occur.

Fundamentally, corrosion is an electrochemical oxidation-reduction reaction. Direct current flows from the anode areas through the electrolyte (conductive liquid) to the cathode regions, and back through the pump metallic path to complete the circuit.

### Principles of Protection

Since corrosion results from a flow of current between anodic and cathodic surfaces, it is possible to reduce pump corrosion by controlling that current. The objective of electrochemical prevention techniques is to reduce the current density, or suppress the current flowing from the anode surfaces. When the current flowing between anode and

cathode areas on a corroding pump surface is lowered, the pump corrodes more slowly.

By using galvanic or external protection circuits, we can place an electrical current on the metal to control the rate of corrosion. Under some conditions we can apply an opposing current to stop corrosion (CP) or, we can adjust the metal's potential so the metal still corrodes, but more slowly when in a passive condition (AP). Both techniques may be visualized by examining the diagram shown in **Figure 1**. This diagram shows the regions of immunity (no corrosion), active corrosion (shaded area), and passivation as related to the metals potential ( $E_H$ ) and solution pH.

Most metals corrode within a certain electrical potential and solution pH range. At more negative potentials, we enter the immunity (no corrosion) region and corrosion ceases (CP). At more positive potentials, some metals passivate and corrosion current is reduced (AP), as shown in **Figure 2**.

Notice that corrosion is unlikely at a given pH if the pump metal potential is maintained in its immunity zone. Likewise, if an actively corroding metal's electrical potential is shifted towards the immunity direction - as with CP - then corrosion is preventable.

Similarly, the corrosion potential of metals exhibiting active-passive behavior, such as Type 316 stainless, can be shifted towards the passivation direction to maintain its protective

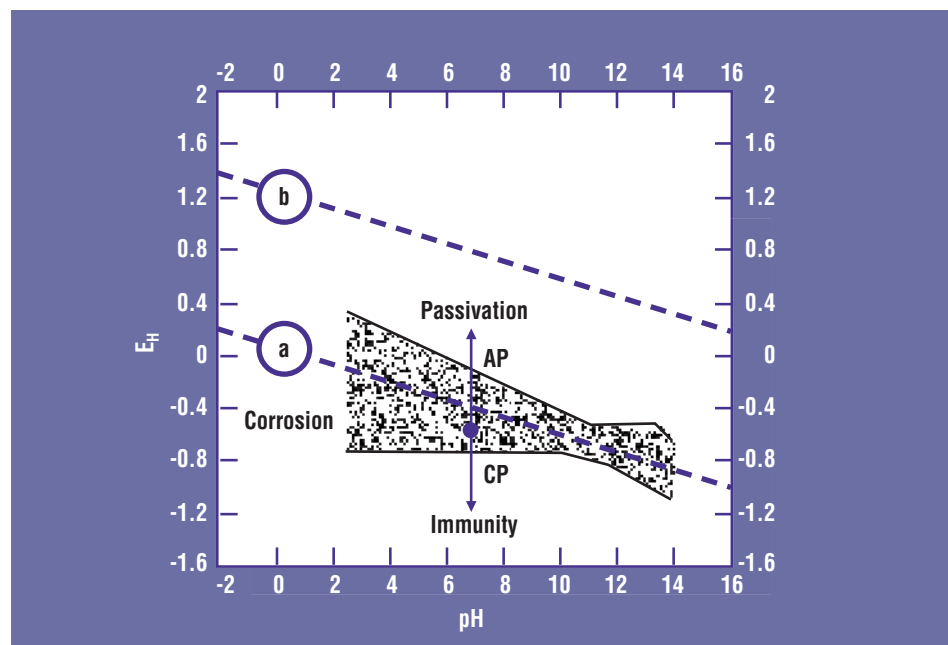


Fig. 1.  $E_H$  - pH diagram for iron in water.

# Material Matters

surface - as with AP - resulting in a large corrosion reduction.

## Anodic Protection

Anodic protection is based on the principles of passivity and refers to corrosion protection achieved by maintaining an active-passive metal in its passive potential region by an externally applied anodic current. The current is supplied by a potential-controlled power supply called a *potentiostat*, which maintains the metal at a fixed potential in the passive range. As a passive surface film forms, a significant decrease in the corrosion current density and corrosion rate is achieved.

Anodic protection can be used to form the passive film on metals in chemical systems that would normally be corrosive. At other times, anodic protection can be used to maintain passivity of a metal so that process upset conditions or process changes do not force the metal to become active and corrode. It is important to emphasize that anodic protection can only be applied to metals that passivate, (e.g., steel, stainless steel, nickel and titanium alloys).

Furthermore, AP can only be applied in certain chemical environments, since pumpage (electrolyte) composition influences passivity. In addition, the corrosion rate of a non-passivating metal will be greatly accelerated if its potential is increased in the electropositive direction, therefore anodic protection techniques should be used with caution.

Anodic protection has been most extensively applied to protect equipment used in the chemical, pulp and paper, and the fertilizer industries. AP has been successfully used to reduce the corrosion rate of steel and 300 series stainless steel in such media as sulfuric acid, phosphoric acid, sodium hydroxide, caustic craft liquors, and corrosive salts such as aluminum sulfate and ammonium nitrate.

Any situation in which a metal/solution combination produces active-passive behavior is a candidate for AP if a corrosion problem develops.

## Cathodic Protection

Before cathodic protection is applied, corroding metal structures have both cathodic areas and anodic areas. CP is based on eliminating corroding anodic areas by making the entire metal surface cathodic through means of impressing a direct current or attachment to galvanic sacrificial anodes. The objective is to make the entire surface exposed to the liquid act as a cathode and collect current, resulting in elimination of the current-discharging anode areas, while directing the anode reactions onto an external electrode (anode).

There are two main types of cathodic protection systems - galvanic sacrificial anode, or passive systems; and impressed-current, or active systems. Galvanic systems are simpler, requiring only a material more anodic to the metal being protected. Both types are widely used.

## Galvanic Sacrificial Anode Systems

A sacrificial anode can be described as any metal that provides an anodic voltage difference with respect to the metal structure being protected, which will discharge (positive) current that flows through the environment to that structure. The voltage differences between anode and cathode are limited in a galvanic system to approximately 1 Volt or less, depending upon the materials coupled and the specific environment.

In galvanic CP systems, alloys of a more-active metal (e.g., magnesium, zinc, or aluminum), are placed in contact with the corrosive environment and electrically connected to the pump or structure to be protected. While galvanic coupling is generally to be avoided in pump design, it can be used to advantage as a corrosion control method. As the galvanic sacrificial anodes preferentially corrode they provide protection to the pump.

Galvanic protection is often used when the current requirements are low, and the pumpage (electrolyte) has relatively high conductivity. Larger voltages are generally required in low conductivity environments, such as fresh water, where sacrificial anodes would have insufficient throwing power to provide adequate protection.

*continued on page 10*

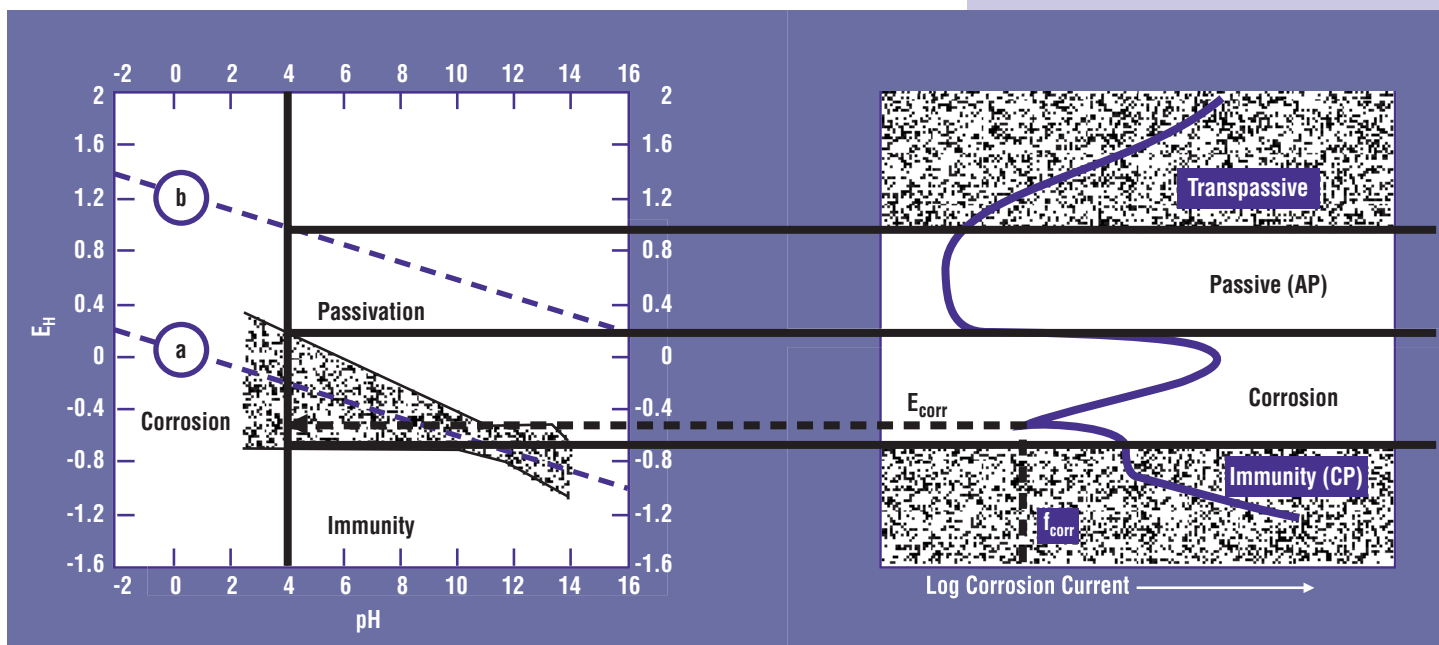


Fig. 2.  $E_H$  and pH diagram in conjunction with an AP polarization curve.

# Material Matters

## Electrochemical...

continued from page 9

### Impressed Current Systems

With impressed-current CP systems, the anodes are not relied upon as an electrical energy source. In these systems, an external source of direct current is connected between the protected metal structure and the system's working electrode (anode). This anode may be an inert material, noble metal, or alloy that corrodes requiring periodic replacement. Impressed-current systems can generate much larger voltages and allow for remote anode placements, which produces a more efficient current distribution across the protected surfaces.

It should be noticed that applying CP does not really eliminate corrosion; instead, corrosion is transferred from the pump or protected surface, to a working electrode (anode) surface designed to discharge the CP current. Simply stated, impressed current cathodic protection is the transfer of direct current into a metal at an equal or greater rate than it flowed out of the metal as it corroded. The greater the rate of corrosion, the more current is needed to stop it and provide protection.

Unlike galvanic anodes, impressed current anodes do not have to be naturally anodic to the metal protected. The direct current power source alters the normal polarity and allows the working electrode to act like an anode. Since the material used as the impressed current working electrode is an anode by definition, material corrosion must occur, or else, as in the case of inert or noble materials, some other oxidation reaction occurs.

Impressed-current systems excel when current requirements and electrolyte resistivity are high. They require a relatively inexpensive source of electrical power (rectifiers and solar cells are common power sources), are well suited to long-time operation, and are better suited for large pump structures. Because of anode consumption, cathodic protection systems have a finite life. However, impressed-current systems usually have a long life compared to galvanic systems because of the slow consumption of the anodes. When the anodes are consumed, they can be replaced and the effective protection of the structure can continue.

The positive terminal of the power source must always be connected to the working electrode (anode), which can then discharge as much cathodic protection current as is needed. It's important to remember that the anodes are forced to discharge current and corrode. If a mistake is made and the positive terminal is connected to the pump, it will become the anode instead of a cathode and will actively corrode. Regardless of the sign convention used, the important thing is to remember that electrons must flow into the structure to provide protection.

### Final Comments

The main advantages of anodic protection are: lower current requirements and operating costs; large reductions in corrosion rates; its applicability to aggressive strong, hot acids and other corrosive media; and ease of design.

Anodic protection is used to a lesser degree because of its limitations to specific metal-chemical systems. In addition, it is possible to accelerate corrosion of equipment if proper controls are not employed. The understanding of anodic protection is also not as widespread.

A very important caution with respect to anodic protection is that if the anodic protection current (power source) fails for some reason, the corrosive environment could rapidly attack the equipment being protected. Also, the ability to accurately maintain the desired potential over the entire structure is very critical. Increasing protection to higher positive potentials (overprotection) can cause a shift into the "transpassive" range, resulting in passive film breakdown and increased corrosion.

The main differences favoring cathodic protection are: its applicability to all metals, not just those that show passivity; in some instances it can be used where there is no source of electrical power by using galvanic sacrificial anodes; and the method is well established and better known.

Major problems associated with cathodic protection are related to the chemical reactions occurring at the surface of the protected structure. For example, if the cathodic reaction is hydrogen reduction, the resulting hydrogen may have a deleterious effect if absorbed. It can cause blistering of certain metals, cause peeling of coated structures, or enter the metal and cause cracking (hydrogen embrittlement or stress cracking) if the structure is under stress. These associated problems are more apparent when the system is overprotected. ■

### Selected References:

1. Joram Lichtenstein, "Cathodic Protection Principles," *Materials Performance*, January 2002, NACE International, Houston, TX, p 66-67
2. Joram Lichtenstein, "Corrosion Prevention by Electrochemical Methods," *Materials Performance*, November 2001, NACE International, Houston, TX, p 51
3. James Ian Munro and Winston W. Shim, "Anodic Protection - Its Operation and Applications," *Materials Performance*, May 2001, NACE International, Houston, TX, p 22-252.
4. "Corrosion Protection Methods for the Petrochemical Industry," *Corrosion in the Petrochemical Industry*, ASM International, Metals Park, OH, 1994, p 77-88
5. "Methods of Corrosion Control," NACE International Basic Corrosion Course-Student manual, Chapter 6, NACE International, Houston, TX, 1996 p 6:33-6:48
6. "Cathodic and Anodic Protection for Corrosion Control," *Corrosion Causes And Control, Fundamentals of Corrosion Part 8*, (Series of articles reprinted from *Chemical Engineering Magazine*, May 17, 1971 through April 3, 1972), Carpenter Technology Corporation, Reading, PA, p 41-47

