

Corrosion control for ASTs: Part 2 - Testing Your Cathodic Protection System

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An earlier article (“Corrosion Control for Aboveground Storage Tanks—Part 1: Causes and Controls,” Nov. 1999, p. 32) discussed basic causes of corrosion and the types of systems for controlling corrosion. This article will discuss the procedures for measuring the effectiveness of impressed-current cathodic protection systems on aboveground tank bottoms and identify common data collection and evaluation errors.

As discussed in my November 1999 PE&T article, metals have an internal energy level created in the refining process. This energy can be measured as a voltage or “potential.” The more work required to refine the metal, the more negative the measured voltage. This potential can be measured by placing the metal into a conductive environment along with a reference cell, then measuring the voltage difference between the two metals. The potentials of common metals are shown in Table 1. Values for steel vary because of differences in steel’s structure and the manufacturing process. The condition of the steel (i.e., new or corroded) also affects the value.

Table 1:
Potentials for common metals

Magnesium	- 1.75 volts
Zinc	- 1.10 volts
Steel	- 0.40 to - 0.60 volts
Copper	- 0.20 volts
Carbon	+ 0.30 volts
Silver	+ 0.80 volts
Platinum	+ 1.20 volts
Gold	+ 1.60 volts

Cathodic protection is applied to a steel structure by providing small amounts of direct electrical current onto the structure. Chemically, this forms a film of negatively-charged ions on the surface of the steel. This is generally known as polarization. The formation of the film can be detected by measuring the soil-to-structure potential with a DC voltmeter and a reference cell. The formation negatively shifts the natural potential of the metal.

The polarized potential can be compared to the original unprotected or native potential to determine

the effectiveness of the cathodic protection on that structure. This makes cathodic protection the easiest form of corrosion control to monitor and maintain.



Figure 1:
Copper/copper sulfate reference cell

Cathodic protection monitoring

In evaluating a cathodic-protection system applied to an aboveground storage tank, the soil-to-structure potentials must be measured at various points around and, if possible, under the tank. These measurements are collected using a high impedance voltmeter and a reference electrode. The most common reference electrode is a copper/copper sulfate reference cell (see Figure 1). This cell consists of a bar of copper immersed in a copper/sulfate solution. The cell has a porous ceramic tip, allowing for electrical continuity between the liquid environment in the cell and the soil.

The potential measurement is made by placing the tip of the cell in the soil, connecting the common (usually black) lead of the voltmeter to the cell, then connecting the positive (usually red) lead to the structure (see Figure 2). The value displayed is an average potential for the surface area of the continuous system in the immediate vicinity of the cell. This average reading may include a portion of the anode potential if the cell is placed between the tank and the anode. If the reading is collected while the cathodic protection system is operating, this reading is called the “on” or “with-the-current applied” potential. In large aboveground tank systems, this reading normally includes a significant error caused by the current flowing through the soil and the effect on the average by the anode potential. This error is called IR drop.

Industry practices call for compensation for this error when evaluating cathodic protection systems. There are various methods to correct for IR drop. The most common is to interrupt the cathodic protection current. If the current flow is zero, then the IR drop is zero. The current can only be interrupted for a short period of time so that the polarization does not decay. To control the cycle, a current interrupter is used between the tank and anodes (or rectifier) to turn the system on and off at a preset cycle. This allows measurements to be made throughout the facility. A typical setting of 27 or 30 seconds “on” to three seconds “off” applies to most soil conditions. Using a digital voltmeter, the lowest reading in the “off” cycle can be used as the interrupted measurement.



Figure 2:
Cathodic protection monitoring with the tip of the reference cell in the soil

Cathodic protection criteria

NACE International (formerly the National Association of Corrosion Engineers), in their recommended practice RP-0193-93, External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms, October 1993, provides the criteria used in evaluating cathodic protection system effectiveness. NACE documents are consensus standards developed by those involved in the practice of corrosion control. RP-0193-93 offers two basic criteria:

- -850 millivolts relative to a copper/copper sulfate reference cell (CSE) adjusted for IR drop error.
 - 100 millivolt polarization, or negative shift in the potential from the native or depolarized potentials.
- This criterion compares the “off” potential to the potential measured prior to application of cathodic protection.

Typical potential values and criteria are shown in Figure 3. These acceptable levels were established based on empirical data, i.e., years of field results collected within the industry.



**Figure 3:
Typical potential values and criteria for
evaluating cathodic protection systems**

The application of the first criteria is rather simple and is the most commonly used. The second criteria requires more testing. To determine the polarization level, accurate “native” potential data (the reading before the cathodic-protection system is applied) must be available. Measurements used to evaluate the cathodic protection must be collected with a reference cell in the same location as the original native potential measurement. If the native potential data is not available, the cathodic protection system must be turned off and the structure allowed to depolarize. The depolarized measurements can be considered equivalent to native potentials. It is important that the reference cell locations are consistent.

Depolarization time varies depending on site conditions. At times, most of the depolarization takes place in a few hours; at other times, it may take days. By collecting periodic readings at a defined location, the potential can be tracked to ensure that the structures are depolarized and that the values measured are stable enough to allow measurement at various points without continued change. It is important to collect repeatable data.

Once the depolarized values are collected, they can be compared against the interrupted or “instant off” potential to determine if 100 millivolts of polarization have been achieved. The system is then turned back on and, after a few days, a brief resurvey should be performed to ensure the system repolarized to the previous levels.

Common monitoring errors

Common errors in monitoring and collecting data on cathodic protection systems include the following:

IR drop

This error is caused by current flowing through the soil from the anodes to the structure or other points and by the contribution of the anode potential to the average measured value. As discussed previously, this error can be corrected by interrupting the current source. There are times when interruption may be impractical or impossible due to the site configuration and the number of current sources.

One method to reduce IR drop error is by placing the cell as close to the structure as possible without

touching it. This practice, however, localizes the measurement and is more common for pipeline applications. In this practice, cell placement is critical. Data must be collected at the anticipated points of least protection on the structure based upon site conditions, system configuration and field measurement.

Another option is to use corrosion monitoring probes under the tank. This allows for direct measurement of the corrosion rate of the tank bottom in mils (thousandths of an inch) per year. It can be used to determine system effectiveness without a potential reading. Various types and sizes of corrosion probes are available. Some probe configurations allow interruption of the current to the exposed probe for measuring IR drop values without interrupting the cathodic protection system from the tank. Again, the information provided is localized, meaning that it only applies to a specific point under a tank. Some investigation must be carried out to ensure that measurements are collected at the “worst-case” location.

Cell placement

Too many tank owners still rely on measurements collected at the perimeter of a tank to determine the effectiveness of the protection over the entire floor. Many assume that inflating the minimum reading at the perimeter ensures the tank is protected all the way across. This assumption is incorrect. With a good understanding of the system and a wealth of experience, some prediction can be made, but only by measuring the interrupted potentials at the center can a true evaluation be made.

Product level

Typical aboveground storage tank bottoms bow or lift off the tank foundation in areas when the tank is empty. This deflection in the steel plates results in a reduced surface area in direct contact with the soil. An empty tank will require less current to provide protection because less of the tank bottom is in contact with the soil. When the tank is full, the entire tank floor is in contact with the soil, and the protection levels are at the lowest. Evaluations made when the tank has less than five feet of product include errors due to the reduced surface area being measured. Always record the product level along with the potential data when surveying a tank.

Surface conditions

This error factor is created by attempting to gather potentials in or on improper surfaces. The cell should be placed in clean soil similar to, and continuous with, the tank bottom. Many tanks have a perimeter skirt of asphalt or concrete for erosion control. Putting the cell on top of these surfaces affects the reading, introducing an error that cannot be predicted. Other tanks may have gravel layers placed around them for erosion control. Placing the cell on dry gravel creates error. In gravel, the cell needs to be dug in to contact the soil. Any time site conditions exist that affect the survey, the conditions and the change in procedure should be noted on the record sheet to allow for proper data evaluation. For instance, note on the data sheet that the tank has an annular ring of concrete and, therefore, that the cell placement is two feet from the tank perimeter.

When evaluating cathodic protection, structure-to-soil potentials must be measured in such a way that these error factors are eliminated or at least minimized. Site details should be noted when reviewing the data. A NACE certified corrosion or cathodic protection specialist should be involved in the data review and interpretation.



Figure 4:
Cathodic protection with reference cell in slotted well screen under tank

Avoiding the errors

One way to eliminate most of the errors is to be able to collect measurements inside the perimeter of the tank. This is accomplished by either installing permanent reference electrodes under a tank or by installing a monitoring tube under the tank to allow the use of a temporary cell for field measurement. Cell placement combined with interrupted current flow allows minimal error and provides the most security in knowing that the tank bottom is protected.

New tank installations can be equipped with a slotted well screen laid horizontally under the tank as it is constructed (see Figure 4). This also is true of retrofit double-bottom tanks. Another option for new bottoms is to install permanent reference cells under the tank floor and to extend the lead wires to the perimeter of the tank for testing. If the tank is existing, horizontal-boring or directional-drilling equipment is available, which provides monitoring tube installation under an operating storage tank. The technology used for tank boring uses a different tracking technology than that used for utility drilling (see Figure 5). In typical utility-drilling applications, one can “walk” the drill to confirm or determine the head’s location. The tank system uses a computer to control and monitor the head location throughout the bore. This minimizes the risk of damaging the tank bottom.



Figure 5: Horizontal-boring equipment being used to install monitoring tube under UST

A case in point

A terminal in the southeastern United States was experiencing tank-bottom failures due to corrosion at a higher than normal rate. To reduce the corrosion problems, a cathodic protection system employing a shallow distributed anode bed was installed around the tanks. Once installed, potential measurements were collected around each of the tanks and the NACE criterion of -850 millivolts “off” at the perimeter was satisfied.

Within a year, two additional tanks failed due to external corrosion of the bottoms. Horizontal-boring equipment was used to install open slotted wells under the tanks, and measurements of the structure-to-soil potentials were collected. Measurements at the perimeter of each tank easily demonstrated compliance, while the “on” and “off” readings at the center of each tank were nearly the same at about -400 millivolts, far from the accepted criterion (see Table 2).

In an effort to resolve the low potentials, new semideep anode beds were installed around the tanks. The new anodes were at the maximum allowable depth before encountering bedrock. The deeper

anodes allowed improved current distribution. Monitoring the potentials across the tank diameter allowed the deficiency to be found and corrected.

Table 2: Measurements at one of the two failed tanks

Distance	Rim	+20	+40	+50	+60	+80	Rim
On	-810	-829	-821	-822	-811	-799	-1322
Off	-810	-833	-807	-820	-886	-721	-997

Conclusion

Why is any of this important? Effective corrosion control can extend the life of the tank floor indefinitely. The anodes of the cathodic-protection system can always be replaced at a lower cost than replacing a floor. One major oil company cited an average floor life of 25 years without corrosion control. Corrosion-control measures have doubled the anticipated floor life. This determination has been made based on data from internal inspections of protected tanks.

Not only does effective corrosion control extend the life of the tank floor, it minimizes operating costs. The most tangible evidence of the benefits of corrosion control is the decrease in the requirement for internal inspections. API 653, Tank Inspection, Repair, Alteration and Reconstruction, calls for internal inspections of tanks based on the measured corrosion rates on the tank floor. If a tank floor originally constructed of .250-inch steel has corroded to .125 inches in 10 years, the corrosion rate would require re-inspection of the tank within the next five years.

The typical cost of emptying and cleaning a tank for inspection is \$30,000 or more. This, combined with the costs of the inspection, results in a significant cost to the owner. Plus, there is lost revenue related to the tank being out of service during the inspection. If effective cathodic protection can be applied, the inspection intervals can be extended to the maximum of 20 years. This provides not only the life extension of the tank floor, but also a reduction in maintenance costs at a typical terminal.

Determining the effectiveness of cathodic protection provides useful information to a tank owner. This data is used for planning inspection and maintenance activities as well as cost budgeting. However, to be useful, the cathodic-protection evaluation must be based upon valid measurements in the field. Avoiding errors in the readings and collecting sufficient data allow for true evaluation of system performance and effective corrosion control.

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