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INSTALLATION OF AN INSTRUMENTED CATHODIC PROTECTION SYSTEM ON A LARGE DIAMETER AST

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ABSTRACT

Corrosion on tank bottoms has been a problem for storage facilities that has led to many solutions. A common practice is to use secondary containment, or double bottom tanks as a means of ensuring that any leaks in the primary bottom would not lead to environmental contamination. These systems have been installed for several years, yet there has been little in the literature to document the effectiveness of the cathodic protection (CP) systems installed in the shallow spaces between the two bottoms. This paper describes the installation of a highly instrumented CP system on a large above ground storage tank bottom and provides data demonstrating the effectiveness of the system.

INTRODUCTION

Corrosion on aboveground storage tank bottoms has been a problem for facility owners that has led to many solutions. In an attempt to slow down the corrosion process, tanks were erected on concrete or oil soaked sand. At some locations this did slow down the rate of corrosion, but failures continued to occur. One method of repair has been to weld patches to the areas that had suffered corrosion and put the tank back in service. This is a short-term fix because it only repairs the existing damage; it does not eliminate or reduce the amount of corrosion occurring on the tank bottom. Eventually, the use of cathodic protection became more prevalent. Systems were developed that had the anode material around the outer wall of the tank, or in some cases, directionally bored in order to get the anode material under the tank bottom. When it became practical to directionally bore close to tank bottoms while they were still in service, more information became available to the corrosion engineer. It now became possible to place or install reference electrodes under tanks to measure the potential that resulted from the installed cathodic protection systems. These potential readings showed that a number of tanks that had cathodic protection were not fully protected, especially toward the center. Additional current would be necessary in order to achieve the goal of meeting CP criteria over the entire tank bottom. Some evidence indicated that an anode array placed in very close proximity to the tank bottom actually provided a more uniform distribution of cathodic protection current.

Secondary containment, or double bottom tanks, came into favor as a means of ensuring that any leaks in the primary bottom would not lead to environmental contamination. In this approach, a secondary containment that also served as a dielectric barrier was installed prior to installing the tank. A layer of sand was installed between this containment and the new tank bottom. On existing tanks, the tank was opened up, and the barrier was installed on the old bottom. Clean sand filled the interstitial space, and a new tank bottom was installed above the old tank bottom. The space between the secondary containment and new floor is usually between six and eight inches (15 to 20 cm). Since the dielectric barrier would not allow a conventional cathodic protection system installed below the tank to protect the primary bottom, a separate system must be installed in the interstitial space. These systems have been installed for several years, yet there has been little in the literature to document the effectiveness of CP systems installed in such shallow spaces. This paper describes the installation of a highly instrumented CP system on a 150 foot (45 meter) diameter aboveground storage tank bottom and provides data demonstrating the effectiveness of the system.

DESIGN AND INSTALLATION

Both sacrificial and impressed current anodes have been used beneath ASTs. Sacrificial anodes are either magnesium or zinc ribbon while impressed current anodes are either platinum or mixed metal oxide surfaced titanium wire or strip. Anodes are typically placed in a geometric array. Impressed current anodes were selected for this particular tank bottom because they offer a higher degree of control of current output.

One of the variables in the design of this system is anode spacing. Proximity of the anode to the structure suggests that the anodes be closely spaced to ensure uniform coverage over the tank bottom. Placing anodes three feet (0.9 m) has been used for some tanks to attain this goal. Anecdotal evidence exists that with a five foot (1.5 m) spacing, the polarization layer would eventually cover the bottom. On this tank, the decision was made to use a five foot spacing and to closely track the development of the polarization layer after the system was energized.

A modular linear anode system was chosen. Each anode is 50 feet (15 meters) long and consists of a copper-cored titanium ribbon with a platinized surface and a parallel #14 HMW/PE shunt wire. The two wires are enclosed in a non-metallic mesh to prevent the anode from shorting to the tank bottom. The anodes have mating connectors fitted on the ends to allow individual anode lengths to be plugged together at the job site. A stepped spiral layout, as shown in Figure 1, was used because this is the most economical pattern for this style anode. Seventy-three anodes lengths and five power feeds were required for this diameter tank and anode spacing, as calculated using a spreadsheet supplied by the manufacturer.

The installation was done in May 2001. The tank was opened up, cleaned, and the process begun. A liner was installed on the old floor and the anodes were placed directly on the liner. The first anode ring was placed 2 ½ feet (3/4 meter) in from the wall. Subsequent rings were offset 5 feet (1 ½ meters) in from the previous ring as the linear anode was gradually spiraled in toward the center. A power feed was plugged on to each end using the mating connectors; three additional power feeds were similarly connected at locations equally spaced along the anode length. Since all the anodes and power feeds are part of a single circuit, this multiple redundancy means that loss of any anode or power feed still allows current to flow to the entire anode array. The anodes were covered with an eight inch (20 cm) layer of sand.

Several operational tests have been performed in a laboratory environment, but very little testing has been conducted and reported on for actual field installations. The tank owner permitted us to install additional reference electrodes to more closely monitor the development of the polarization layer. Normally, a tank of this size would require three reference electrodes: one each at the center, mid-radius and near the outer wall. On this tank, twelve permanent references were installed. Two arrays of five reference electrodes each were installed; one near the center and one near the outer ring (see Figure 1). In addition, a single reference electrode was installed at the center and another at the mid-radius location. All reference electrodes were placed at a depth of four inches (10 cm).

The reference electrode arrays are shown in detail in Figure 2. As stated earlier, the anodes were placed 60 inches (150 cm) apart. The five reference electrodes were equi-spaced from a location six inches (15 cm) away from the anode to a point midway between two anodes. The outermost reference electrodes in each array (the one mid-way between the anodes) was fitted with a steel rod coupon, 1/8” (3 mm) dia. X 2” (50 mm) long. This enabled us to make measurements with reduced IR drop error by measuring the instant-off potential when the coupon is momentarily disconnected from the tank bottom.

Figure 3a shows the anodes resting on the secondary containment in a stepped spiral pattern prior to placing the sand fill. Figure 3b shows one of the reference electrode arrays as installed. A section of anode is visible at the upper left while the rod coupon can be seen next to the reference electrode at the lower right. The total length of anode required was 3,650 feet (1,100 meters). A three-person crew was able to complete the anode installation in 6 ½ hrs. After the remaining sand was emplaced, two people installed the reference electrode arrays in about 2 hours. A new floor was then installed on the sand bedding. The anodes are powered by a 24 amp rectifier; the anode material is designed to operate at this current level for 40 years.

Since the anode material is installed between the liner and the new floor or between the lined old and new floors, all the chemical reactions that occur in the normal operation of a cathodic protection system now occur in a confined space. Corrosion engineers have known for years that acids are formed at the anode and that bases are formed at the cathode as a consequence of electrochemical reactions taking place at these locations. The result is that a very corrosive environment is created, particularly for the anode. Therefore, it is best for the corrosion engineer to operate the system at the lowest current density possible. One of the goals during commissioning of this system was to determine the lowest current necessary to adequately protect the entire tank bottom.

COMMISSIONING

Static or native potential measurements were collected at all locations on May 30, 2001. The values ranged from -0.301 volt to -0.431 volt to the permanent reference electrodes ($Cu/CuSO_4$). The rectifier that was used for this project was a constant current and/or constant voltage unit with a capacity of 24 amps at 60 volts. The original setting provided 8.14 volts and 6.7 amps. Potential measurements were recorded with the unit on. They ranged from -0.595 volt to -4.29 volt. Polarization occurred immediately. The lowest potential occurred at the center of the tank. Based on these readings, the rectifier was adjusted on June 19 to operate in the constant current mode at 5.0 amps. It was left at this level for eight days. Then, on June 27 the system was retested and instant off or IR drop free readings were collected at the four critical points. It was determined that over 200 millivolts of polarization had occurred at all locations. The system output was reduced again to 2.5

amps. This was less than half the output of the original setting. The system was tested again eight days later on July 5. Polarization was still the same, and the unit was left at the same current output.

Fourteen days later on July 19, the system was tested again. The polarization was continuing, so it was determined to further lower the rectifier output to 2.0 amps. The system was retested on August 4. The polarization had fallen off to only 33 millivolts at one location. It should also be noted that the product level on that date had gone from approximately 22-23 feet to 24 feet. The system was reset to operate at 2.5 amps. The system was retested 15 days later on August 20 and again 42 days later on September 26. Both times, the polarization was continuing to increase.

Three days later on September 29, the system was retested. The product level in the tank had risen to 34 feet. The rectifier was reset to operate at 3.0 amps. Six days later it was retested, and 100 millivolts of polarization had now occurred at all locations. The system has continued to operate at this level of polarization for over a year. Because we have the ability to closely monitor the CP system for this tank, it was possible to monitor the polarization as the level of current is raised and lowered.

RESULTS

Current Level

This aboveground storage tank is 150 foot (45 meter) in diameter tank with over 17,600 square feet (1,600 square meters) of bare surface area. Experience might normally suggest that a current density of one milliamp per square foot (10 mA/m^2) of surface area be used for this tank. To achieve that current density, over 17 amps of current would be needed. By utilizing a constant current rectifier, applying the 100 millivolt polarization criteria, and monitoring the system very closely, it was shown that the tank could be protected with a much smaller amount of current. The final current density that was applied to the tank was less than 0.17 milliamps per square foot (1.7 mA/m^2) of surface area. At this lower current density, the normal change in the chemistry of the electrolyte occurs over a much longer period, the normal reduction of moisture caused by the operation of the system is reduced, and the life of the cathodic protection system is extended.

Operating the cathodic protection system at the lowest possible current output that provides adequate cathodic protection should be the goal of the corrosion engineer. This can best be managed by operating the rectifier unit at a constant current. This method of operation ensures that potential measurements can be maintained during normal operating changes of the tank. The current necessary to provide adequate cathodic protection when tank product levels are high is established and the rectifier is set to operate at this level of current. Changes may occur that will warrant adjustments, but these changes will most likely occur over an extended period of time. For example, if the tank is nearly empty for an extended period, the tank bottom will lift up in some areas which will increase the current density at those sections of the bottom still in contact with the sand bed. This will result in more negative potentials than necessary to achieve protection at these areas.

Reference Electrode Placement

IR drop error for current-on measurements can be significant in this environment due, in part, to the high electrolyte resistivity. One would expect the error to be highest at a location closest to the anode and drop off to a minimal level at a point midway between the anodes. This is, in fact, the case as can be seen clearly in Figure 4. Figure 4a shows current-on potentials as measured by the five references in Array #1 near the tank center. The reference closest to the anode, #3, gave the most negative readings and the measurements became less negative closer to the mid-point between the anodes (#7). The magnitude of this error varied directly with the rectifier output as it was being adjusted during the commissioning phase. Similar data from array #2 is shown in Figure 4b. It is important to note that in order to get meaningful potential measurements, it is critical that the reference electrode be as close as practical to the exact mid-point between adjacent anodes.

Figure 5 contrasts the current-on potential measurement made by the reference electrode closest to the midpoint with the IR drop free measurement made with the adjacent coupon. To make this measurement, the instant-off potential of the coupon was measured when it was momentarily disconnected from the structure. For reference #7 (Figure 5a), the two readings were virtually identical which suggests that it was located very close to the mid-point between anodes. This was not the case for reference #12 (Figure 5b). Since small differences in location can have large effects on the amount of IR drop error incorporated into potential measurements, it is not a good idea to rely just on accurate electrode placement to get IR drop free measurements. For the most accurate measurements, it is necessary to either interrupt the rectifier or use coupons.

Figure 6 illustrates the close correlation which exists between instant off measurements made by interrupting the rectifier (Cell #1) and those made by momentarily disconnecting the coupon from the structure (Coupon #7). The two measurement locations are about ten feet (3 meters) apart at the center of the tank. The two measurements converged as the polarization became more uniform with the passage of time. This data can also be interpreted as a demonstration of the amount of polarization which has occurred. This is done by subtracting the native potential from the instant off potential measured at that location. Figure 7 shows the polarization measurements made at two locations: the center (Cell #1) and the mid-radius (Cell #2). Throughout the entire commissioning period, the potentials at both locations exceeded the 100 millivolt shift NACE criterion.

CONCLUSIONS:

When planning and installing cathodic protection on a double bottom tank, it is important to design and install sufficient monitoring capability into the system.

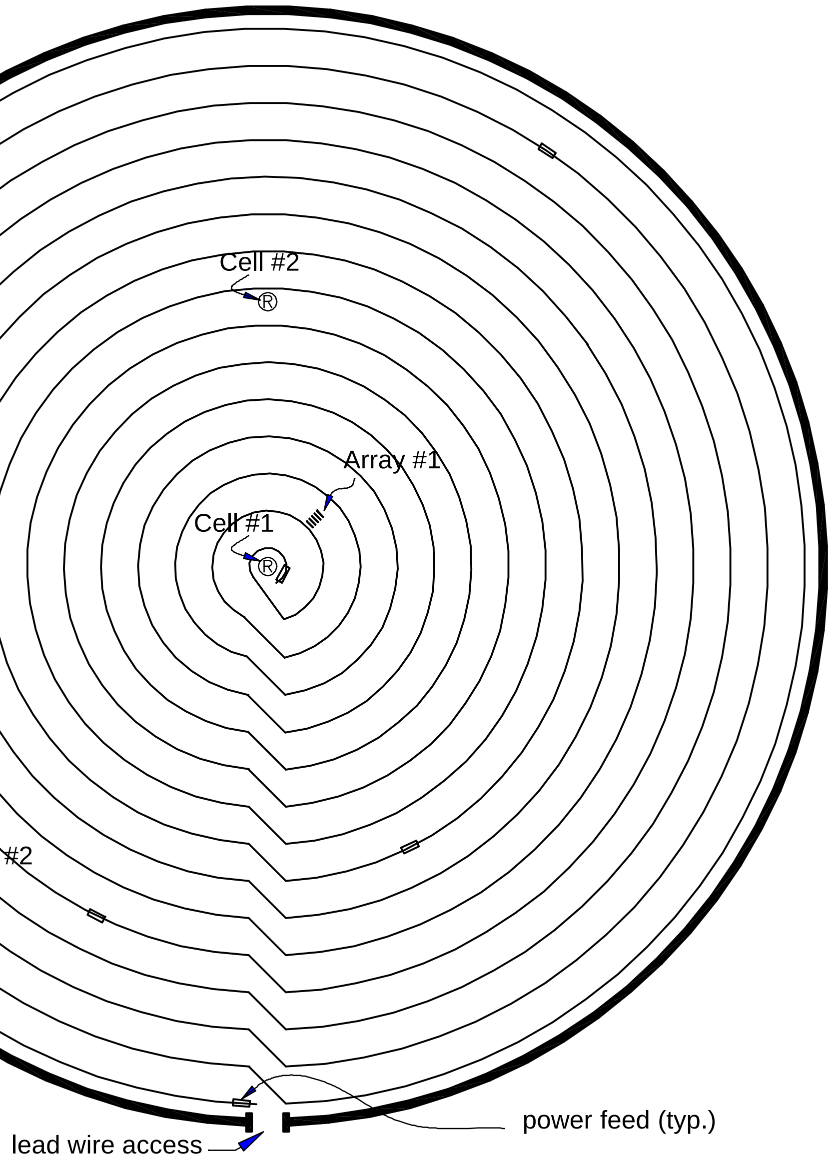
Reference electrodes must be placed exactly mid-way between anodes to minimize IR drop error in potential measurements. More precise potential measurements can be obtained by either interrupting the rectifier or using cathodic protection coupons placed very close to the reference electrodes.

In this particular installation where the anodes were placed eight inches (20 cm) below the primary bottom, a five foot (1 ½ m) inter-anode spacing was adequate to obtain cathodic protection out to the mid-point between anodes.

Polarization or depolarization takes time on any uncoated structures. The structure should be regularly monitored after the system is energized and applied current periodically adjusted in order to obtain the desired results.

For this application, it is best to use a constant current rectifier to have complete control over the applied current levels.

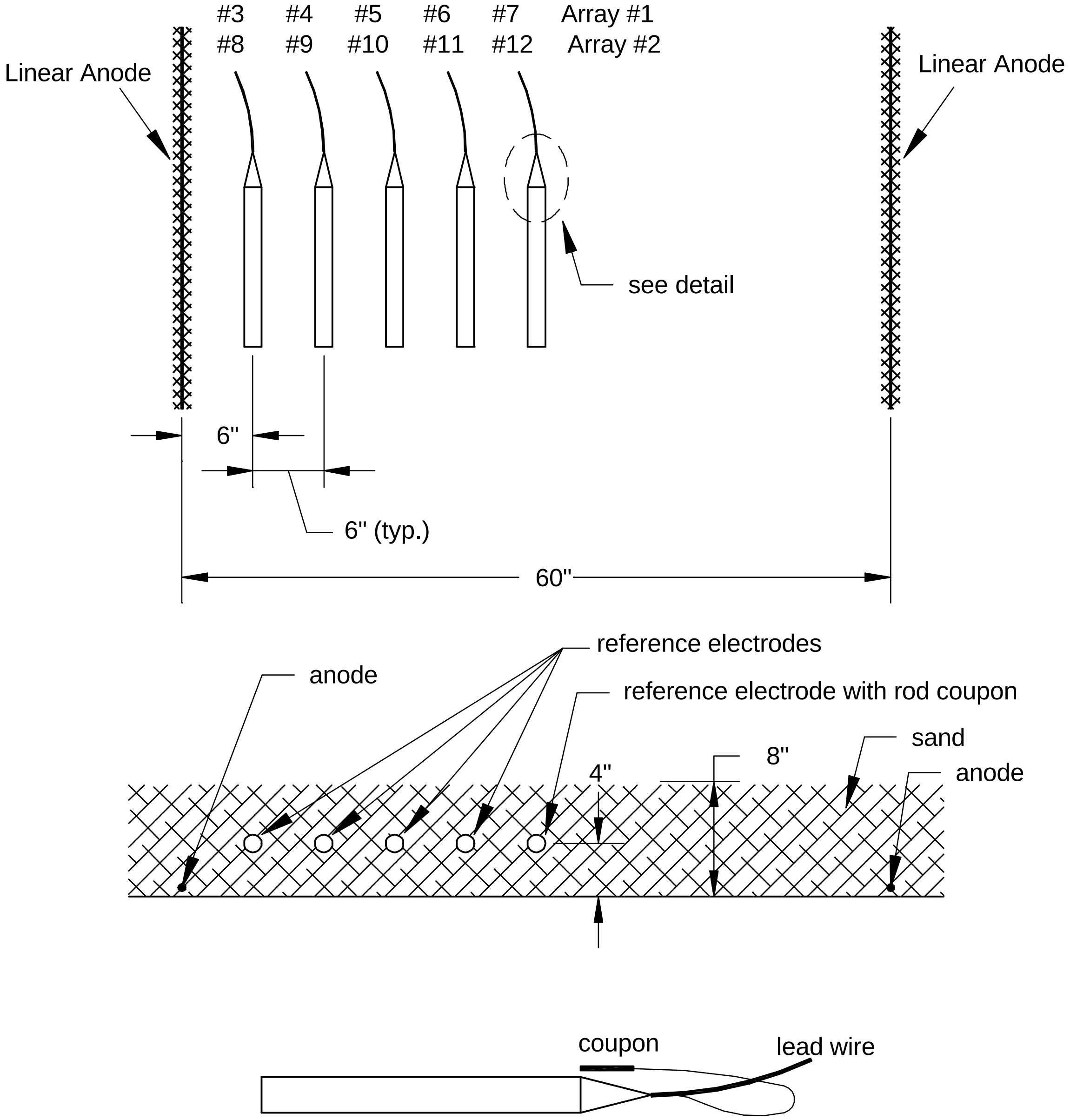
Anode life can be maximized and electrolyte dry out minimized by using the lowest level of current necessary to meet NACE criteria.



Anode Placement - First anode ring placed 2 1/2 feet (3/4 meter) in from outside edge. Subsequent anode rings placed 5 feet (1 1/2 meters) in from previous ring. Power feeds located at both ends and at three equi-spaced intermediate points.

Reference Electrode Placement - A single reference electrode is located at center (cell 1) and at mid-radius (cell 2). A five reference electrode array is located near the center (array 1, cells 3 - 7) and near the outer edge (array 2, cells 8 - 12). On each array, the cell furthest from the anode (#7 and #12) are fitted with CP coupons.

Figure 1 Plan view of the cathodic protection system installed between the primary and secondary containments on a 150 foot (45 meter) aboveground storage tank.



Detail - place coupon about 1/2" above bag of reference electrode.

Figure 2 Details of reference electrode arrays.

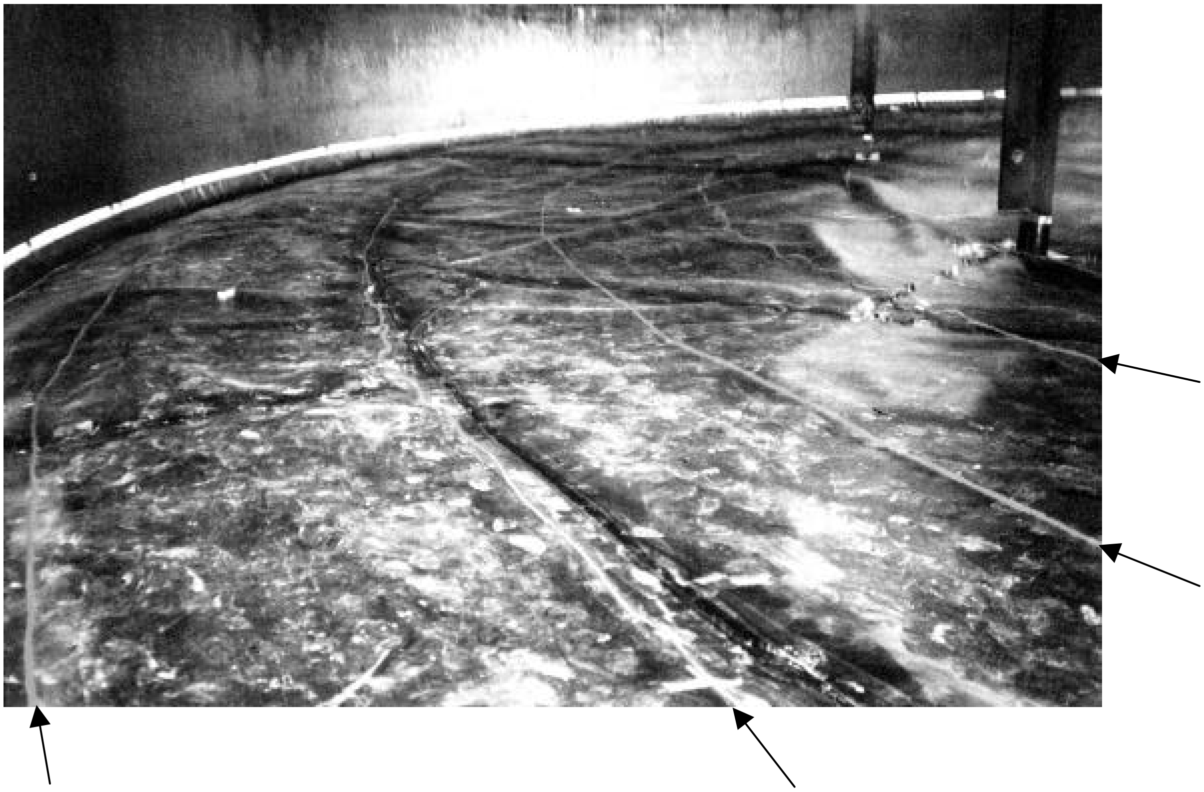


Figure 3a View of linear anode string resting on secondary containment (arrows designate anodes). The individual anode lengths are connected in the field and placed in a stepped spiral configuration, starting at the outside and working toward the center.

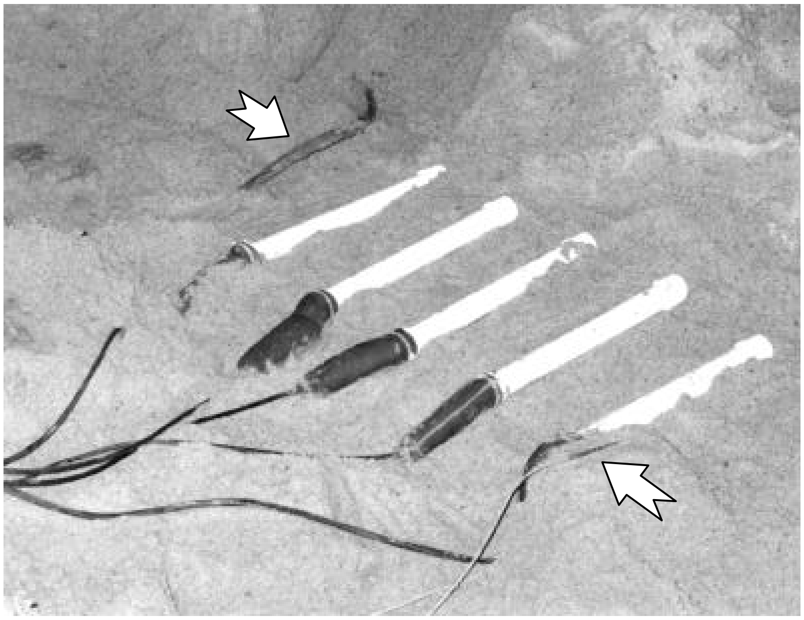


Figure 3b View of one of the reference electrode arrays. The anode is visible in the upper left part of the photo; the coupon can be seen resting on the reference electrode at the lower right.

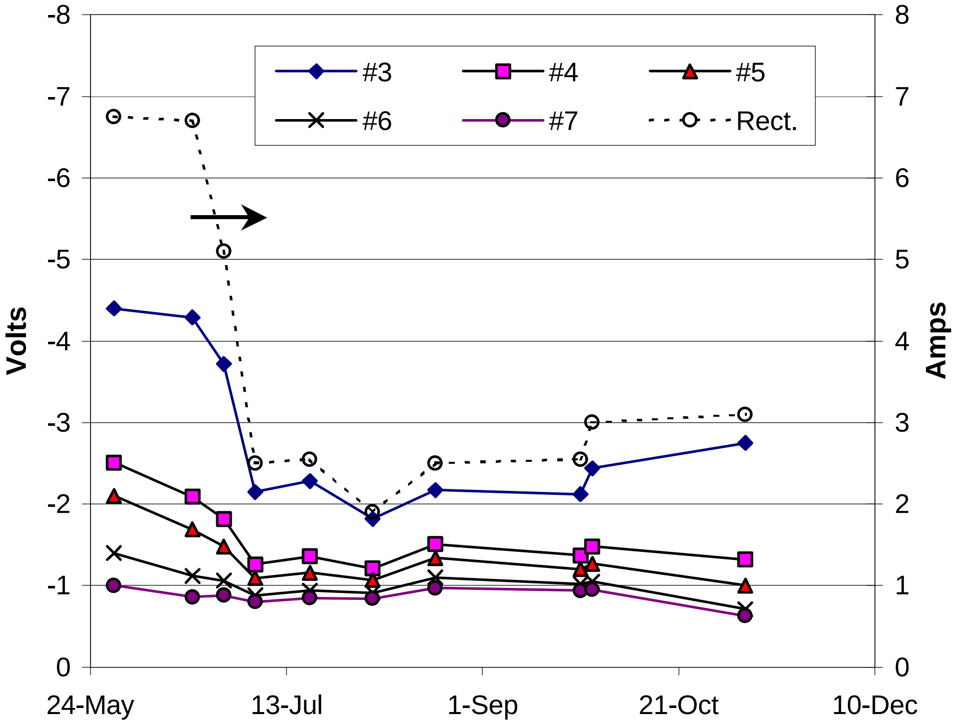


Figure 4a Current-on potentials from Array #1. Reference electrode #3 is located six inches (15 cm) from the anode. The remaining reference electrodes are located 12, 18, 24 and 30 inches (30, 45, 60 and 75 cm) from the anode. The closer the reference electrode is to the anode, the greater the IR drop error in the reading.

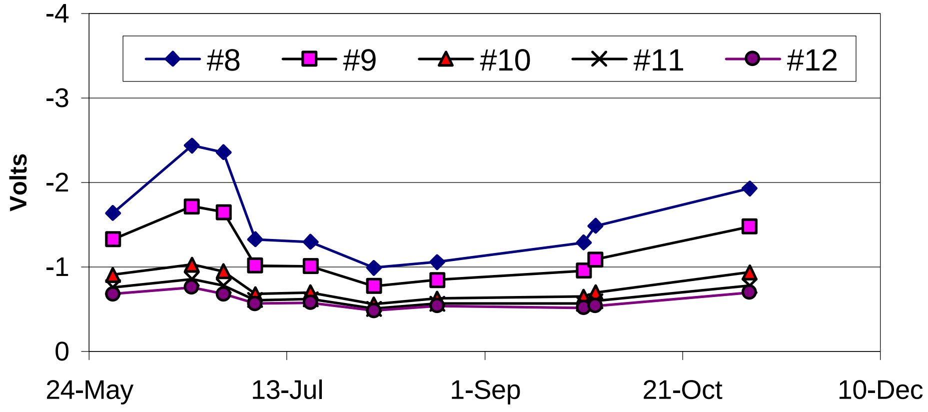
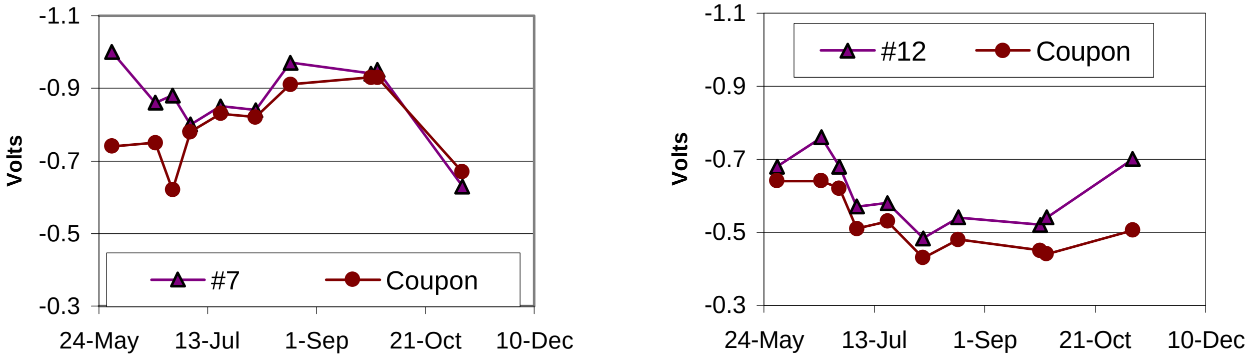


Figure 4b Current-on potentials from Array #2. The reference electrode spacing is similar to that in Array #1.



a) Data from Array #1

b) Data from Array #2

Figure 5 The current-on potential measurement from a reference electrode located mid-way between anodes is contrasted with the instant-off potential (coupon disconnected from structure) of adjacent coupon. When the reference electrode is exactly centered between the anodes, the difference in these readings will be minimal.

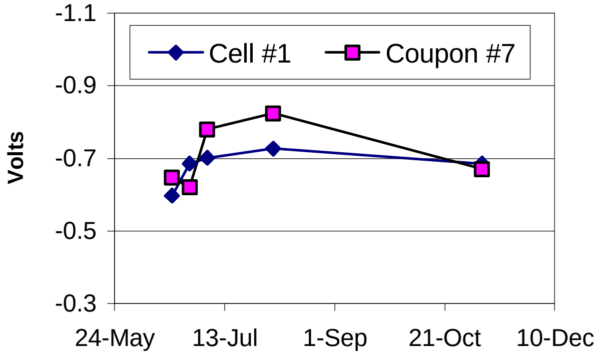


Figure 6 A close correlation was observed between instant off potentials measured at Cell #1 (center, rectifier interrupted) and Coupon #7 (10 feet away, coupon momentarily disconnected). Either method can be used to measure IR drop free potentials.

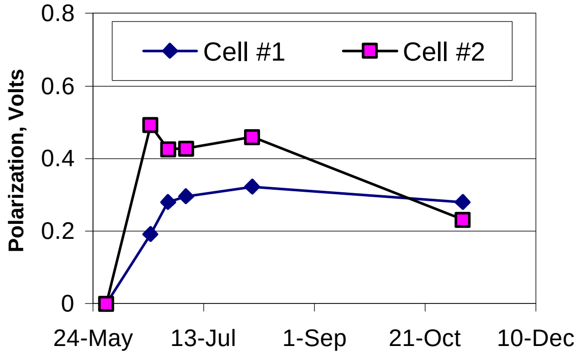


Figure 7 The amount of polarization at the center (Cell #1) and the mid-radius (Cell #2) remained well above the 100 mV criterion as the current level was adjusted. The final current level was set at 0.17 mA/sq. foot (1.7 mA/sq. meter).