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# Cathodic Protection of Surface Storage Tank Bottoms

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*Soil side corrosion of surface storage tanks can be a serious problem. In many industries the life of the tank is limited by external corrosion of the tank bottom. Cathodic protection (CP) is a cost effective technique used to eliminate soil side corrosion and hence can indefinitely extend the life of the tank bottom and significantly increase the intervals between internal inspections as recommended in API 653.*

*Many owners are now installing secondary containment when constructing new tankage. Most of these containment liners are fabricated from non-conductive materials that may prevent the application of cathodic protection unless specific components are installed concurrently with tank fabrication.*

*This paper will examine the corrosion mechanisms of tank bottoms as well as the various designs of CP systems with and without secondary containment.*

The soil side corrosion of surface storage tanks has not been historically a serious problem to the process industry. This may have to do in part with the fact that most tanks are constructed on elevated granular pads which afford good drainage and also as early as the 1940's,<sup>[1,2]</sup> cathodic protection was being used sporadically for the external surfaces. For one or a combination of reasons, tank bottom corrosion has

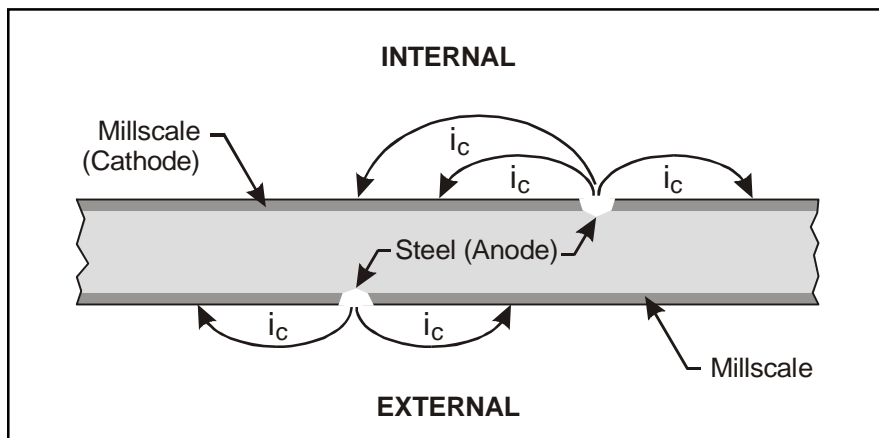
become a concern more recently. Certainly, environmental and safety considerations are more important now than at any other time in the past, and more significantly, much of the existing surface storage tankage has now accumulated considerable age. Whereas piping systems are often abandoned or replaced when plant modifications are made, this is not usually the case for tankage which is commonly retained for future service.

There is therefore a general need to make existing storage facilities serve a longer and longer period of time.

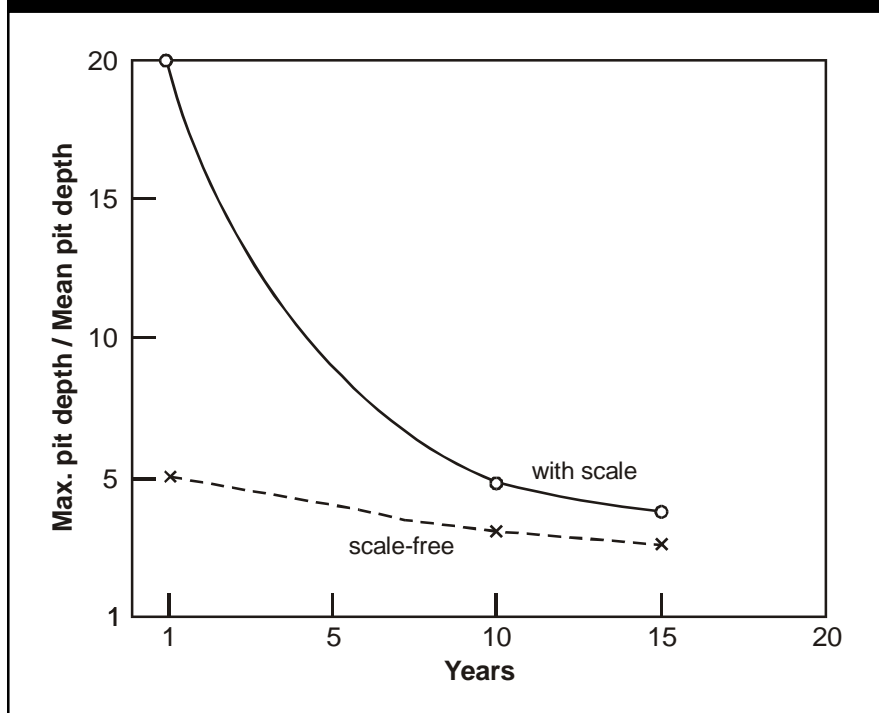
Whether or not corrosion occurs on a structure does not necessarily create a corrosion problem since the problem arises only when the corrosion rate relative to the life of the structure is significant. Even very modest rates such as 0.1mm per year is a serious corrosion rate on a 6 mm thick tank bottom approaching 25 years of service. The age of the vast majority of storage tanks currently in use is greater than 10 years, with a high proportion greater than 25 years.

## **CORROSION CHARACTERISTICS**

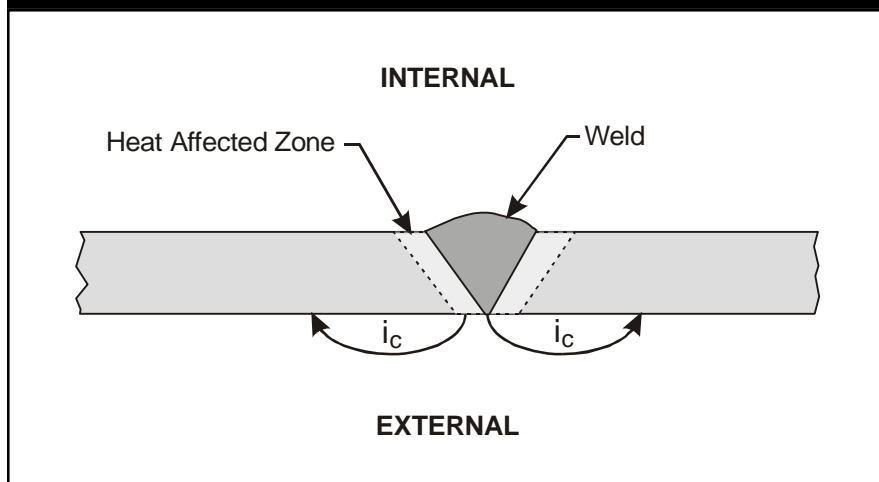
It is well known that steel has a tendency to corrode in the presence of an aqueous environment and this factor is, of course, a key determinant in whether or not internal or external



**FIGURE 1 • Corrosion Cell Between Steel and Millscale**



**FIGURE 2 • Effect of Millscale on Pitting of Steel in Seawater**



**FIGURE 3 • Corrosion Activity in the Vicinity of the Overlap Welds**

corrosion occurs on a storage tank bottom. The seriousness of the corrosion depends on the corrosion rate relative to the thickness of the metal which is more than just a function of whether or not moisture is present.

Corrosion activity on the bottom plates of a storage tank is initiated primarily as a result of a corrosion cell developed between the steel and a surface millscale coating as illustrated in Figure 1.

Millscale is formed during hot rolling of the steel plates when the surface is oxidized by the air. A typical millscale would be about 15 $\mu$ m thick and contain 70% ferrous oxide (FeO), 20% magnetite (Fe<sub>3</sub>O<sub>4</sub>), and 10% ferric oxide (Fe<sub>2</sub>O<sub>3</sub>).<sup>[3]</sup>

Magnetite is a good electrical conductor and cathodic to steel.<sup>[4]</sup> The millscale therefore can sustain and accelerate the corrosion activity depending on the surface area ratio between the millscale and exposed steel. The relative impact of millscale on corrosion severity is shown in Figure 2.<sup>[5]</sup>

In the presence of an aqueous environment, steel/millscale corrosion cells can therefore exist and result in severe pitting although the millscale effect diminishes with time.

Corrosion cells can also develop in the vicinity of the welds owing to differences in the surface metallurgy in the heat affected zone and in the weld material relative to the adjacent steel or millscale covered plate as shown in Figure 3.

Again this activity can arise either internally or externally, requiring only the presence of moisture at the steel surface.

Regardless of the type of corrosion cell developed, the rate of corrosion

and hence the severity of attack is a function of aqueous media factors such as dissolved oxygen concentration, pH, temperature, and electrical resistivity and is also proportional to the relative surface area ratio between the cathode and anode sites.

## External Corrosion

The most commonly observed corrosion pattern on the underside of surface storage tanks, particularly where the tanks are heated, consists of severe corrosion on the outer perimeter as shown in Figure 4. This may be due to the fact that these surfaces have greater access to moisture and particularly moisture that is oxygen saturated as was found in one study.<sup>[6]</sup> Furthermore, low pH rainwater can collect around older storage tanks which have settled resulting in continuous exposure to an extremely corrosive electrolyte.

It is also possible for a macro-corrosion cell to develop whereby the perimeter bottom plates are anodic to the center plates. The center plates may become more cathodic with time due to the formation of a magnetite protective film under high pH and low dissolved oxygen conditions.<sup>[7]</sup> This corrosion pattern is often very pronounced on tanks that operate at an elevated temperature since higher temperatures aid in the formation of a cathodic magnetite film. Common iron corrosion products (oxides) exhibit cathodic polarization behaviours similar to noble metals such as platinum<sup>[8]</sup> which make them very effective cathodes.

## CORROSION CONTROL

### External

When severe external corrosion is discovered, the tank bottom is often replaced at a relatively high cost. On

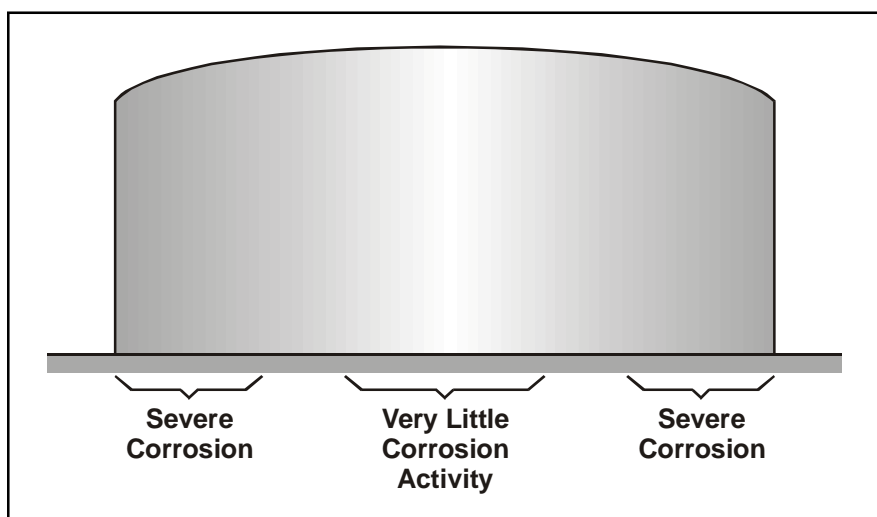
the other hand, if the structural integrity of the tank is not threatened by the corrosion loss, CP is a very practical alternative and indeed the only economical one since typical costs are less expensive than replacement.

Replacement of the tank bottom has the disadvantage that should moisture still be present at the external surfaces between the new and old tank bottom, a corrosion cell would be developed in which the new tank bottom will be the anode with respect to the old tank bottom as shown in Figure 5. This corrosion cell can cause perforation

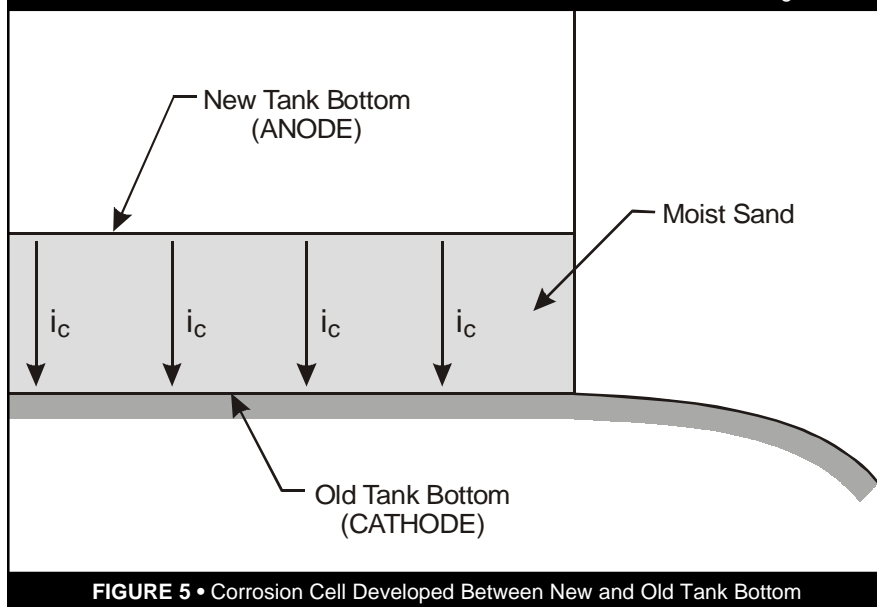
sooner on the new bottom than would normally occur.

## Background of Cathodic Protection

Cathodic protection is one of the most effective techniques for controlling corrosion on both existing and new structures when the structures are continually in contact with soil or water. Cathodic protection is the application of a direct current to a metallic structure from an electrolyte (e.g. soil or water) which causes the electrical potential across the metal/electrolyte



**FIGURE 4 • Characteristic Corrosion Pattern on the Underside of Surface Storage Tanks**



**FIGURE 5 • Corrosion Cell Developed Between New and Old Tank Bottom**

# CATHODIC PROTECTION

interface to change as illustrated in Figure 6.

As the change in potential ( $\Delta E$ ) is increased the corrosion rate is proportionately decreased, usually to negligible values.

Cathodic protection was first applied in 1824 by Sir Humphrey Davies to protect the copper sheeting on war ships. Since then, the breadth of its application has spread to a wide range of mostly ferrous structures such as:

- ▶ Ships: external (1824) and internal
- ▶ Pipelines: external (1930's) and internal
- ▶ Docks, jetties
- ▶ Reinforcing steel in concrete (1970's)
- ▶ Heat exchangers
- ▶ Storage tanks: underground (1970's) and surface
- ▶ Hydraulic & pneumatic hoist cylinders
- ▶ Effluent clarifiers
- ▶ Well casings (water and oil)
- ▶ Electrical grounding systems

When cathodic protection is operated continuously at the required current output, then the service life of many of the structures being protected can be extended indefinitely.

## Cathodic Protection Methods for Existing Tanks

The primary objective in providing cathodic protection for the external surface of surface storage tanks is to obtain uniform current distribution and hence uniform corrosion control. This can be difficult to achieve on storage tank floors since it has been mathematically demonstrated by Ewing and Hutchinson<sup>[9]</sup> that primary current distribution (eg. neglecting polarization effects) will produce a cathodic current density at the center of the tank bottom which is one-half of the average current density. Furthermore, on existing tanks it is not practicable to place the cathodic protection current sources close to the tank center. Accordingly, it is often difficult to obtain adequate protection on the center plates.

When the anode materials are positioned around the periphery of the tank structure as shown in Figure 7, then a more even and uniform current distribution can be expected providing the soil is of relatively homogeneous nature and low electrical resistivity. Although cathodic protection can be achieved using galvanic anodes,<sup>[11]</sup> the high current requirements usually necessitate the use of impressed current systems. In low resistivity soils, with the application of CP using distributed anodes and given time for secondary polarization effects to take place, a relatively modest difference in potential between the outside edge and the centre of the tank has been found in a number of instances.<sup>[1,2,10,11]</sup> Where high resistivity earth conditions prevail such that the peripheral distributed system would not provide

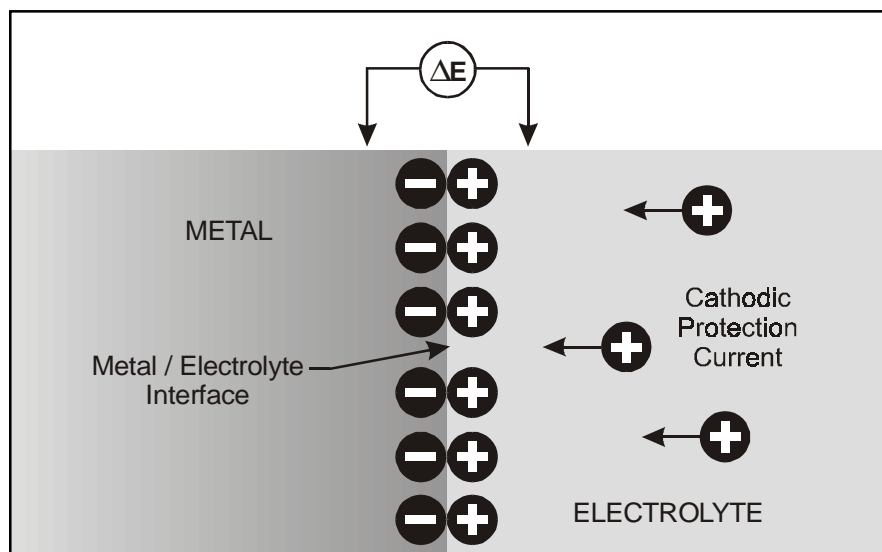


FIGURE 6 • Cathodic Protection Application (Corrosion Rate at  $1/\Delta E$ )

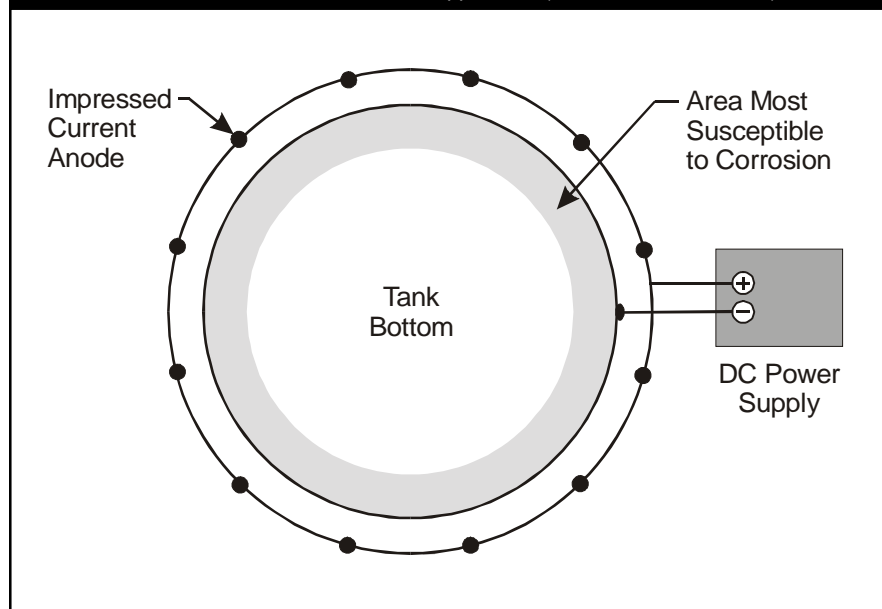


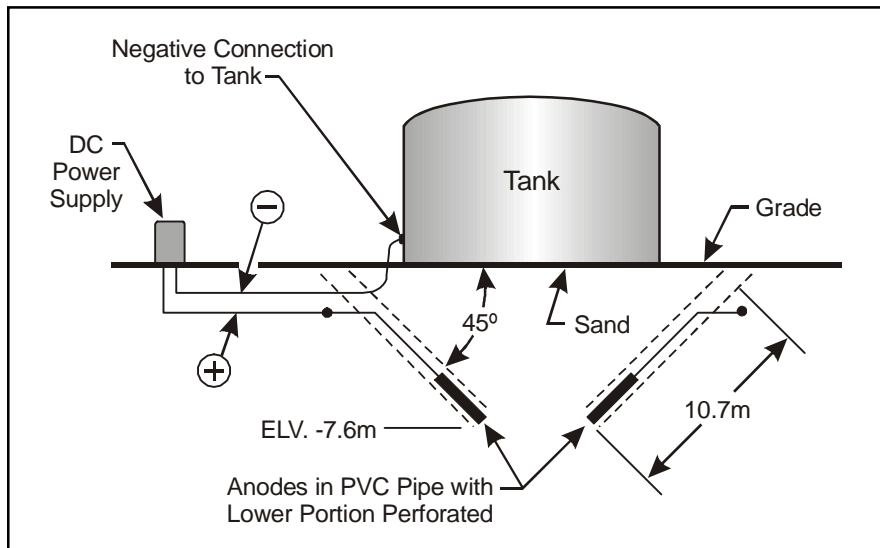
FIGURE 7 • Distributed Cathodic Protection Anode Arrangement

uniform current distribution, a more innovative anode arrangement has been proposed by Garrity.<sup>[12]</sup> This involves placing the anodes at an angle with respect to the tank bottom so that the anode position is closer to the centre of the tank as shown in Figure 8.

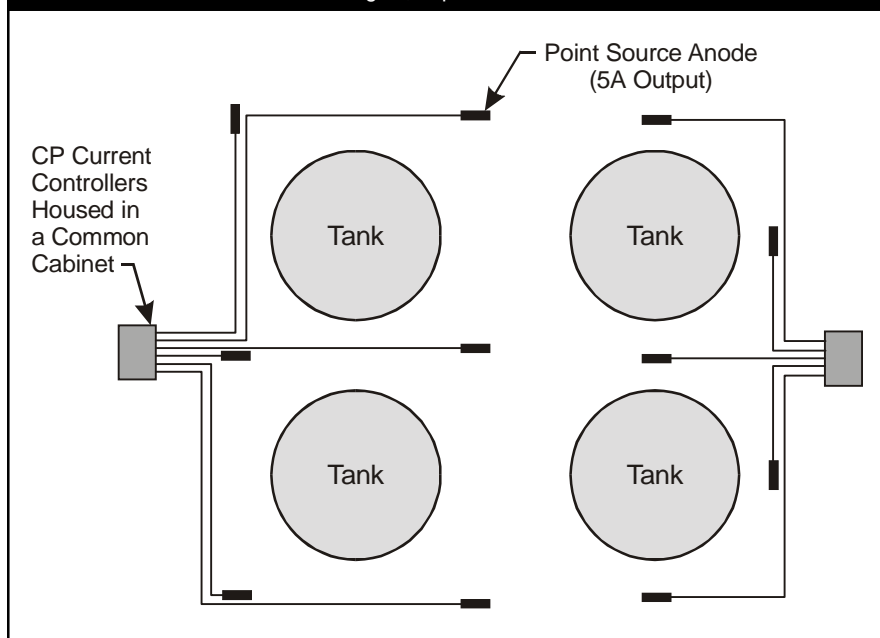
This installation requires more sophisticated construction methods than does a simple vertical or horizontal anode installation around the perimeter of the tank.

When more than one tank requires protection, then the distributed anode approach around each and every tank in a multiple tank array is relatively expensive. Furthermore, the distributed system has the disadvantage that with all the anodes connected in parallel, one anode can easily be discharging a different amount of current than adjacent anodes and hence consuming itself at a different rate. To obtain a satisfactory system life the distributed system therefore, must be conservatively rated in order to allow for different rates of anode consumption. When protecting a group of tanks however, larger current sources and point source anodes can be used and separately controlled as shown in Figure 9. By attaching each point source anode to a separate controller and operating the controller at a constant current, the current density on each anode can be adjusted to produce an optimum anode life. Advances in electronics has now made this type of system practical and economical.

Also, if one tank requires additional current, the set point can be changed on one or more anodes independently rather than changing the output of all anodes. When the current is uniformly distributed, a current density of about 1 to 2 mA per square foot of tank bottom surface area is sufficient to achieve satisfactory protection from corrosion for ambient temperature



**FIGURE 8 • Angled, Impressed Current Anodes**

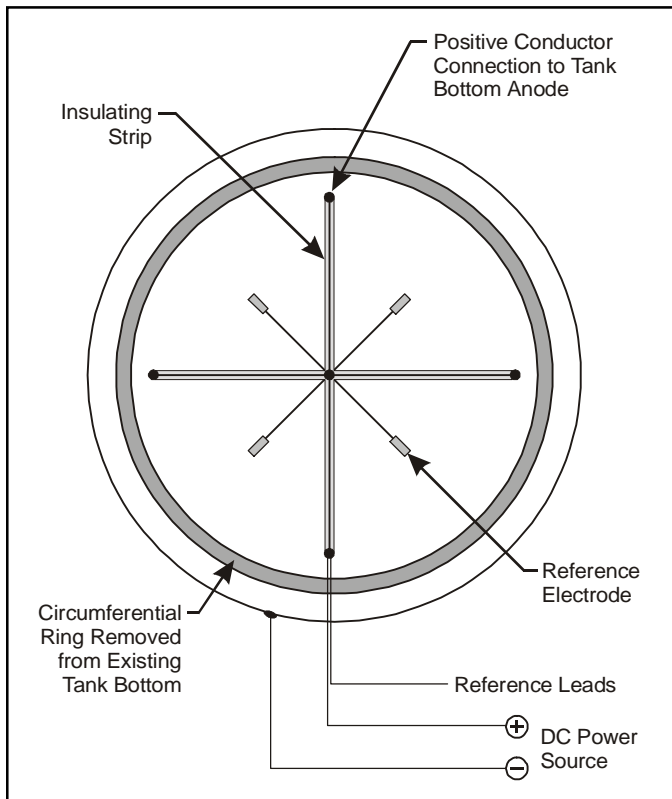


**FIGURE 9 • CP of Tank Farm Using Individually Controlled Distributed Anodes**

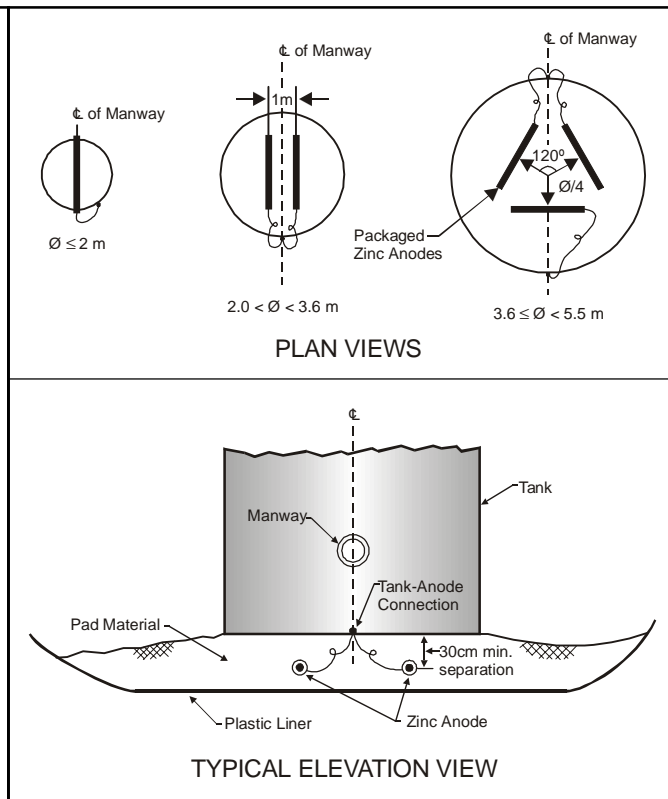
conditions. Heated tanks require a higher current density.

Another innovative cathodic protection arrangement, which is the subject of a patent application, uses the old tank bottom as an impressed current anode to protect a new tank bottom. This arrangement, shown in Figure 10, is applicable in situations where the tank bottom is being replaced with a new tank bottom but requires that a circumferential ring be removed from

the old tank bottom to electrically isolate it from the tank shell and the replacement tank bottom. It is critical to the success of this installation that sufficient space be placed between the new and old tank bottom. This space is normally filled with sand and any contact between new and old tank bottom would destroy cathodic protection effectiveness. Several connection points are made with an insulating strip covering the anode plate between the connection points



**FIGURE 10 • Use of Existing Tank Bottom as an Impressed Current Anode**



**FIGURE 11 • Arrangement of Packaged Zinc Anodes for Various Tank Diameters ( $\Delta$ )**

in order to ensure that electrical continuity is not lost when the anode plate corrodes preferentially near the connections. In addition, reference electrodes are installed between the new and old tank bottom in order to monitor the potential change as a result of the application of cathodic protection current. This type of cathodic protection system is not only extremely effective but is particularly economical.

### CP METHODS FOR NEW SURFACE STORAGE TANKS WITH CONTAINMENT FACILITIES

As a result of environmental protection considerations, most new surface storage tanks have a liner installed beneath the tank in order to contain any spilled or leaking product. If the containment liner is a dielectric

material such as PVC or polyethylene, then cathodic protection anodes must be placed between the liner and the tank bottom at the time of construction. Attempting to retrofit CP to a tank having an insulating containment liner would be technically difficult and therefore economically impractical.

Small surface storage tanks are normally factory fabricated which provides an opportunity to apply a dielectric coating to the bottom with the same quality as is achieved on underground storage tanks. It is recommended that zinc galvanic anodes be placed in the pad material and arranged as in Figure 11, to protect the steel at coating defects.

The bottom plates on field erected surface storage tanks are usually uncoated which necessitates the use

of an impressed current system to obtain sufficient protection current to prevent corrosion. The limited space between the tank bottom and the liner places constrictions on the available current paths such that a distributed impressed current anode is required. Typically the impressed current anode of choice is a catalyzed titanium mesh placed approximately 30 cm from the tank bottom in the tank pad material as shown in Figure 12. The mesh impressed current anode has approximately the same surface geometry as the tank bottom resulting in a relatively expensive cost.

A number of innovative methods have been used to reduce the surface area of the mesh and hence the system cost. Strips of catalyzed titanium or platinum clad niobium wire have been used under tank bottoms in lieu of the continuous mesh.



Strip and wire anode spacing must be carefully calculated to ensure adequate current distribution to the entire tank bottom surface as the non-conductive containment liner will severely reduce the current paths from the anodes to the tank bottom. Greater than optimal anode spacing will result in unprotected bands between the anodes.

A method to reduce cost yet provide uniform current distribution has recently been developed (patent pending). A small number of platinum clad niobium anodes are installed above the liner which are covered by a layer of cokebreeze (electronically conductive carbon). The protection current is discharged from the primary anodes (platinum clad niobium) via electronic transfer and hence do not corrode to any appreciable degree. The secondary anode (coke breeze) provides a uniform current distribution to the tank bottom at an attractive cost.

## SUMMARY

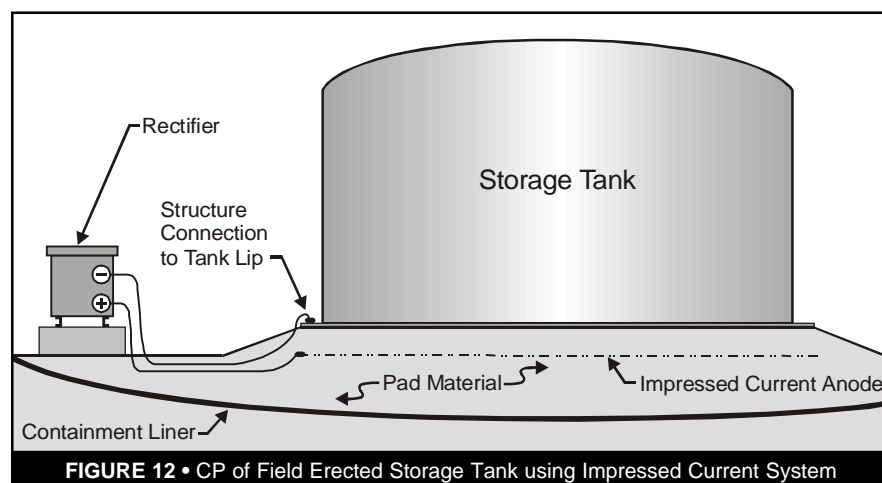
The corrosion causes and corrosion control options for surface storage tanks have been recently well documented<sup>[13]</sup>. The installation of a CP system to arrest corrosion on the soil side surface of surface storage tanks can be accomplished at a fraction of the cost of a replacement tank bottom

or the application of an internal lining. Proper and comprehensive inspection by ultrasonic thickness testing is important in assessing the condition of the soil side surfaces. Even on severely corroded tank bottoms, the application of cathodic protection can extend the effective service life of that tank bottom indefinitely, providing the cathodic protection system is properly designed, installed and maintained.

The type of CP system which would be most effective depends on the number and size of tanks being protected, the nature of the soil conditions, and the operating temperature of the tank(s). New storage tanks having secondary containment liners which are also electrically insulating must have CP installed simultaneously with the tank because a retrofit installation would be economically prohibitive.

## RELEVANT STANDARDS

- American Petroleum Institute (API) Recommended Practice 651 - Cathodic Protection of Aboveground Petroleum Storage Tanks
- National Association of Corrosion Engineers (NACE) Recommended Practice – RP0193-93 – External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms.



**FIGURE 12 • CP of Field Erected Storage Tank using Impressed Current System**

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