CORROSION CONTROL OF FLAT BOTTOM STORAGE TANKS

Presented at the

N.A.C.E. Toronto Section Meeting
Tuesday, November 15, 1988
Sarnia, Ontario

by

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TECHNICAL PAPER #11119

CORROSION SERVICE

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BACKGROUND

The corrosion of flat bottom storage tanks has not been historically a serious problem to the petroleum refining 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[1,2], cathodic protection was being used sporadically for the external and in some cases, internal 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 refinery or petrochemical plant modifications are made, this is not usually the case for tankage which is commonly retained for future service. Indeed, when a large number of refineries were decommissioned in the early '80's, often the storage tanks were retained for future product storage. 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 10 mils per year is a serious corrosion rate on a 0.250 in. 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 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 there is moisture 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.

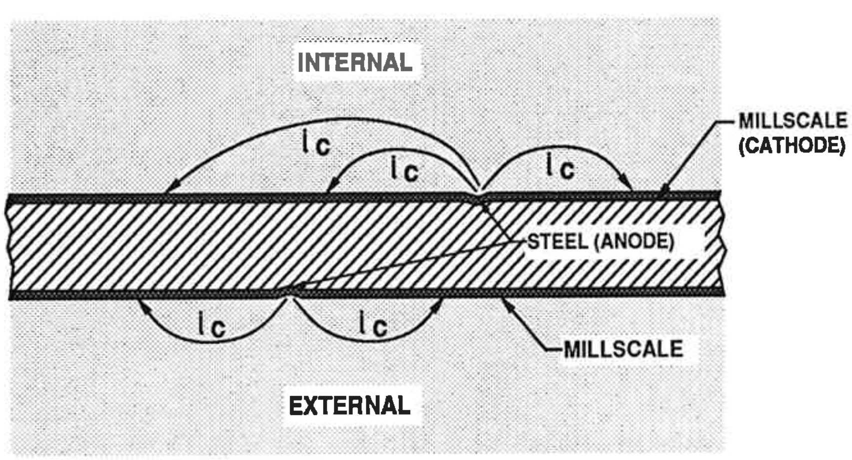

FIGURE 1 – CORROSION CELL BETWEEN STEEL AND MILLSCALE

Millscale is formed during hot rolling of the steel plates when the surface is oxidized by the air. A typical millscale would be about 15µm thick and contain 70% ferrous oxide (FeO), 20% magnetite (Fe_3O_4), and 10% ferric oxide (Fe_2O_3)[3].

Magnetite is a good electrical conductor and cathodic to steel[4]. 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[5].

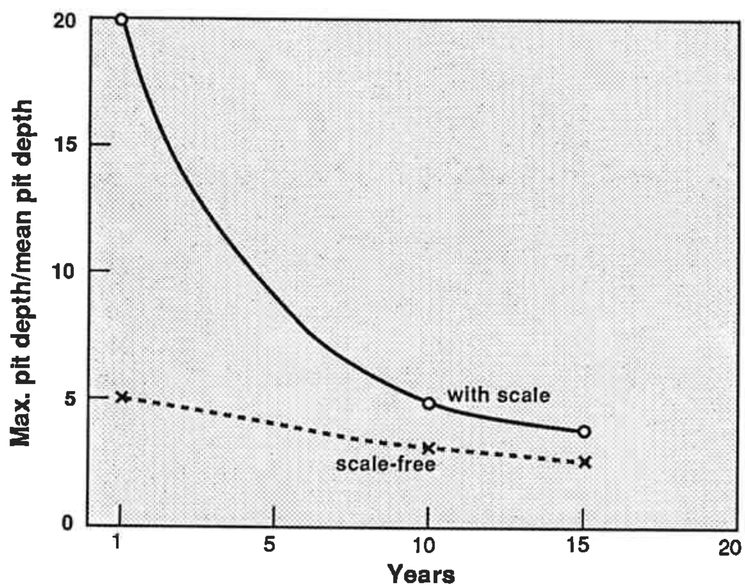

FIGURE 2 – EFFECT OF MILLSCALE ON PITTING OF STEEL IN SEAWATER

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

Corrosion cells can also develop in the vicinity of the overlap 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.

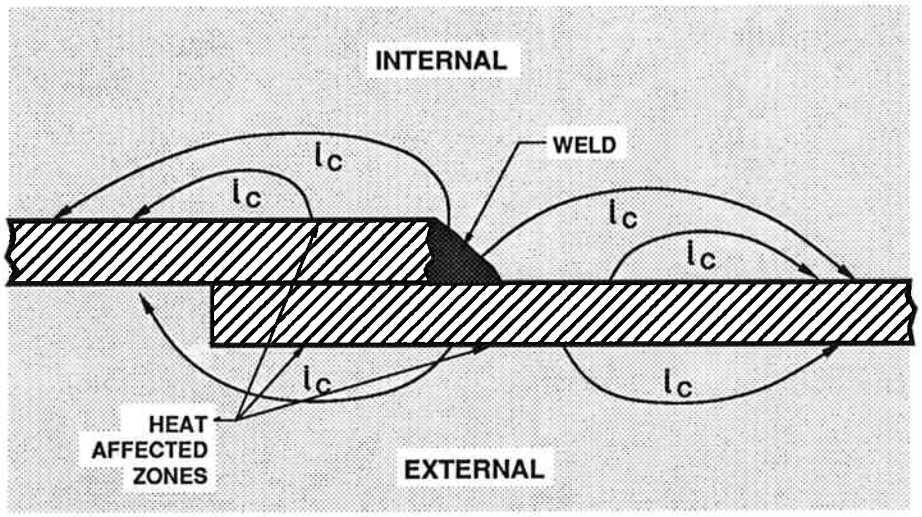

FIGURE 3 – CORROSION ACTIVITY IN THE VICINITY OF THE OVERLAP WELDS

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.

Internal Corrosion

Internal corrosion can appear as localized pitting or general corrosion depending on the type of product stored and service conditions. For instance, generalized corrosion of the roof and above product storage line surfaces can occur as a result of humid air being drawn in during emptying of the product and then condensing on the exposed metal surfaces. The intensity of attack is further enhanced by the degree of air pollution that exists. The relatively short life of galvanizing on galvanized steel in the vicinity of petrochemical plants is testimony to generally high levels of atmospheric corrosivity.

The floor plates can be intentionally subjected to an aqueous environment such as in the case of naptha storage[6] where a heel of water is constantly maintained or in tanks used for ballast water storage. Not all localized pitting is due to the previously described corrosion cells and, where the pitting is very steep sided, as illustrated in Figure 4, bacterially induced corrosion is the likely cause. Usually the bacteria can only exist in a deaerated environment which is often the case beneath heavy oils and sludges.

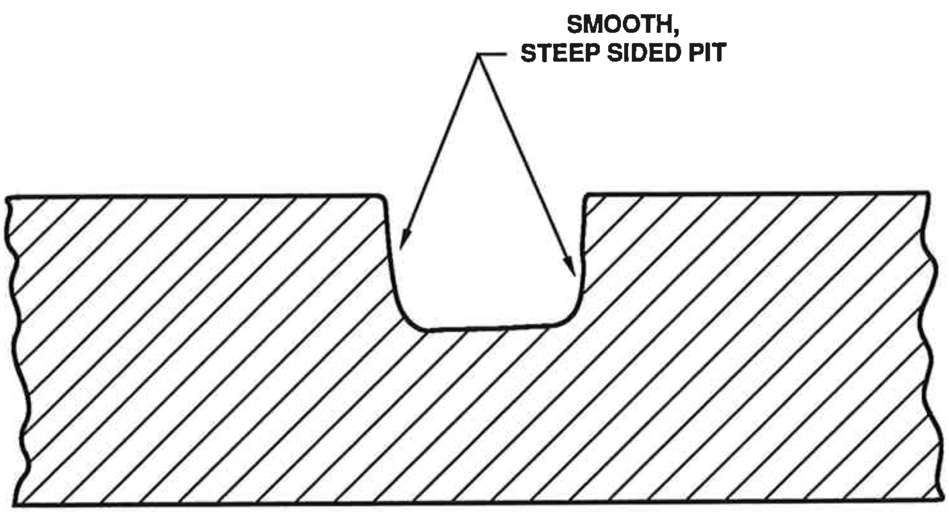

FIGURE 4 – CHARACTERISTIC APPEARANCE OF BACTERIALLY INDUCED CORROSION PIT

External Corrosion

The most commonly observed corrosion pattern on the underside of flat bottom storage tanks, particularily where the tanks are heated, consists of severe corrosion on the outer perimeter as shown in Figure 5. 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[7]. Furthermore low pH rainwater can collect around older storage tanks which have settled resulting in poor drainage.

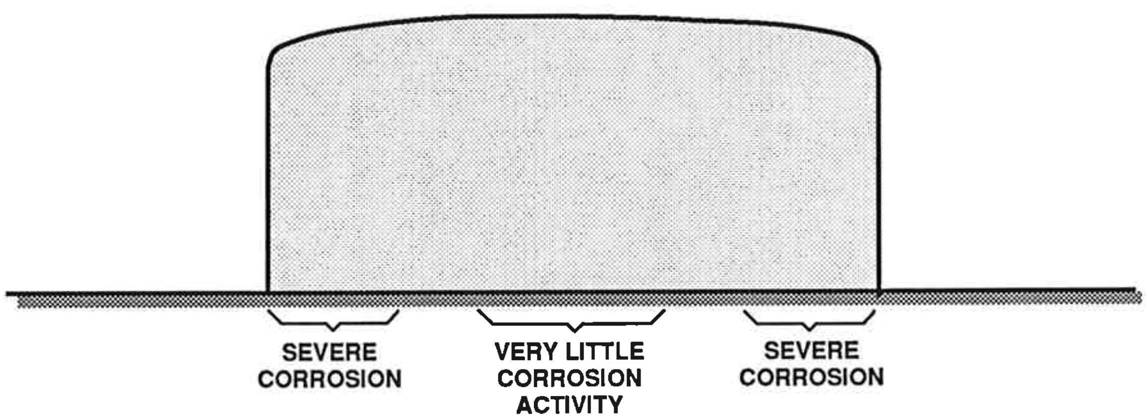

FIGURE 5 – CHARACTERISTIC CORROSION PATTERN ON THE UNDERSIDE OF FLAT BOTTOM STORAGE TANKS

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.[8] 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. Furthermore even common iron rusts exhibit cathodic polarization behaviours similar to noble metals such as platinum[9] which make them very effective cathodes.

CORROSION CONTROL

Internal

The principal method of addressing an internal corrosion control problem is to install a fiberglass reinforced polyester lining often to a thickness of 125 mils which is not only applied to the bottom but also about a 0.5 m up the side walls[10]. The major disadvantage of this method involves its reliance on the integrity of the bottom plate for successful performance. If the bottom plate is weakened due to external corrosion, then it is possible through bottom plate warping and fluctuating during filling and emptying for the lining to fatigue crack. Accordingly, internal lining can be expected to give good performance providing the substrate metal remains intact. To counter bacterially induced corrosion, biocides are often added to the product. Also, where moisture is expected to collect by condensation or precipitation as in the case of fuel oils, inhibitors such as sodium nitrates can be added to the product. Floating roof as opposed to fixed roof tank structures are useful in preventing condensation and atmospheric induced corrosion. Tank bottoms exposed to continuous moisture such as ballast water tanks can be cathodically protected internally.

External

When severe external corrosion is discovered, the tank bottom is often replaced at a relatively high cost (eg. $1,000 - 2,000 per foot diameter). On the other hand if the structural integrity of the tank is not threatened by the corrosion loss, cathodic protection is a very practical alternative and indeed the only economical one since typical costs are less than $300 per foot diameter.

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 6. This corrosion cell can cause perforation sooner on the new bottom than would normally occur.

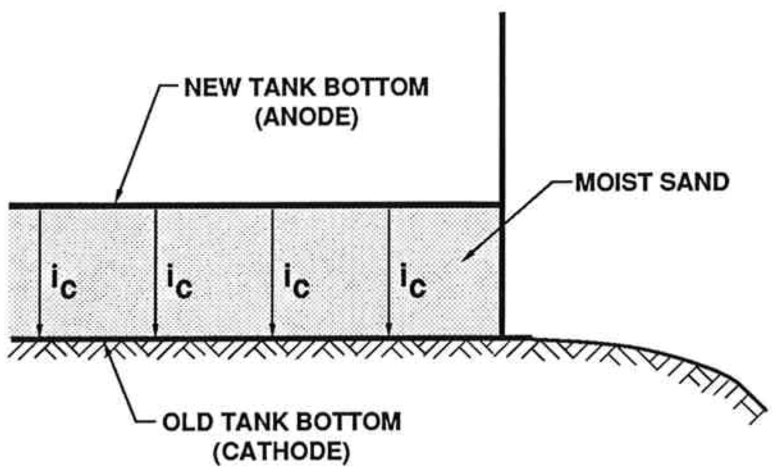

FIGURE 6 – CORROSION CELL DEVELOPED BETWEEN NEW AND OLD TANK BOTTOM

CP Methods

A major objective in providing cathodic protection for the external surface of flat bottom storage tanks is to obtain uniform current distribution and hence uniform corrosion control. This can be difficult to achieve since it has been mathematically demonstrated by Ewing and Hutchinson[11] that primary current distribution (eg. neglecting polarization effects) will produce a CP 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. For instance, the potential between a reference electrode and the bottom plates was measured on a 177 foot diameter gas storage vessel with a cathodic protection current being discharged from an 8" diameter abandoned pipe located on one side of the tank. The resulting voltage profile between the outside edge of the bottom and the centre is shown in Figure 7. Here the potential of approximately -0.40V is substantially less than -1.50V near the outer edge which dramatically illustrates the lack of CP current distribution to the center compared to the outer edge.

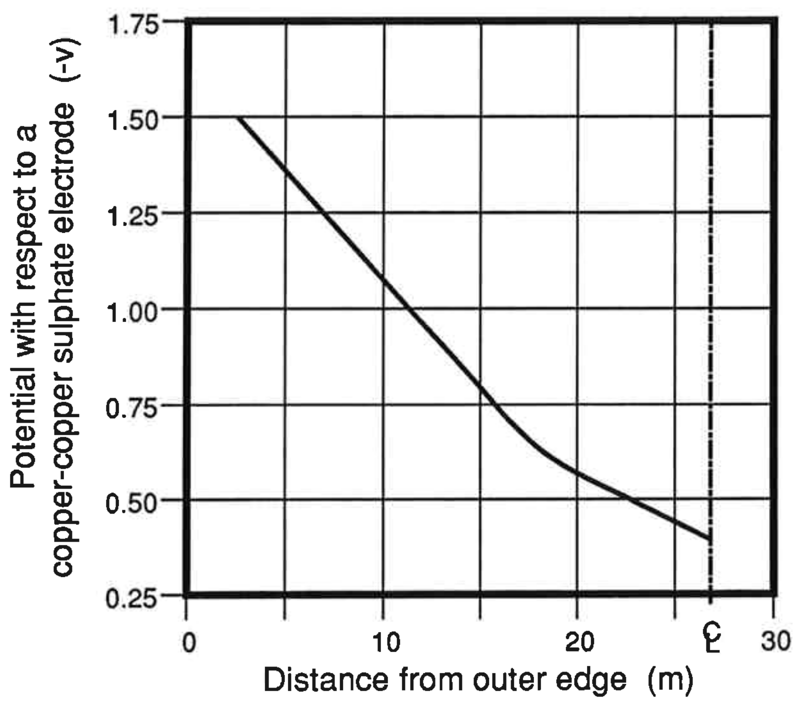

FIGURE 7 - TANK POTENTIAL PROFILE [12]

When the current is well distributed as in the case of locating anode materials around the periphery of the tank structure as shown in Figure 8 then a more even and uniform current distribution

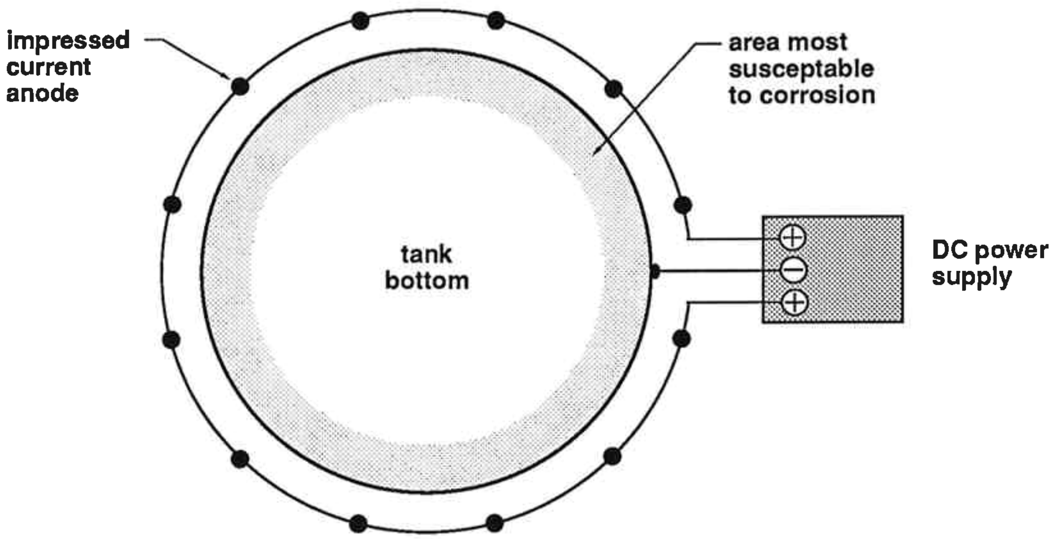

FIGURE 8 - DISTRIBUTED CATHODIC PROTECTION ANODE ARRANGEMENT

can be expected providing the soil is of relatively homogeneous nature and low electrical resistivity. Although CP can be achieved using sacrificial anodes[13], the high current requirements usually require impressed current CP systems. In low resistivity soils, with the application of cathodic protection 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 [1, 2, 13, 14]. Where high resistivity earth conditions prevail such that the distributed system would not provide uniform current distribution, a more innovative anode arrangement has been proposed by Garrity [15] which 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 9. This installation requires more sophisticated construction methods than does a simple vertical or horizontal anode installation around the perimeter of the tank.

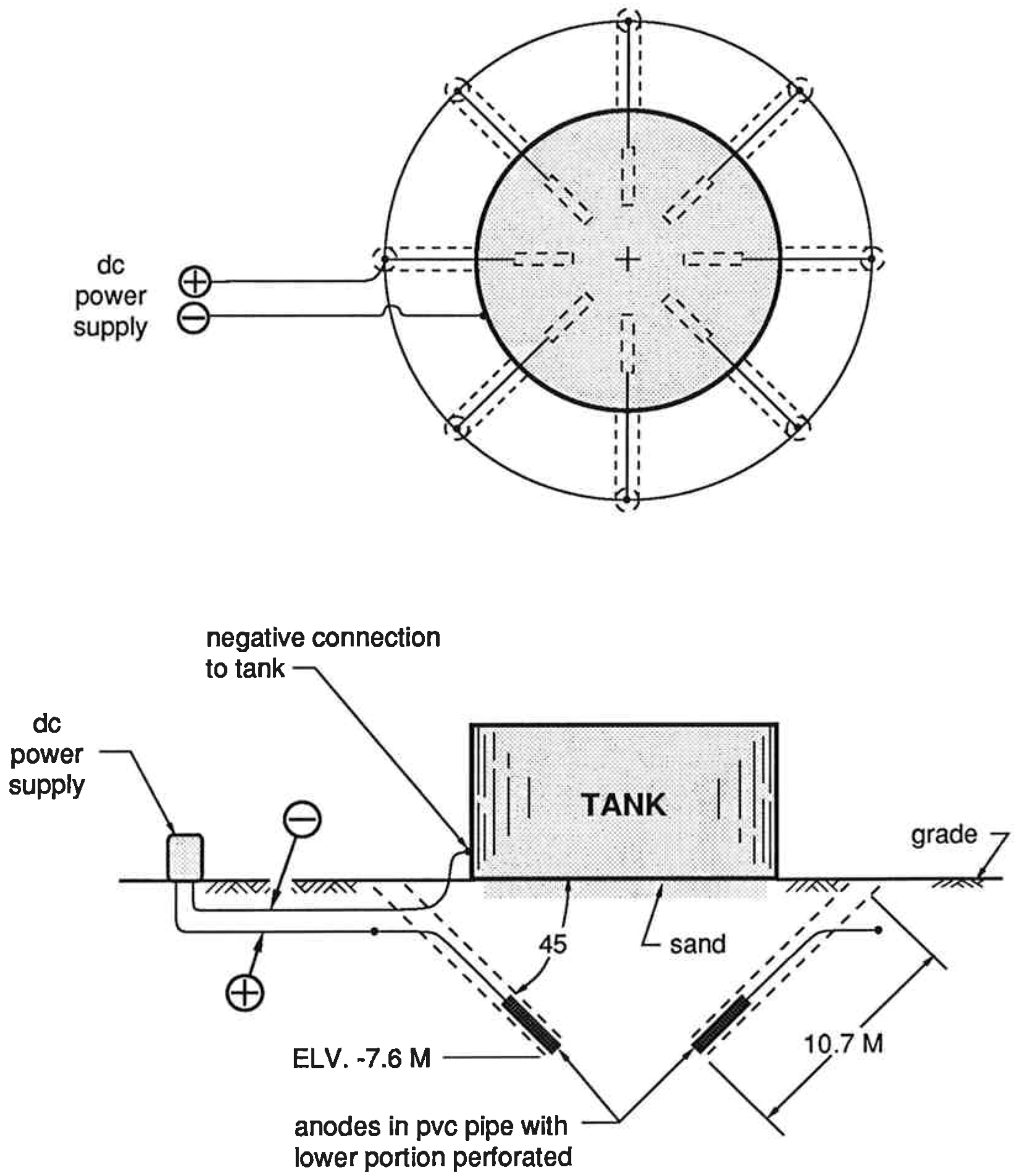

FIGURE 9 - ANGLED, IMPRESSED CURRENT ANODES

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 10. 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 fixed to produce an optimum anode life. Advances in electronics has now made this type of system practical and economical.

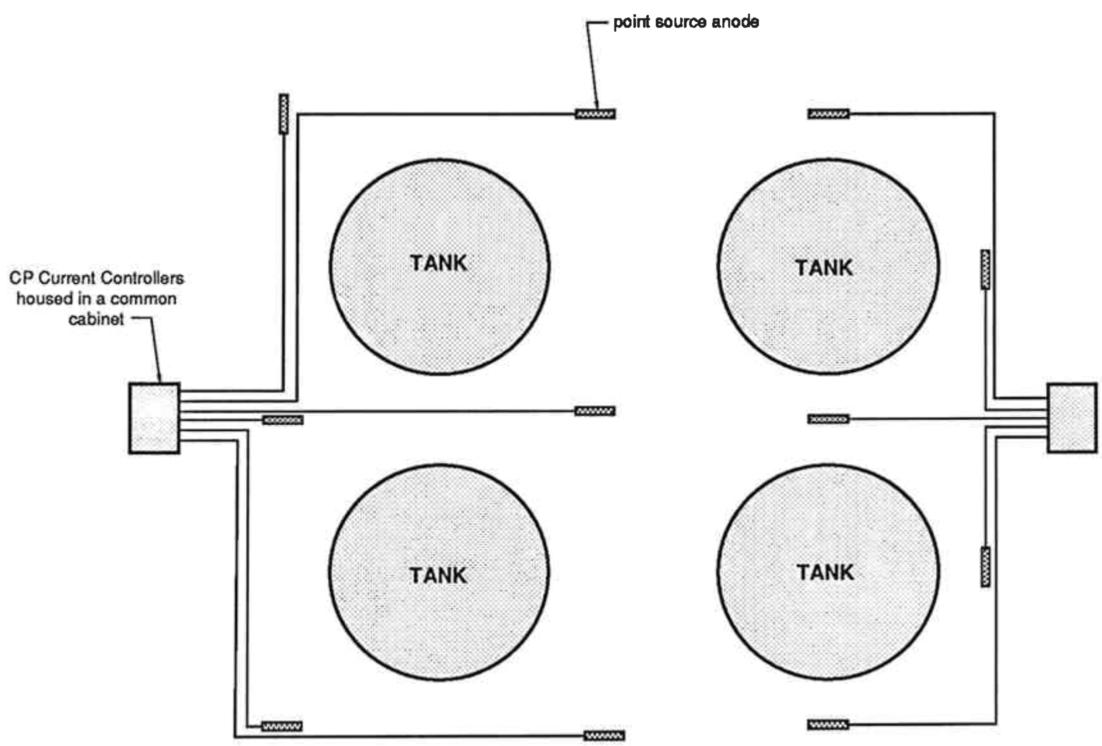

FIGURE 10 - CP OF TANK FARM USING INDIVIDUALLY CONTROLLED DISTRIBUTED ANODES

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 sq. foot of tank bottom surface area is sufficient to achieve satisfactory protection from corrosion for ambient temperature 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 11, is applicable in situations where the tank bottom is being replaced with a new tank bottom but requires that a circumferential ring be removed

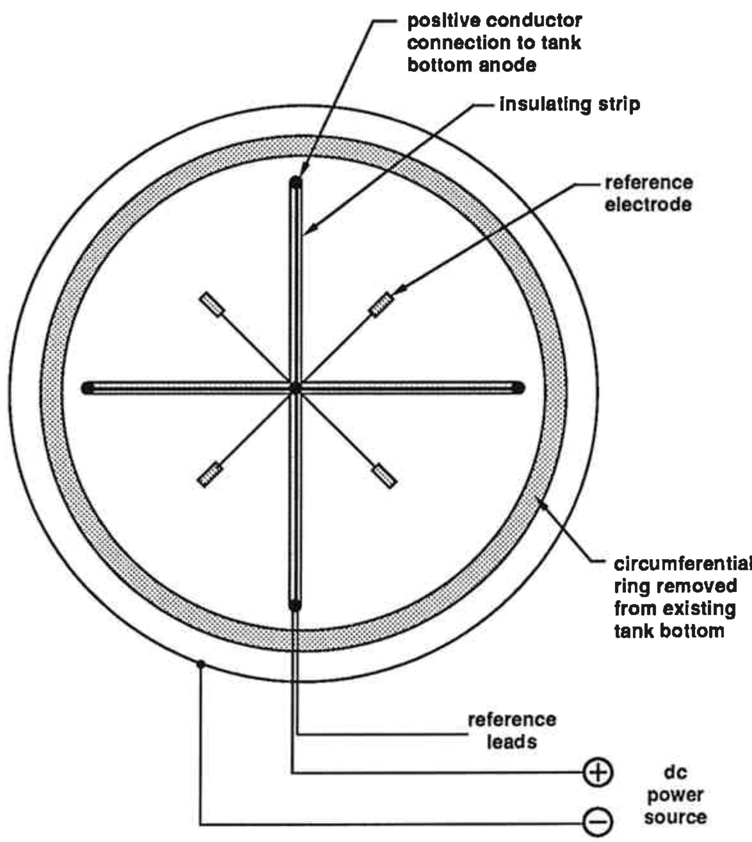

FIGURE 11 - USE OF EXISTING TANK BOTTOM AS AN IMPRESSED CURRENT ANODE

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 in order to ensure that electrical continuity is not lost by the anode plate corroding preferentially near the connections. Furthermore, 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 CP current. This type of cathodic protection system is not only extremely effective but is particularly economical, usually costing less than $150 per foot of tank diameter.

INSPECTION OF TANK BOTTOMS

Extensive internal corrosion is easily identified by a visual inspection after the tank has been taken out of service and properly cleaned. Localized pitting can be remedied by welding and generalized thinning can be addressed with a plate overlay repair. Corrosion on the external surface is more difficult to identify but a comprehensive ultrasonic thickness test can identify a corrosion pattern or be used to statistically calculate maximum pit depths. Removal of sample coupons to examine the bottom in more detail is also beneficial in order to assess the degree of corrosion activity and verify the non-destructive testing technique. If it is determined that cathodic protection is required, then reference electrodes should be installed during the inspection downtime. These are usually placed in the pad material beneath the tank floor to provide monitoring of the tank bottom potential after the installation of the cathodic protection system when the tank is back in service. On heated tanks the inspection should be concentrated around the outer 10% or 15% of the tank diameter and in the vicinity of the heating coil as these areas are the ones which usually experience the most severe corrosion. If the corrosion is not severe in this area, then it is unlikely that the corrosion will be worse anywhere else.

SUMMARY

The installation of a cathodic protection system to arrest corrosion on the soil side surface of flat bottom 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 cathodic protection 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).

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