CORROSION CONTROL
FOR
UNDERGROUND AND SURFACE
STORAGE TANKS

by

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TABLE OF CONTENTS

PART A – UNDERGROUND STORAGE TANKS

PART B – SURFACE STORAGE TANKS

PART A – UNDERGROUND STORAGE TANKS

A.1 BACKGROUND

The corrosion susceptibility of steel storage tank systems is now well recognized by government regulatory agencies and most Provincial governments in Canada have introduced legislation making it mandatory that new tank installations incorporate corrosion control equipment and that existing tanks and piping be upgraded to mitigate the impact of corrosion on the serviceability of the storage systems. The significance of these regulations are being repeatedly reinforced by ever increasing environmental constraints.

A.2 GENERAL CORROSION CONTROL METHODS

There are a number of standard corrosion control solutions that can be applied to storage tank systems and the choice of technique or combination of techniques will depend to a large extent on whether a storage system is new or existing and to a lesser extent on the environmental sensitivity of the location. A number of these corrosion control techniques are discussed below.

A.2.1 Material Selection

The tank and piping material can be selected for its corrosion resistance when one is considering new or replacement installations. The principal choices are between steel and fiberglass reinforced plastic (FRP), although double-walled steel, double-walled FRP tanks, and stainless steel have been used on a limited basis. In all cases for steel tanks in new installations, cathodic protection is a mandatory requirement.

There is also the option of placing steel tankage inside a reinforced concrete vault which is drained. These steel tanks are usually not backfilled and hence do not require cathodic protection.

A.2.2 Environmental Control

Certain environmental aspects on both new and existing installations can be controlled to mitigate corrosion. For instance, backfilling the tankage with the appropriate backfill such as sand in the case of steel tanks and pea gravel in the case of FRP tankage ensures a homogeneous environment. The uniform backfill around a steel tank can eliminate the development of isolated corrosion cells owing to differential soil conditions. In addition surface paving and effective drainage can lessen the corrosivity of the environment by preventing the soil around the tanks and piping from becoming contaminated with corrosion accelerators such as chlorides from deicing salts. Also any improvement in drainage particularily at tank depth tends to keep the soil dryer thus minimizing the corrosion rate. In fact, many tanks that survive for more than 20 years are usually found to be in soils which are are relatively dry because of good drainage. Environmental control measures unfortunately are not recognized by the regulatory bodies as sufficient corrosion control.

A.2.3 Inhibitors

Inhibitors have a limited use for corrosion control on underground storage systems except for internal corrosion. An alkaline sodium nitrite inhibitor has been demonstrated to inhibit internal corrosion in domestic fuel oil tanks.[1] Inhibitors for external control are not practical, both because of a need for repeated application and also because of the possibility of introducing a pollutant into the environment.

A.2.4 Coatings

There are three fundamental types of protective coatings, namely; metallic, organic, and inorganic. For external corrosion control, organic coatings such as epoxy and urethane are the most widely used. ULC Standard S616-M, 1981 is a coating standard that covers the testing required to qualify any organic coating. Metallic coatings, such as zinc galvanizing, have been used in the past, for piping.

A recent panel of experts on corrosion assembled by the U.S. Environmental Protection Agency commented that the zinc galvanizing was inadequate corrosion protection. This expert panel stated that "galvanized pipes should not be used in the underground piping of UST systems because the zinc coating does not serve as a cathodic protection anode and in the long term, the galvanized pipe has the same corrosion rate as bare iron and steel pipe."[2] Since all new UST installations containing underground metal piping must be cathodically protected, there is no advantage in using galvanized pipe. In fact, the new edition of ULC 603.1M will require that galvanized piping be cathodically protected.

Concrete is the most common form of inorganic coating but it is not usual, in this country, to apply it to steel tanks and piping, although it is a common practice in England, where a minimum of 6" of concrete must surround all tanks and piping. Normally when steel is surrounded by concrete, it develops a passive film which inhibits corrosion activity.

The application of a protective coating to the external surface is a practical solution only on new installations, although internal linings have been applied to existing tankage. Indeed this application of an internal lining is generally recognized by most provincial regulatory bodies as an acceptable method of up-grading existing steel tanks. This is often done in accordance with API-1631, recommended practice for the entire lining of existing steel underground storage tanks.

A.2.5 Cathodic Protection

The only electrochemical technique that can be applied to both new and existing underground storage systems is cathodic protection which involves forcing a DC current to flow across a tank/soil interface thereby causing a required change in electrical potential across the interface as shown in Figure 1. There are two basic types of cathodic protection systems namely, galvanic and impressed current as illustrated in Figures 2(a) and 2(b).

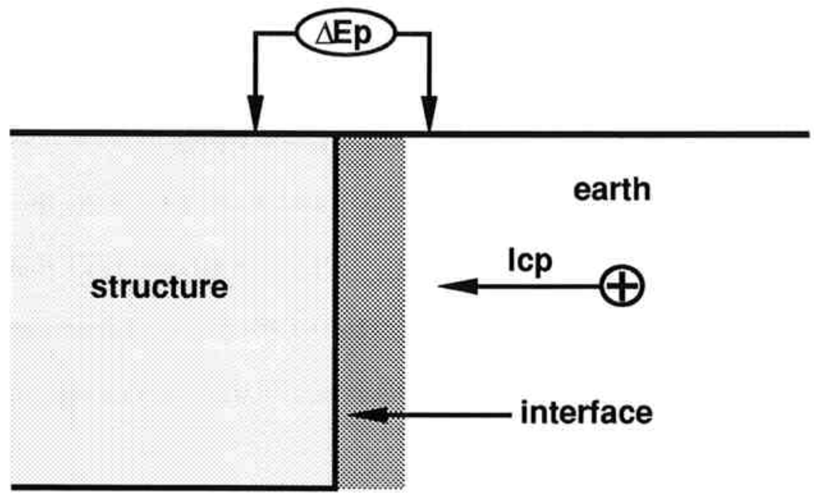
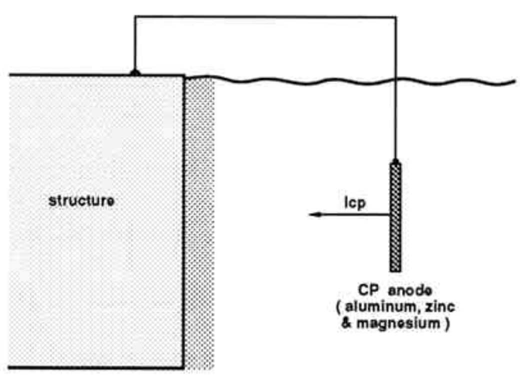
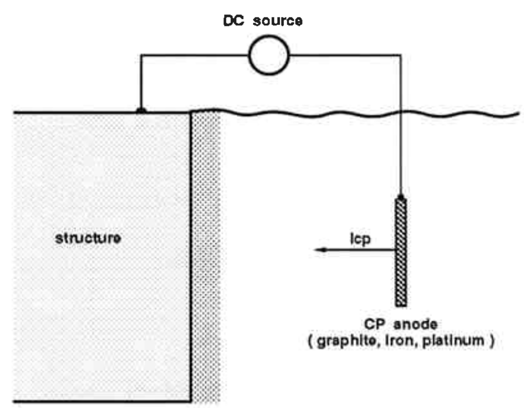


FIGURE 1



GALVANIC CATHODIC PROTECTION

FIGURE 2(a)



IMPRESSED CURRENT CATHODIC PROTECTION

FIGURE 2(b)

Galvanic cathodic protection systems consist of attaching rods that are cast or extruded made of alloys of metals having a high corrosion reactivity (anodes) to metals with a lower corrosion reactivity (structures) thus forming a corrosion cell in which the structure requiring protection is forced to become a cathode surface in its entirety. When protecting ferrous structures alloys of magnesium, zinc and aluminum (sea water only) are commonly used. These materials corrode to produce a corrosion current which flows to the structure causing a beneficial potential shift across the interface, thereby reducing corrosion. In most soil applications these anodes produce only a few milliamperes of cathodic protection current and are therefore limited in their application to protecting small structure surface areas such as on well coated tanks.

Galvanic cathodic protection is generally applied to new tanks in accordance with ULC Standard S603.1 M1982 entitled "Standard for Galvanic Corrosion Protection Systems for Steel Underground Tanks for Flammable and Combustible Liquids". Since it would be difficult to retrofit to existing tankage unless the existing tankage had been coated originally in accordance with the ULC S616M Standard.

Impressed current cathodic protection systems utilize an external source of power, usually an AC transformer/rectifier combination, which supplies DC current to corrosion resistant anode materials such as graphite, high silicon cast iron and platinum-clad niobium. These materials have a low electrochemical consumption rate compared to galvanic anode materials and hence provide a longer service life at the larger CP currents at which impressed current systems operate. Typically a single impressed current system can protect steel surface areas, many times larger than can a single galvanic anode. Impressed current cathodic protection is most commonly applied in a retrofit manner to existing tankage in accordance with PACE report no. 87-1. This technique can also be applied to ULC 603.1 tanks or to the occasional location where a bare and unprotected steel tank can be nested with some existing tanks, and the entire group cathodically protected.

A.3 NEW INSTALLATIONS

The primary choice for new storage system facilities is principally between a steel tank protected in accordance with ULC 603.1M Standard and an FRP tank. On average there is little cost advantage for either steel or FRP. The expectation of having an FRP tank last a minimum of 30 years, which appears to be not only a practical but also a conservative estimate, has considerable appeal to owners of fuel storage systems.

There is no reason however that the ULC 603.1M tank would not last equally as long or even perhaps longer than an FRP tank providing the cathodic protection system was replaced when required. Theoretically, as long as the cathodic protection is maintained on the outside of the steel tank then it should remain free of serious external corrosion and provide a measurable structural strength advantage over FRP. It should be recognized that plastic materials will experience a deterioration in their structural properties with time and hence the question remains as to how rapid is the deterioration. At this point, the typical life expectancy is not known, although certainly a greater than 30 year life can easily be anticipated based on current performance of FRP tanks.

The corrosion control features of the ULC 603.1M steel tank are illustrated in Figure 3.

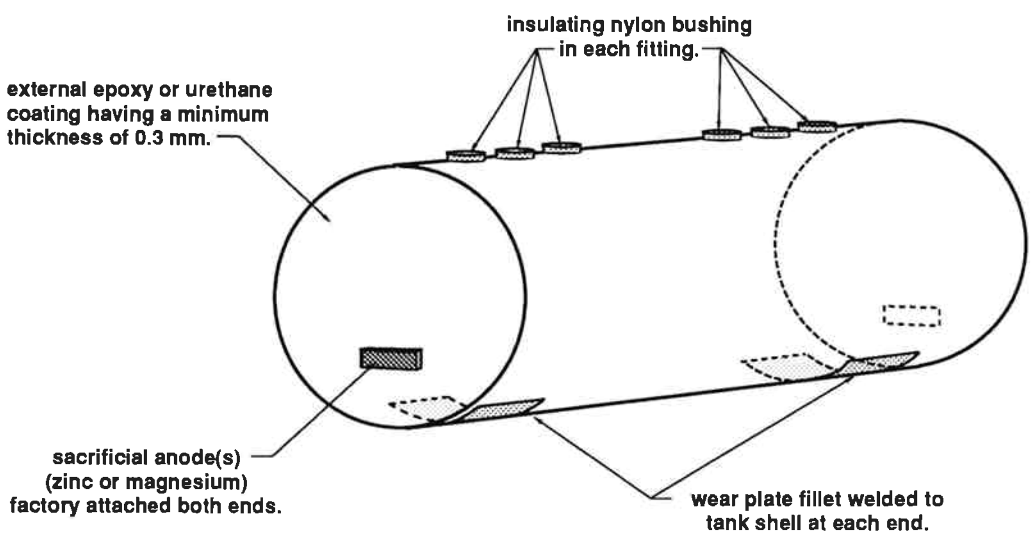


FIGURE 3 - SCHEMATIC OF CORROSION CONTROL FEATURES ON ULC 603.1M STEEL TANK

The external surface of the tank is coated with epoxy or polyurethane having a minimum dry film thickness of 0.3 mm and conforms to ULC Standard S616-M 1981 in other respects. In addition, there are nylon insulating bushings placed in all the tank entries in order to both interrupt any galvanic interaction between the tank and its associated piping, as well as to electrically isolate the tank from the piping to ensure that the factory attached galvanic anodes will effectively protect the tank. The cathodic protection system consists of two or more galvanic anodes, bolted on opposite ends of the tank. These anodes are either zinc or low potential magnesium alloys packaged in a select backfill of gypsum, bentonite and sodium sulphate.

Internally protection is provided from the erosion-corrosion cell that is set up as a result of the gauging operation` by inclusion of two wear plates placed directly beneath each of the tank entries and fillet welded on all sides to the tank shell. The wear plates were only introduced to the ULC 603.1 M programme in the 1982 revision and there is not sufficient information yet as to the success of this feature. It has been stated however by Mr. R. Wright of Underwriter's Labs of Canada at a recent expert panel gathered to discuss cathodic protection of underground storage tanks by Environment Canada that of over 34,000 listed 603.1 tanks none have leaked due to external corrosion.[3]

This performance history is very promising inasmuch as the first ULC tanks were being installed in the early '70's and this amounts to at least 15 years performance history on some tankage, although the early tankage did not have the internal wearplate and will be more susceptible to internal corrosion. There have been a few instances of ULC 603.1 tanks having corroded internally. Nevertheless, it is apparent that as long as cathodic protection is maintained externally and providing internal corrosion features presently being built into new steel tanks or retrofitted to existing ULC 603.1 tanks are effective, then a steel underground storage tank should remain leak-free from a corrosion point of view indefinitely.

A.4 EXISTING INSTALLATIONS

Many provincial government regulations permit the upgrading of existing underground steel tank installations by a number of methods, typically by:

a. replacement with ULC 603.1M steel tanks or FRP tanks

b. lining of the internal surfaces of the tank

c. the application of cathodic protection by the impressed current method

These upgrading methods are generally applied to tanks that have been installed either prior to the introduction of the ULC 603.1M standard and to any non-ULC 603.1M tanks.

A.4.1 Replacement

The most expensive method of upgrading existing tanks is by replacing the tankage. Not only are the excavating and material costs high, but there can be additional costs incurred when contaminated soil is encountered since there are an increasing number of government restrictions on disposing of hydrocarbon contaminated soil. Accordingly, upgrading by replacement cannot usually be justified on a cost-effective basis but rather is done when the capacity of the storage system needs to be increased, when a tank condition assessment has indicated that there is a high leak probability or when a leak test shows a failure. As mentioned above, replacement costs are often inflated if contaminated soil is encountered since its removal and disposal is often subject to intense scrutiny by environmental agencies.

A.4.2 Internal Lining

Lining of the inside surfaces of a steel tank is allowed in most regulations as an up-grading method. For instance, in Nova Scotia, the lining must be in accordance with API 1631 entitled "Recommended Practice for Interior Lining for Existing Steel Underground Storage Tanks". In Ontario, lining must be done in accordance with the Provincial Energy Branch Standard GH-10. Often the tank is only lined up to the half-way position on the tank shell because most internal corrosion is observed to be on the bottom of the tank. The GH-10 Specification refers to the same coating tests that are specified for the external coating of 603.1 tanks. In practice, the two principal lining systems consists of either a fiberglass mat either in one or two layers with the resin applied by a roller or epoxy with shredded fiberglass applied by spraying. The two layer fiberglass mats with the roller applied resin, resulting in a total lining thickness of 125 mils, is the superior lining system.

The major weakness of upgrading with an internal lining is that the lining relies on the structural integrity of the steel shell to maintain an effectively tight storage vessel. As external corrosion continues the steel substrate will become thinner leaving the tank subject to failure as a result of operational stresses. Accordingly, in Ontario all lined tanks must either be replaced or cathodically protected by year end 1995.

A.4.3 Retrofit Cathodic Protection

The installation of an impressed current cathodic protection system is permitted in almost all provinces as an upgrading method providing the system is installed in accordance with PACE Specification 87.1 entitled "Guidelines Specification for the Impressed Current Method of Cathodic Protection of Underground Petroleum Storage Tanks". This standard, first introduced in 1979, has been adopted by many of the major oil companies for retrofitting on existing storage facilities that in most cases were determined to have either a low risk of leaking or have been tested as leak-free. The general arrangement of this impressed current system is outlined in Figure 4. The system utilizes a packaged impressed current anode consisting of platinum clad niobium wire inside a 2" diameter EMT conduit containing calcined petroleum coke. Typically these anodes are in the order of 10 feet long and are commonly installed in 2 or 3 inch augered holes. The length of the anode is important

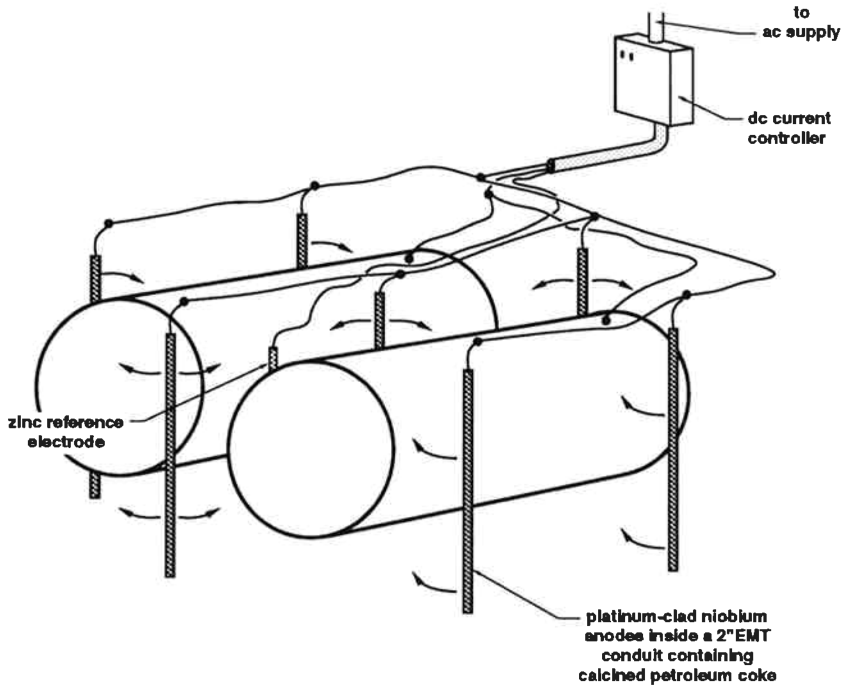


FIGURE 4 - TYPICAL IMPRESSED CURRENT CATHODIC PROTECTION SYSTEM IN ACCORDANCE WITH PACE SPECIFICATION 87-1

in obtaining uniform current distribution to both the top and bottom of the tank and the small diameter allows for insertion of the anodes between tanks where the distribution of protective current to the tank surfaces is most difficult. The anodes are connected to the positive terminal of a DC current controller and the negative terminal is connected to both the tanks and the tank piping using underground rated insulated cables. A zinc reference electrode must be inserted between each pair of tanks to sense the level of protection on either a continuous or intermittent basis.

Cathodic protection is by far the least expensive of the the upgrading methods but has the disadvantage of requiring periodic monitoring to ensure that the system remains operating at a level sufficient to arrest the corrosion. In order to simplify this surveillance process, remote monitoring equipment has been developed to allow the monitoring of the cathodic protection parameters via a telephone link.

The major weakness in the PACE 87-1cathodic protection system as shown is that it does nothing to address any potential internal corrosion problems. As the external corrosion is mitigated over a long period of time, it can be expected that the internal corrosion will eventually result in perforation unless some internal corrosion control measures are taken where needed.

A.4.4 Cathodic Protection Performance Monitoring

Whether or not the steel tank is a ULC 603.1 tank having galvanic anode cathodic protection or existing tanks with PACE 87-1 impressed current cathodic protection system, there are ongoing monitoring requirements. In the case of the ULC 603.1 tank the electrical potential of the tank relative to a copper-copper sulphate reference electrode must be measured as illustrated in Figure 5. Three readings are taken, one at each of three reference electrode positions (over each end of the tank and over the middle of the tank) with the connection to the tank being made via a temporary probe through the fill pipe making sure that the probe contacts the tank bottom. Generally this must be done following the installation of the tank before the installation is considered acceptable and then

CP Performance Monitoring

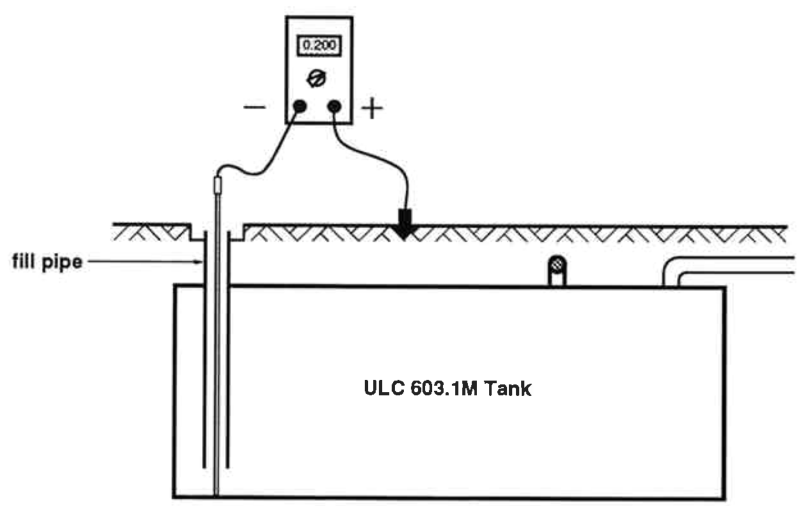


FIGURE 5 - MEASUREMENT OF TANK CATHODIC PROTECTION POTENTIALS

periodically ranging from every year to every two years thereafter. If the potential indicated on the voltmeter when taking this reading satisfies the criteria published by the National Association of Corrosion Engineers in RP01-69-92, then the tank is considered adequately protected.[4]

The field data survey requirements for PACE 87-1 impressed current systems are more onerous than for ULC 603.1 tanks. It is still necessary to measure the potential at three locations over each tank but in this case the protection current must be interrupted and the potential observed after the immediate disconnection of the current source. This "instant off" potential is compared to the minimum potential criterion of -850 mV, with reference to a copper sulphate electrode. In addition, the power supply of an impressed current system must be monitored on a monthly basis. This requirement is difficult to comply with for most companies if done manually. The installation of remote monitoring equipment,however, makes this requirement more manageable.

A.5 SUMMARY

New FRP and ULC 603.1 steel tanks have proven to be relatively immune to corrosion activity and therefore owners of underground storage systems can reasonably expect to realize a minimum of 30 years of corrosion free service from new tank installations.

Up-grading of existing steel tanks is a mandated requirement in most provinces. Both internal and external corrosion must be controlled in order to safely extend the service life of existing tankage. Although both cathodic protection and internal lining can be used independently to up-grade existing tankage, the combination of both will produce a superior corrosion resistant storage facility comparable to a new system.

A.6 RELEVANT STANDARDS

- Control of External Corrosion on Metallic Buried, Partially Buried, or Submerged Liquid Storage Systems, RP-02-85, National Association of Corrosion Engineers (NACE), Houston, TX.

- Galvanic Corrosion Protection Systems for Steel Underground Tanks for Flammable and Combustible Liquids, CAN/ULC 603.1M, Second Edition, Underwriter's Laboratories of Canada (ULC), Scarborough, ON.

- Magnesium and Zinc Anode Assemblies and Zinc Reference Electrodes, CAN/ULC-S618M, Second Edition, Underwriter's Laboratories of Canada (ULC), Scarborough, ON.

- Guideline Specification for the Impressed Current Method of Cathodic Protection of Underground Petroleum Storage Tanks, PACE Report #87-1, Petroleum Association for Conservation of the Canadian Environment, Ottawa, ON.

REFERENCES

1. Internal Corrosion in Domestic Fuel Oil Tanks, R. Wieland and R. Treseder, Corrosion, NACE, Vol. 10, 1954, p406.

2. Proceedings and Recommendations of the Expert Panel on Corrosion for Policy and Standards Division, Office of Underground Storage Tanks, Environmental Protection Agency, EPA Contract No. 68017383, July 16, 1987.

3. Report of the Meeting of the Panel on Cathodic Protection of Underground Storage Tanks, September 11, 1987, Charlottetown, Prince Edward Island

4. 'Control of External Corrosion of Submerged Metallic Piping Systems', National Association of Corrosion Engineers (NACE), Houston, TX.

PART B – SURFACE STORAGE TANKS

B.1 BACKGROUND

The corrosion of surface 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.

B.2 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 6.

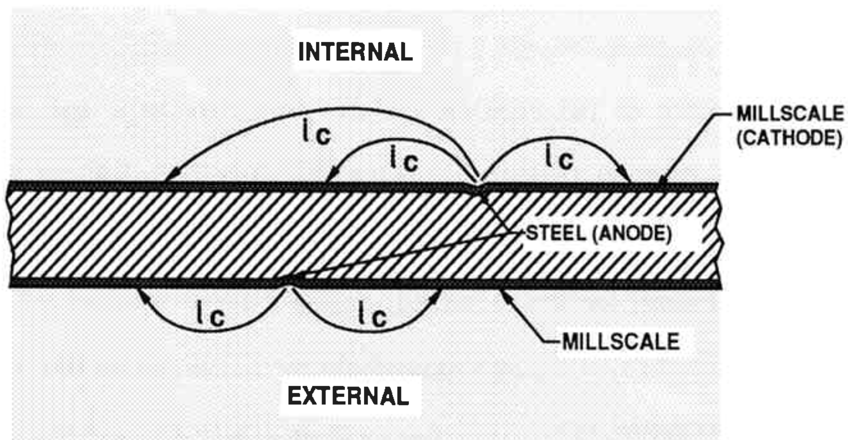


FIGURE 6 – CORROSION CELL BETWEEN STEEL AND MILLSCALE

Millscale is formed during hot rolling of the steel plates when the surface is oxidized by the air. A typical millscale would be about 15 μm 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 7[5].

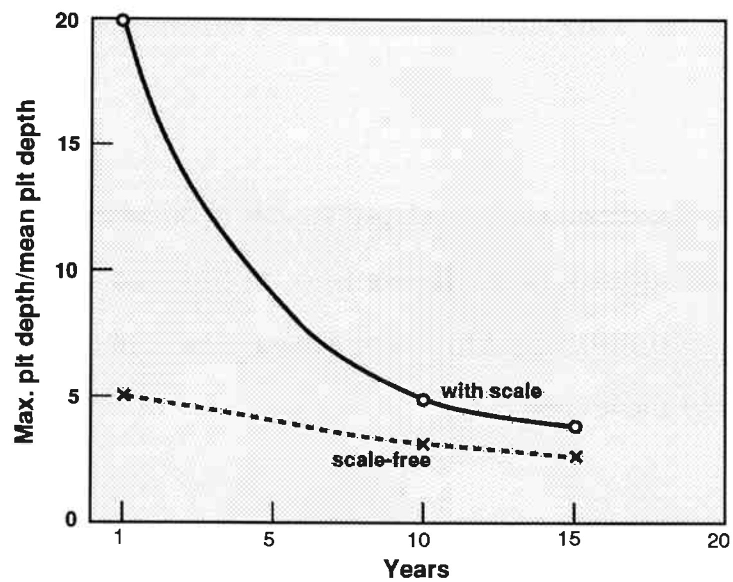


FIGURE 7 – EFFECT OF MILLSCALE ON PITTING OF STEEL IN SEAWATER

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 8.

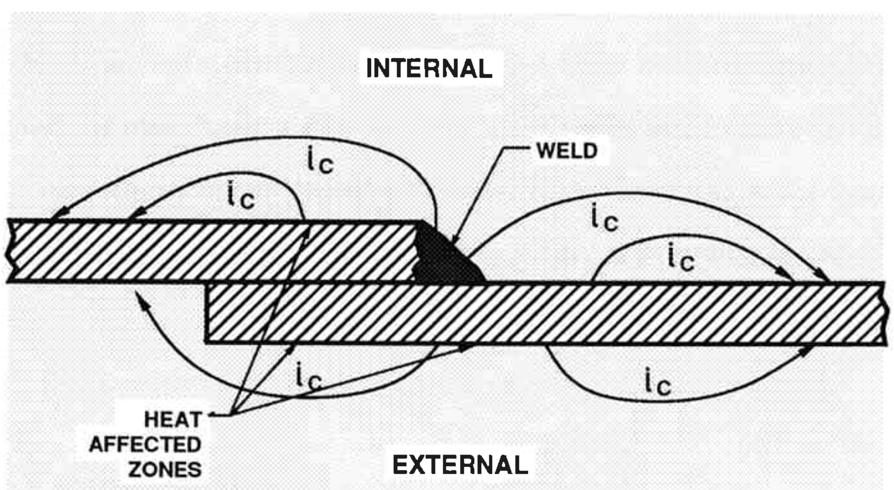


FIGURE 8 – CORROSION ACTIVITY IN THE VICINITY OF THE OVERLAP WELDS

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.

B.2.1 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 9, 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.

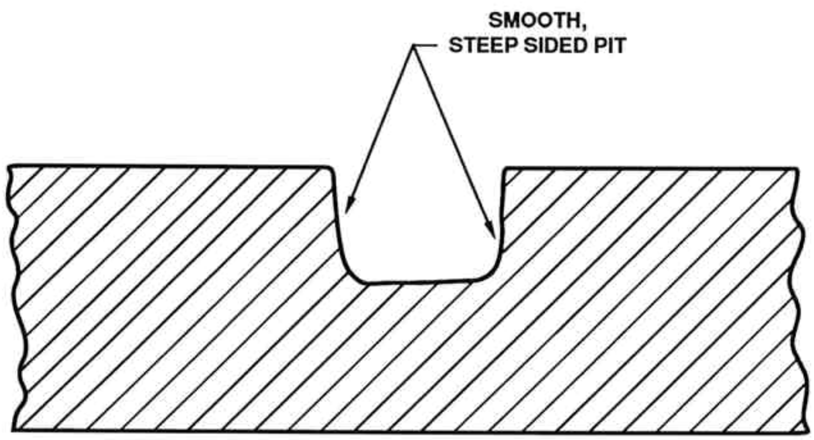


FIGURE 9 – CHARACTERISTIC APPEARANCE OF BACTERIALLY INDUCED CORROSION PIT

B.2.2 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 10. 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 continuous exposure to an extremely corrosive electrolyte.

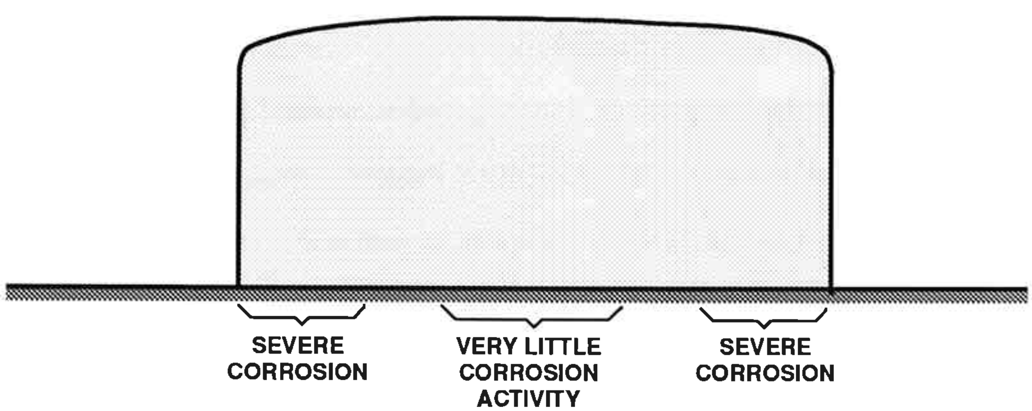


FIGURE 10 – CHARACTERISTIC CORROSION PATTERN ON THE UNDERSIDE OF SURFACE STORAGE TANKS

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.

B.3 CORROSION CONTROL

B.3.1 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.

B.3.2 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 11. This corrosion cell can cause perforation sooner on the new bottom than would normally occur.

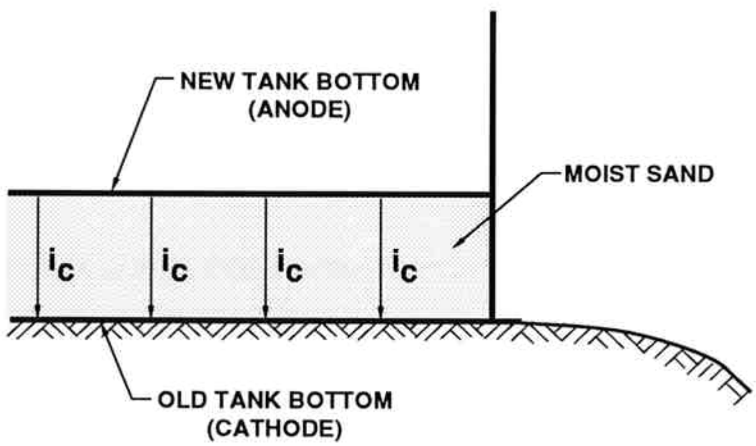


FIGURE 11 – CORROSION CELL DEVELOPED BETWEEN NEW AND OLD TANK BOTTOM

B.3.3 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 since it has been mathematically demonstrated by Ewing and Hutchinson[11] 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 current is well distributed as in the case of locating anode materials around the periphery of the tank structure as shown in Figure 12 then a more even and uniform current distribution can be

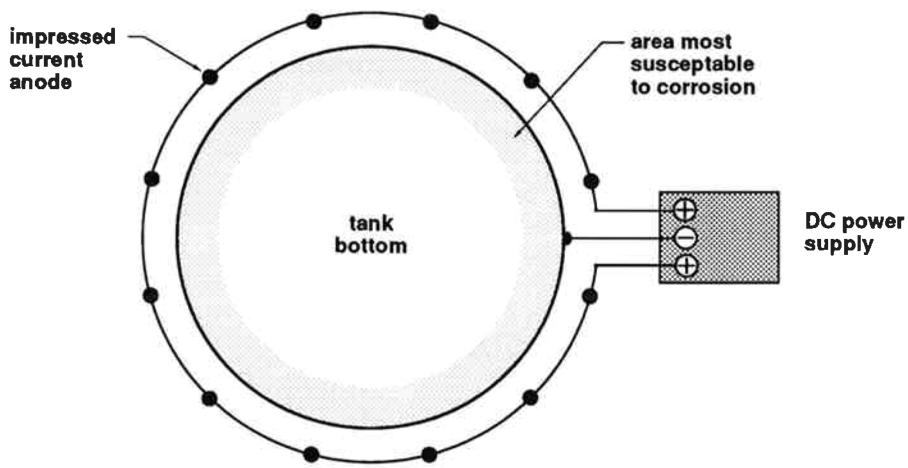


FIGURE 12 - DISTRIBUTED CATHODIC PROTECTION ANODE ARRANGEMENT

expected providing the soil is of relatively homogeneous nature and low electrical resistivity. Although cathodic protection can be achieved using galvanic anodes[13], the high current requirements usually necessitate the use of impressed current 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, 12, 13]. 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 [14] 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 13.

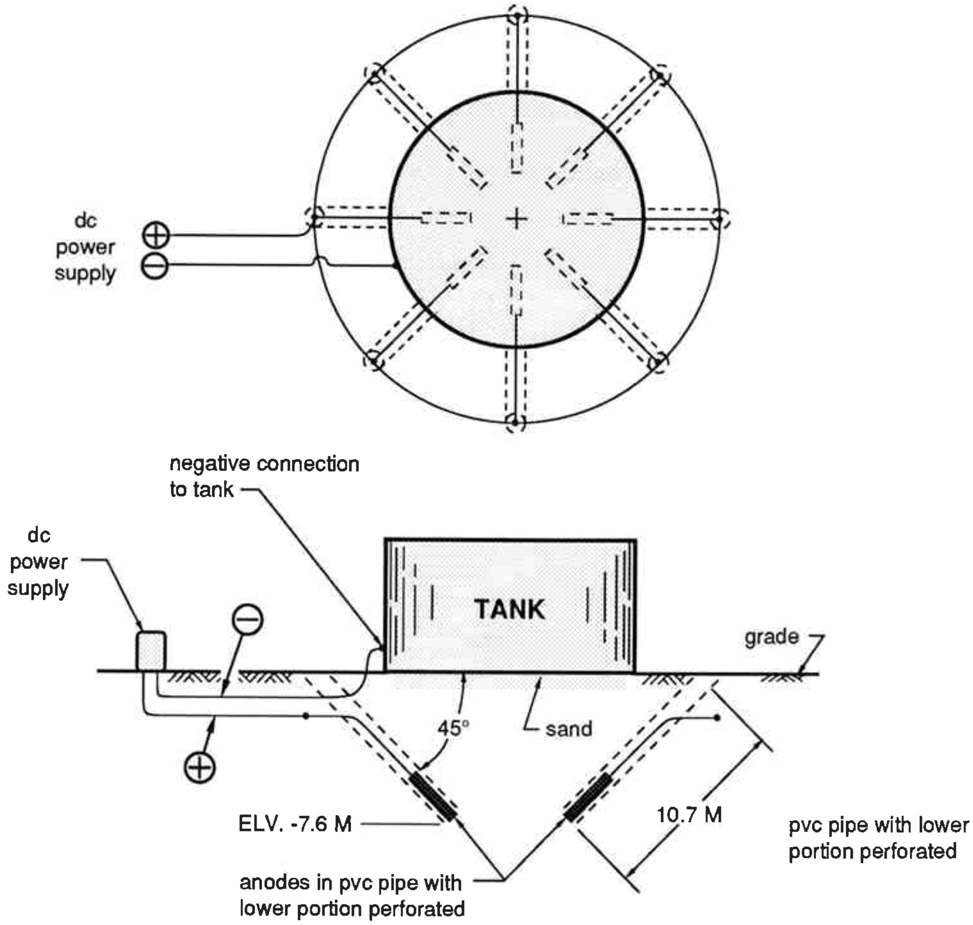


FIGURE 13 - ANGLED, IMPRESSED CURRENT ANODES

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 14. 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.

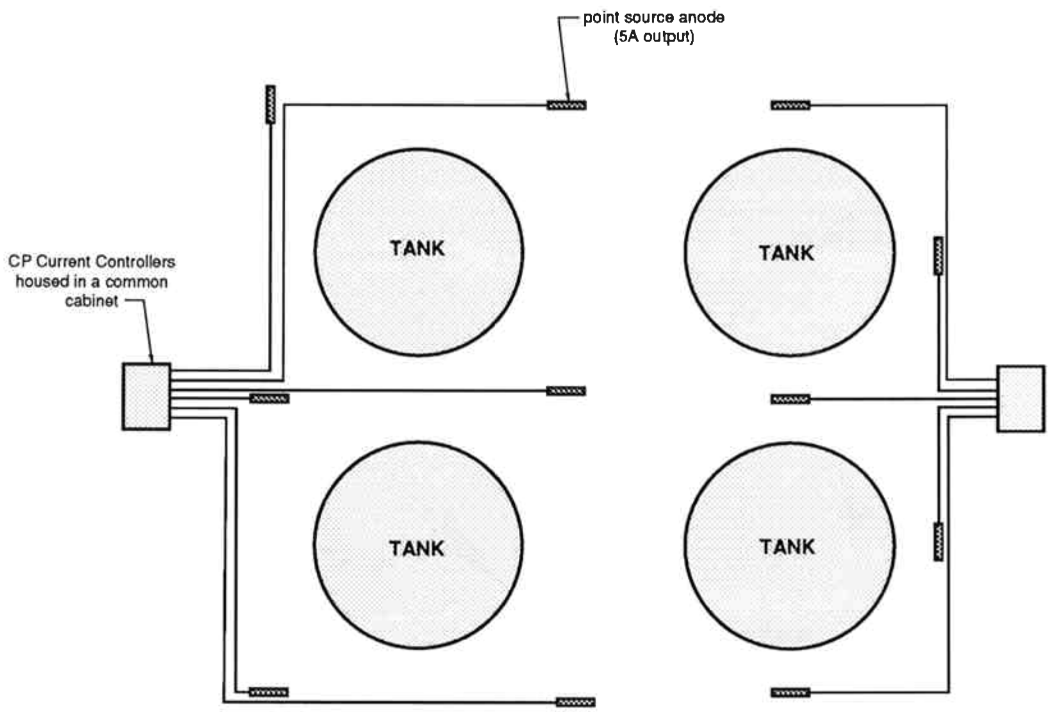


FIGURE 14 - CP OF TANK FARM USING INDIVIDUALLY CONTROLLED DISTRIBUTED ANODES

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 15, 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 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.

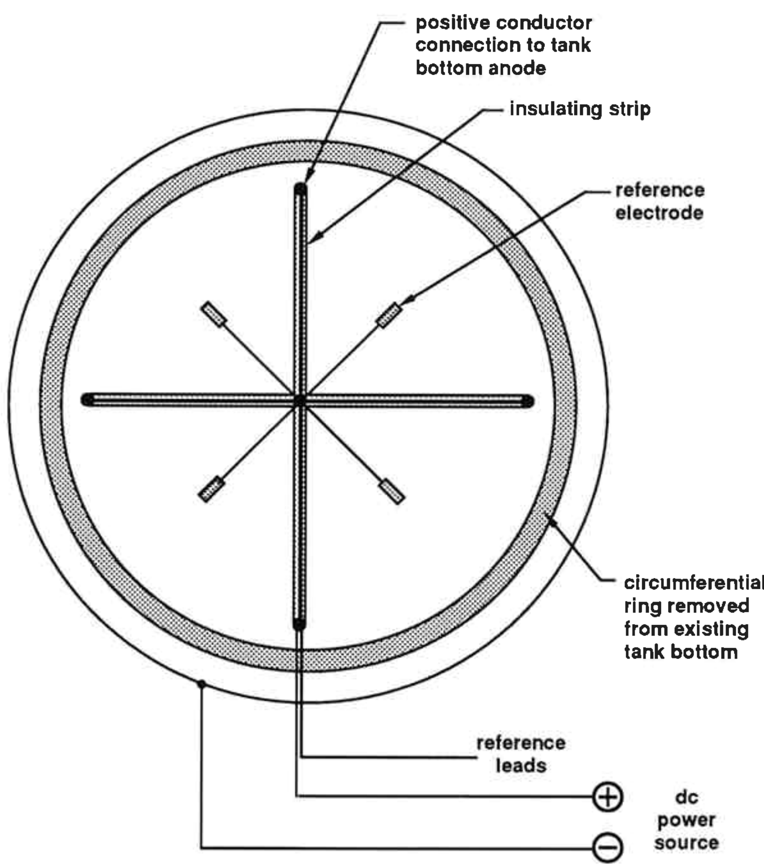


FIGURE 15 - USE OF EXISTING TANK BOTTOM AS AN IMPRESSED CURRENT ANODE

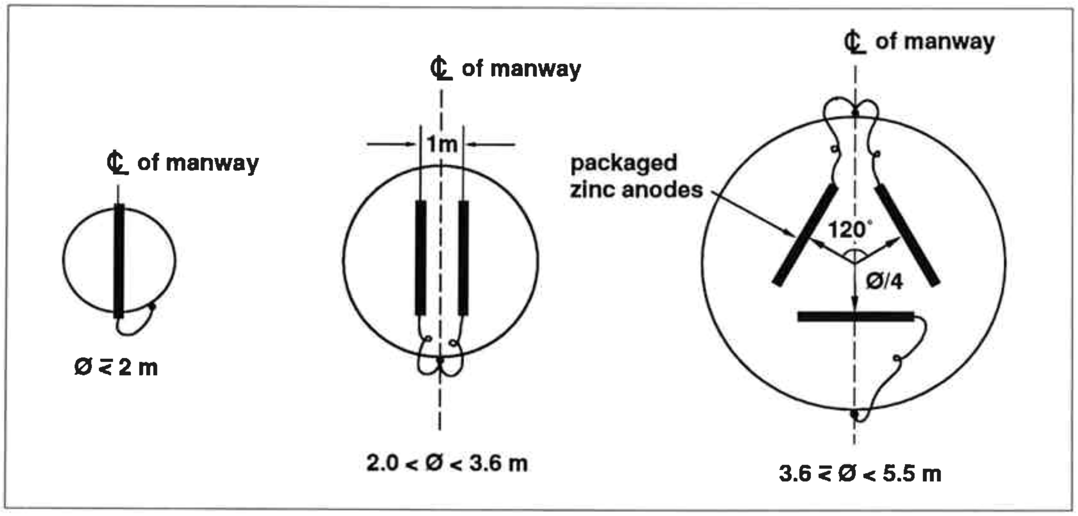
B.4 INSPECTION OF TANK BOTTOMS

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.

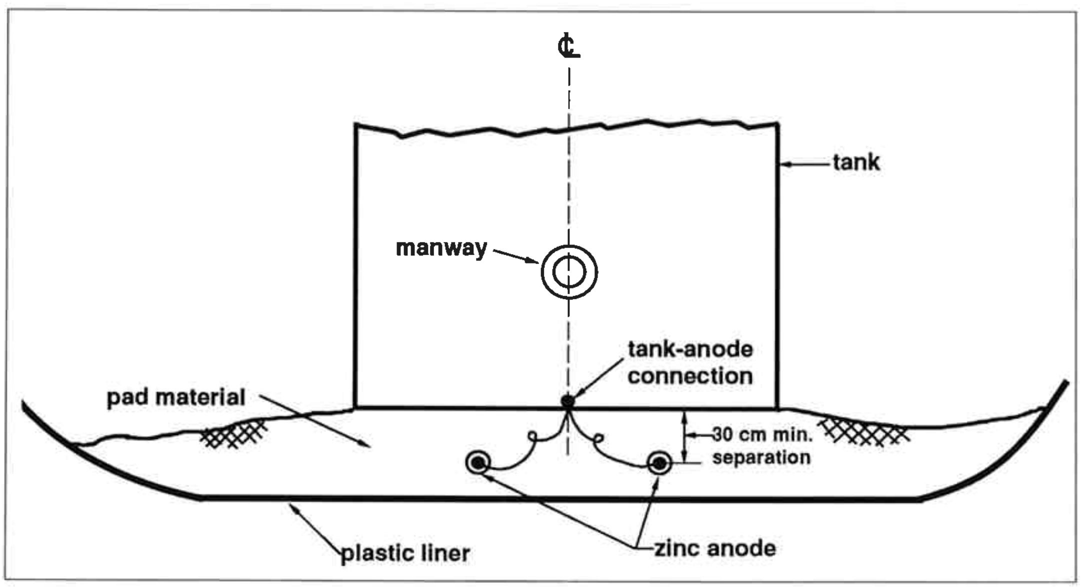
B.5 CATHODIC PROTECTION METHODS FOR NEW SURFACE STORAGE TANK WITH CONTAINMENT FACILITIES

Because 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 cathodic protection 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 16, to protect the steel at coating defects.



PLAN VIEWS



TYPICAL ELEVATION VIEW

FIGURE 16 - ARRANGEMENT OF PACKAGED ZINC ANODES FOR VARIOUS TANK DIAMETERS (Ø)

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 achieve protection. 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 17. The mesh impressed current anode has approximately the same surface geometry as the tank bottom.

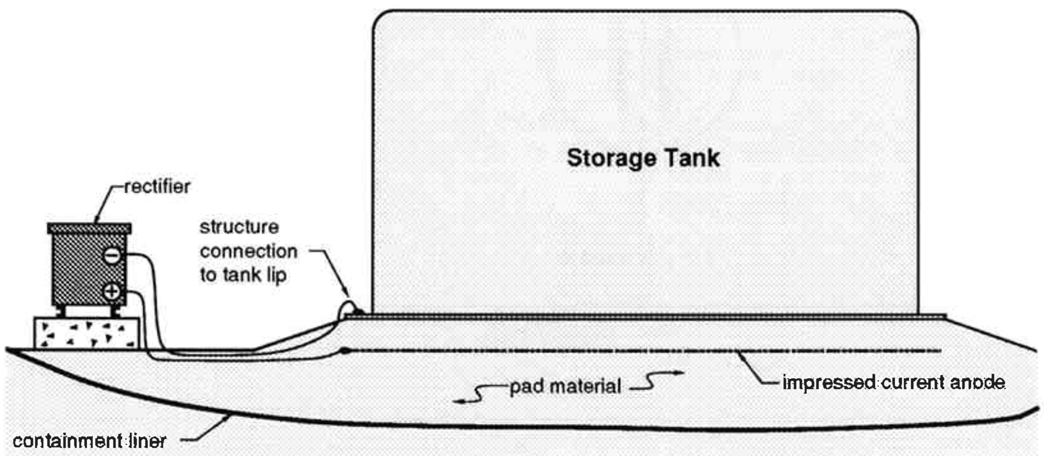


FIGURE 17 - CATHODIC PROTECTION OF FIELD ERECTED STORAGE TANK USING IMPRESSED CURRENT SYSTEM

B.6 SUMMARY

The corrosion causes and corrosion control options for surface storage tanks have been recently well documented.[15] The installation of a cathodic protection 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 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). New storage tanks having secondary containment liners which are also electrically insulating must have cathodic protection installed simultaneously with the tank because a retrofit installation would be economically prohibitive.

B.7 RELEVANT STANDARDS

- American Petroleum Institute (API) Recommended Practice 651 - Cathodic Protection of Aboveground Petroleum Storage Tanks
- PACE/CPPI - Environmental Code of Practice for Aboveground Storage Tank Systems (in committee draft form only)
- National Association of Corrosion Engineers (NACE)– Technical Committee T-10A-20 – External Cathodic Protection of On-Grade Metallic Storage Tank Bottoms - (Standard being prepared)

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