

# **CORROSION OF UNDERGROUND STORAGE TANKS AND PIPING SYSTEMS**

by

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### **BACKGROUND**

It has been estimated that 5 to 10% of the approximately 200,000 petroleum product storage tank systems in Canada are leaking and about 40 to 50% of these are a result of corrosion perforations in the tankage.\* External corrosion is responsible for about 85% of the observed corrosion failures, whereas internal corrosion and mechanical or metallurgical defects make up the balance.\*\* Corrosion is also instrumental in piping failures although joint leaks at screw couplings account for many of the piping leaks.

The primary cause of leaking steel storage facilities is corrosion and the continued acceptability of steel in the face of increased environmental protection regulations hinges on our ability to both understand the corrosion mechanisms and to apply conventional corrosion control techniques to both new and existing facilities.

\* *Leaking Underground Storage Tank Newsletter, Sept/Nov 1987, Vol. 1, No. 4.*

\*\* *Soil Characteristics as a Means of Determining Useful Life of Underground Tanks, Norman A. Kennedy, Underground Storage Tanks Technology Conference, June 1987.*

## CORROSION DEFINITION

Corrosion is generally defined as “the deterioration of a material usually a metal by a reaction with its environment”.\* Corrosion therefore in its broadest sense is equally applicable to the deterioration of non-metallic materials such as plastics, as it is to metallic equipment. The metallic corrosion process however, is distinctively an electrochemical one as illustrated in Figure 1, whereby atoms of a metal lose some of their structural bonding electrons and move freely into the surrounding aqueous environment as an ion (charged atom). This corrosion process produces an electrical potential difference ( $E_p$ ) across the interphase between the solution and the metal because of the charge separation.

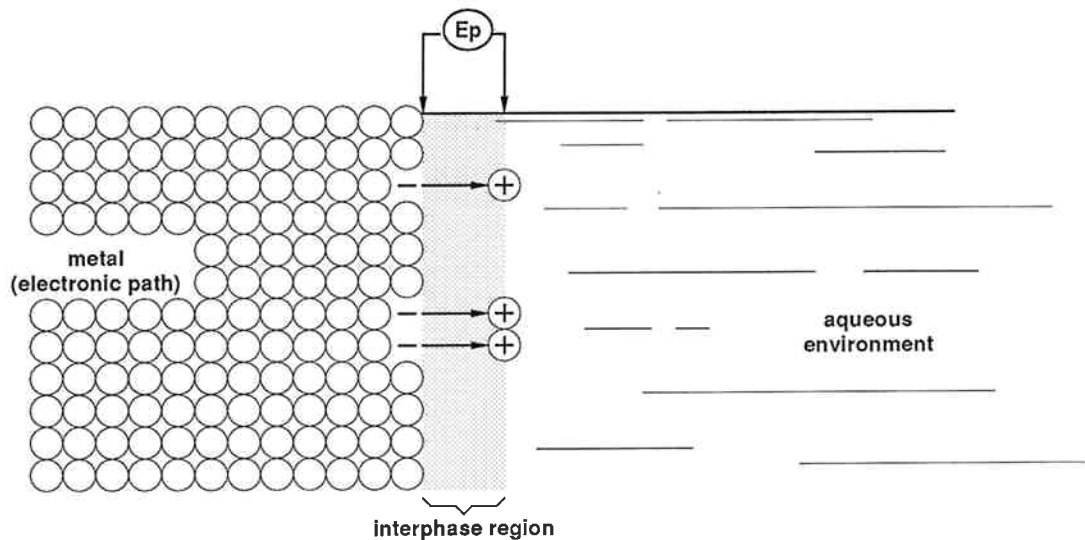


FIGURE 1 - METALLIC CORROSION

\* *Glossary of Corrosion Related Terms - National Association of Corrosion Engineers Houston, Texas.*

The general expression denoting this electrochemical corrosion process is given by the equation



which is an oxidation reaction since the net electrical charge of the metal atoms becomes more electropositive. For iron and steel structures, the equation is



As with all chemical reactions there must be a source of energy which powers the oxidation (corrosion) reaction. This energy, which can be thermodynamically calculated for a given metal in a given environment, is called Gibb's Free Energy which varies from metal to metal and from solution to solution.

When corrosion activity continues to occur, it does so only in the context of a developed corrosion cell as illustrated in Figure 2.

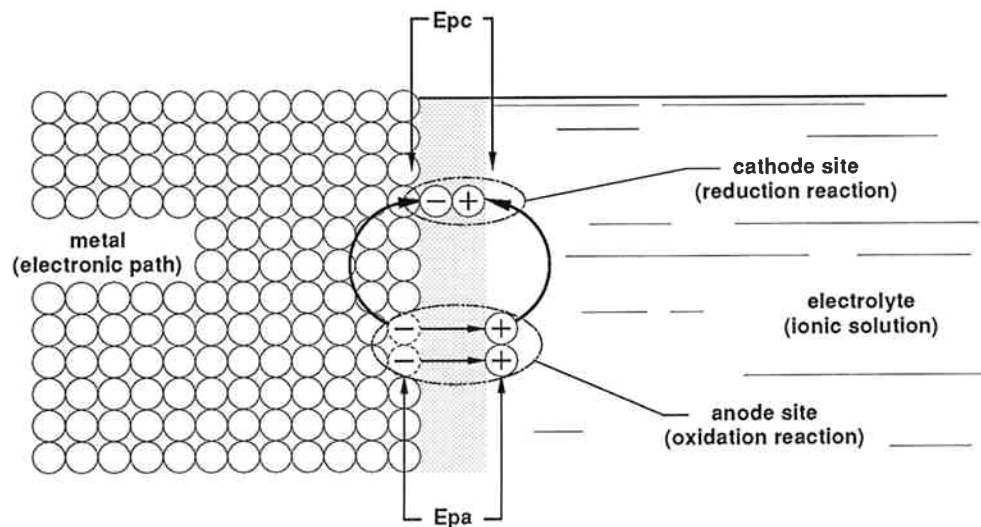
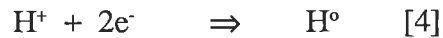


FIGURE 2 - SCHEMATIC DIAGRAM OF A CORROSION CELL

For corrosion activity to be sustained then, a corrosion cell composed of an anode site, a cathode site, an electronic path and an ionic path must be formed. Here corrosion occurs only at the anode site producing a potential difference  $E_{pa}$  and when this potential difference is greater than the potential difference of adjacent areas (eg.  $E_{pa} > E_{pc}$ ) then the charges will flow from the anodic site and be discharged at the cathodic site via a reduction reaction. Two common reduction reactions which are instrumental in transferring charge at the cathode are as follows:

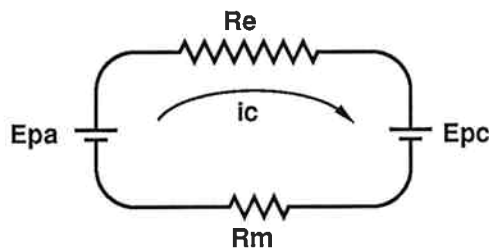


in aerated and neutral to alkaline pH solutions



in acid solutions

This corrosion activity is similar to a battery operation that can be modeled electrically by the equivalent circuit illustrated in Figure 3.



$i_c$  = Corrosion Current  
 $E_{pa}$  = Potential at Anode Site  
 $E_{pc}$  = Potential at Cathode Site  
 $R_m$  = Resistance through Metallic Path  
 $R_e$  = Resistance through Electrolyte

**FIGURE 3 - ELECTRICAL EQUIVALENT OF CORROSION CELL**

The speed with which the charge transfer takes place (eg. the magnitude of the corrosion current density) in a corrosion cell and hence the corrosion rate is directly dependent on the rates of respective oxidation and reduction reactions, the charge transfer path resistances ( $R_m + R_e$ ) and the net potential difference ( $E_{pa} - E_{pc}$ ) between the anode and cathode.

Steel and most other metals have a proportion of their Gibb's free energy available to power the fundamental corrosion reaction and hence these metals are subject to corrosion in most aqueous solutions. Whether or not corrosion results in an operational problem is determined solely by the corrosion rate, all other things being equal. The corrosion rate accordingly, is to a large extent dependent on the characteristics of the corrosion cell mechanism.

## **CORROSION MECHANISMS**

There are a number of different corrosion cells which are commonly established on underground fuel storage systems, and most of these originate from a distinctive difference from one location on the underground plant to another.

### **EXTERNAL CORROSION**

External corrosion produces by far the majority of corrosion leaks experienced in fuel storage systems on both piping and tankage. The examples of corrosion mechanisms pertinent to external corrosion on tanks are equally applicable to the piping. There are several major corrosion cell mechanisms which lead to external corrosion failures.

## Differential Aeration

A difference in oxygen availability (aeration) from one point to another on the storage structure will set up a differential aeration corrosion cell as illustrated in Figure 4(a) and 4(b). Oxygen is a corrosion accelerating factor since it is a reactant in the reduction reaction [3] at the cathode surfaces.

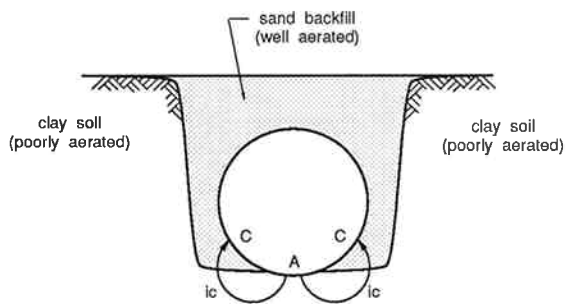


FIGURE 4(a)

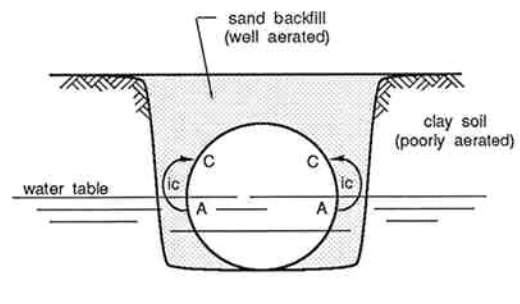


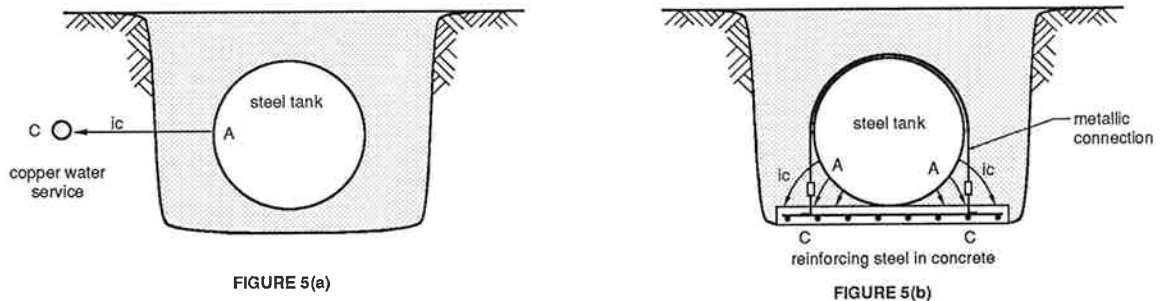
FIGURE 4(b)

FIGURE 4 - EXAMPLES OF DIFFERENTIAL AERATION CORROSION CELLS

In Figure 4(a) a differential aeration corrosion cell is created by the difference in oxygen content at the tank surface between the poorly aerated clay and the aerated sand, with the actively corroding (anodic) site being on the steel surfaces exposed to the clay. Even when the sand surrounds the tank as in Figure 4(b), a differential aeration cell can still form owing to the presence of a water table. In this latter case, water is typically less aerated than sand resulting in corrosion attack on the tank just below the waterline.

## Dissimilar Materials

Galvanic corrosion cells are often initiated on underground storage tanks owing to the fact that corrosion potentials of differing magnitudes are developed on different metals in the same environment and also on the same metal in different environments. For instance, Figure 5(a) exhibits a situation where the steel tank is an anode compared to a nearby copper water service whereby copper becomes a cathode of the corrosion cell. There must be an electronic interconnection between the tank system and the copper water service which is usually the case since all these structures are usually connected to electrical ground. Similarly steel in concrete, as in the reinforced concrete pad shown in Figure 5(b), is cathodic to steel which is exposed directly to the soil. This causes a corrosion cell to develop whereby the reinforcing steel is a cathode and the tank is the anode.

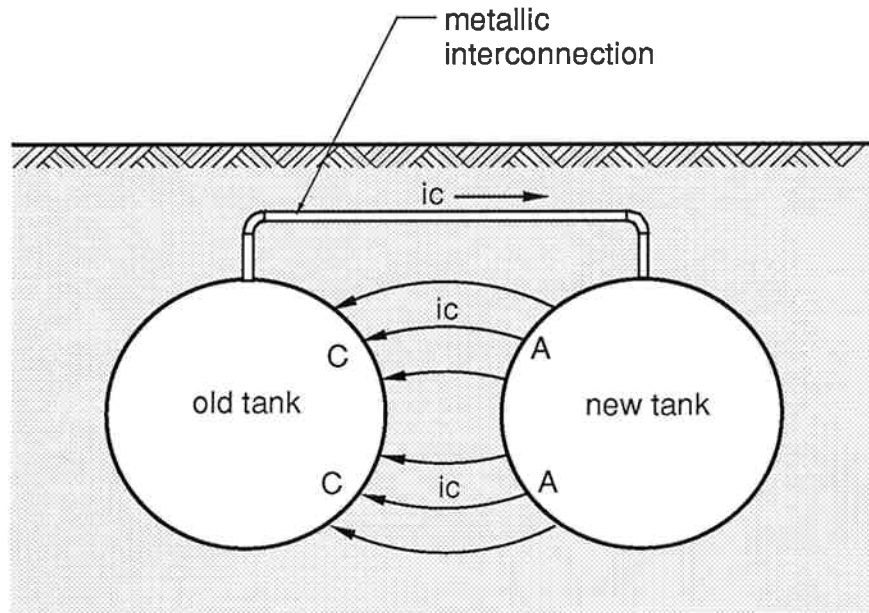


**FIGURE 5- DISSIMILAR MATERIAL CORROSION CELLS**

Another dissimilar material corrosion cell is illustrated in Figure 6 wherein the surface condition of an older existing tank makes it a cathode relative to a new tank surface. Usually an older tank surface will already be corroded to some extent such that its surface

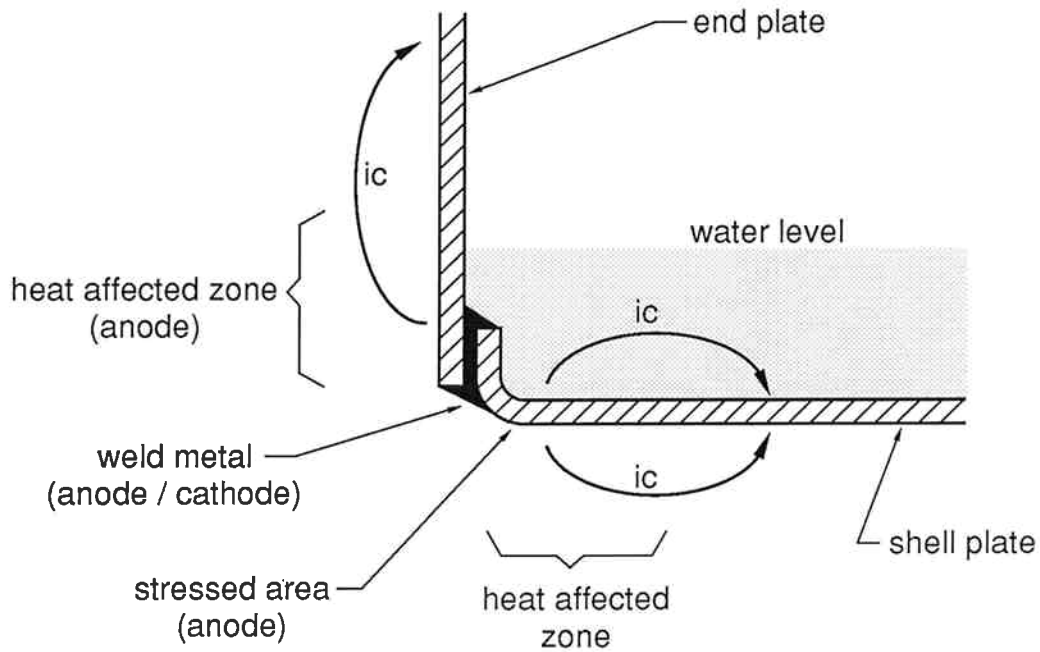


atomic structure will be covered by corrosion product. A new tank surface, particularly one which has been scratched during installation will have a greater corrosion potential than the older tank.



**FIGURE 6 - NEW/OLD STEEL CORROSION CELL**

There are a few other minor external corrosion causes such as stray currents, bacterial corrosion and surface metallurgical differences in the weld areas. Figure 7 shows a cross-section of a weld area in which there are both stress and heat affected zones, both of which can become anodic sites with respect to the rest of the steel tank shell. Furthermore the weld itself depending on the welding electrode alloy can either be an anode or a cathode relative to the surrounding steel shell. Internal corrosion can also occur as a result of this type of metallurgical surface difference.

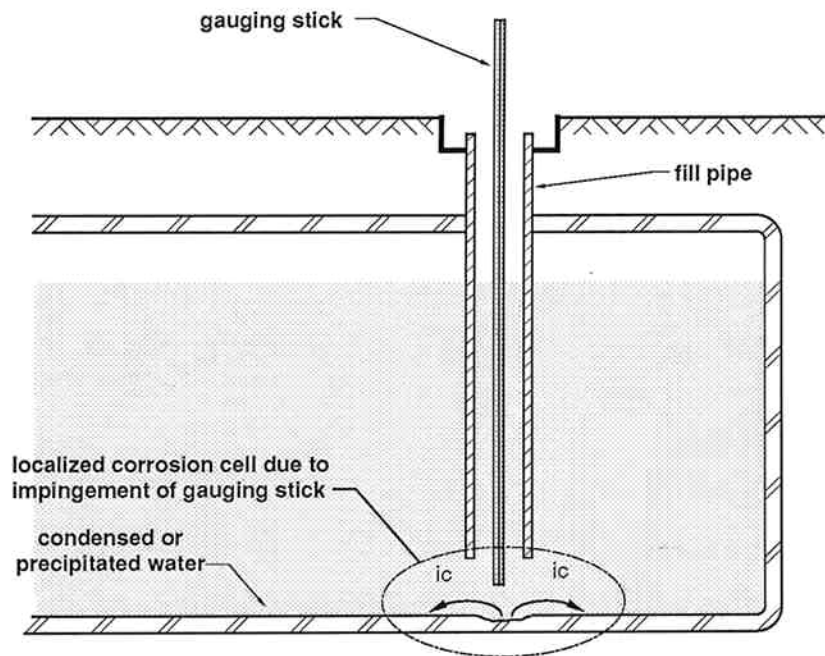


**FIGURE 7- DISSIMILAR SURFACE CONDITIONS CORROSION CELLS**

## INTERNAL CORROSION

Although at the present time internal corrosion causes a relatively small percentage of the total corrosion failures on underground tank and piping systems, it will, no doubt, represent an increasingly larger proportion as the external surfaces of existing steel tanks are cathodically protected. Internal corrosion could become the principal mode of failures if this situation is not addressed.

The corrosion mechanisms associated with bacterial corrosion and surface differences in the weld area apply to the internal surfaces of storage tanks as well as external surfaces, although they do not represent the principal cause of internal corrosion. Most internal corrosion perforations arise from an erosion-corrosion cell developed as a result of the fuel volume measurement procedure involving the insertion of a gauging stick through the fill pipe as is illustrated in Figure 8. The gauging stick impinges on the bottom of the tank



**FIGURE 8 - INTERNAL EROSION-CORROSION**

causing the removal of any protective corrosion product that is formed on the steel thus exposing new metal. This procedure repeatedly exposes a new metal surface of high corrosion energy. Obviously, water must be present on the bottom of the tank in order

for this kind of corrosion attack to originate or be sustained. It is quite, common for water to collect from moisture precipitating out of the product or from condensation of moisture in the air that is drawn in through the vent when the product is being pumped out. The amount of water which accumulates from condensation will not only depend on the frequency of emptying but on the atmospheric relative humidity. It is not surprising therefore that internal corrosion failures are more prevalent in coastal regions and in very humid coastal environments the principal cause of corrosion failures is usually internal corrosion rather than external corrosion. Product filling can also accelerate the corrosion owing to the impingement on the bottom of the tank of product flowing down the fill pipe causing a scouring of the tank surface and consequent removal of protective corrosion products.

## **CORROSION KINETICS**

The formation of corrosion cells on underground storage tank systems in the absence of any specific corrosion control measures is inevitable but their mere presence does not constitute a problem, unless the corrosion rates (eg. corrosion kinetics) are significant. For example a corrosion rate of 1 mil per year (mpy) would not be a serious corrosion problem on underground storage facilities, particularly on a storage tank having a wall thickness of 125 mils. However since many steel tanks have an average life before corrosion perforation of 10 to 20 years, then it is apparent that corrosion rates in the order of 10 mils per year or greater are normal. There are numerous factors such as temperature, aeration, area ratio, and earth electrical resistivity which influence the rate of corrosion.

Certainly in the case of internal corrosion, the frequency of gauging and filling will directly control the corrosion rate on the tank bottom.

#### AREA EFFECT

External corrosion is subject to the degree of aeration and the electrical resistivity of the earth surrounding the tank, as well as the surface area ratio between the cathode and anode sites. In Figure 4(a) for example, where the bottom of the storage tank was in contact with the clay, the anode area is relatively small with respect to the cathode surfaces. The resulting corrosion rate is almost directly proportional to the surface area ratio of the cathode to the anode. For instance, if the anode surface area and the cathode surface area were initially equal and the cathode surface was then increased by a factor of 10, the corrosion rate would similarly be increased by a factor of 10. Accordingly, many tanks which have been removed from the ground have exhibited severe corrosion on the bottom courses owing to this type of corrosion mechanism and the accelerating area ratio factor.

#### EARTH RESISTIVITY

All the mechanisms previously examined are subject to a large degree by the soil characteristics, not only aeration but also the electrical resistance of the soil path itself since the soil provides the current path for the corrosion current (see Figures 2 and 3). The electrical “resistivity” of the soil expressed in units of ohm-cm is the specific resistance of a given geometry of soil and is often measured to determine the corrosivity of soil. Soil

resistivities are directly affected by the concentration of ions in soil and its moisture content. The greater the concentration, the lower the resistivity. One source of increased ion concentration, particularly around service station tankage, arises from chloride ions contributed by the use of deicing salts. The chloride ion also is a corrosion catalyst in the sense that it will stimulate the oxidation reaction and yet will not be consumed in the corrosion process but remains in the soil to keep participating in the oxidation reaction. It is not unusual to discover soil whose resistivity has been decreased by a factor of 10 due to relatively modest concentrations of chloride ions. A decrease in soil resistivity by a factor of 10 and all other things being equal, will result in a corrosion rate increase by a similar factor. A survey of approximately 2900 tank system sites in the U.S. produced the soil resistivity profile shown in Table 1.\* Soils of less than 10,000 ohm-cm can be considered to be moderately to highly corrosive which in this survey was observed in over 53% of the tested locations.

Ohm-cm	% Occurrence
Less than 3000	16.1
3000 to 9990	37.1
10,000 to 19,900	20.7
20,000 to 49,900	16.5
50,000 or greater	9.6

(Mean Value at Site)

**TABLE 1 - SOIL RESISTIVITY\***

\* *Integrity Assurance Program for Underground Tank Systems, David H. Kroon, Materials Performance, NACE April 1988, p29.*

## SOIL pH

The pH of the soil is also important to the corrosion activity. Low pH rains supply hydrogen ions which are reactants in the typical reduction reaction (see Equation [4]) which occurs in acid solutions. An increase in reactants for the reduction reaction will speed up that charge transfer reaction and hence speed up the corrosion which occurs at the anode site. The degree of aeration of soils is important since oxygen is a reactant in the reduction reaction for aerated neutral soil conditions (see Equation [3]). Coarse soils such as sand and gravel are very much more aerated than are the fine soils such as silt and clay. From a corrosion activity point of view, one can argue that sandy soils therefore will lead to a greater corrosion rate than would clay soils given comparable moisture conditions.

## OPERATING TEMPERATURE

Fuel storage tanks which are heated can be expected to exhibit higher corrosion rates because the higher operating temperature accelerates all the electrochemical reactions, not only the reduction reactions at the cathode but also the dissolution or oxidation reaction at the anode sites. Storage tanks handling such products such as Bunker 'C' which requires steam heat to induce product flow, have a notoriously short service life.

## SOIL CORROSIVITY EVALUATION

Clearly since corrosion is the principal cause of leakage on steel underground storage tanks then for existing storage structures an estimate of the tank condition vis-a-vis corrosion is of vital importance in evaluating the integrity of the storage system. Over

the last 20 years a number of evaluation methods have been developed to assess the tank condition based on test conducted on the soil in proximity to the tank. Two of the most widely used methods are described below;

## External

One method called the 'Warren Rogers Tank Integrity Program' involves the extraction of soil samples from the immediate vicinity of the tank (within the original excavation and at the bottom elevation) and the subsequent analysis of these samples for the following parameters; electrical resistivity, pH, moisture, and sulfide content. A mathematical model and statistical procedure is then applied to the data to predict the age at which the tank will leak. This prediction model has apparently been verified in over 10,000 instances. Recently this technique was used and evaluated in Prince Edward Island where a number of tanks were excavated and inspected and then compared to the predicted tank life based on the Warren Rogers analysis. The preliminary results are outlined in Table #2.

Tank Age	Rogers Predicted Tank Life	Actual Tank Condition
13	16	Leaking at seam
20	15	Good
8	17	Good
16	17	Good
9	18	Evenly corroded & pitted
14	14	Poor - holes found
14	12	Severe pitting & holes
18	15	Poor - few small holes
24	15	Pitting but not leaks
5	13	Excellent

**TABLE #2- PRELIMINARY COMPARATIVE RESULTS USING THE WARREN ROGERS TANK INTEGRITY PROGRAM ON 10 TANKS IN P.E.I.\***

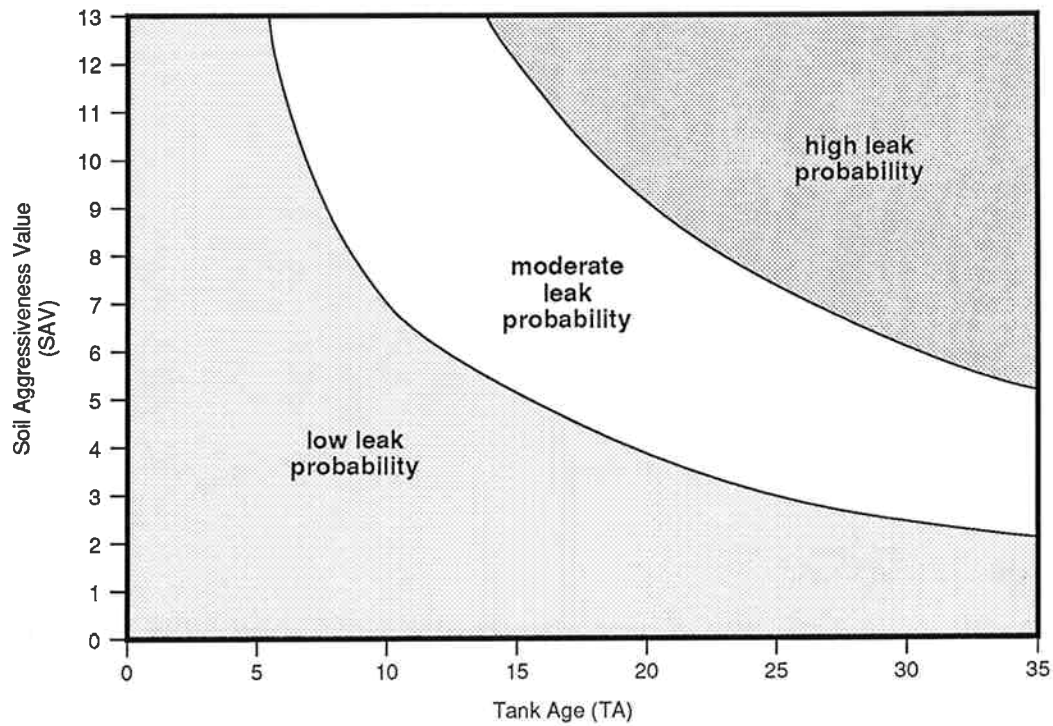
\* *Leaking Underground Storage Tank Newsletter, Environment Canada, April-June 1988, Volume 2, No. 2.*



These preliminary results indicate that although the method does not provide pinpoint accuracy, it does supply a practical technique for estimating tank condition. Furthermore it also verifies to some extent the viewpoint, expressed by one author based on applying the Warren Rogers method over a large number of tanks, that “leaks are rarely encountered in tanks over 20 years”. \* One can see from the table that in the case of two tanks having an age of 20 years old or more, both were in serviceable condition.

A second soil assessment technique is called the PACE method, although it was developed by a major oil company, it has subsequently become known for its sponsor which is the Petroleum Association for the Conservation of the Canadian Environment. In this method it is only necessary to remove soil samples at a 3 foot depth within the vicinity of the tank, preferably from the native soil rather than the backfill material. Each sample is tested for electrical resistivity, pH, moisture, sulfides and also for differential factors based on resistivity variation between samples and pH variation between samples. In addition, the tank age is determined and is multiplied by the Soil Aggressiveness Value (SAV) obtained from the soil testing to produce a corrosion index. The Soil Aggressiveness Value is plotted in Figure 9 (PACE Evaluation Graph) against the tank age to produce a point lying in one of 3 zones; these being zones of high leak probability, moderate leak probability and low leak probability.

\* *Soil Characteristics as a Means of Determining Useful Life of Underground Tanks, Norman A. Kennedy, Underground Storage Tanks - Technology Conference, June 1987.*



**FIGURE 9 - TANK EVALUATION GRAPH**

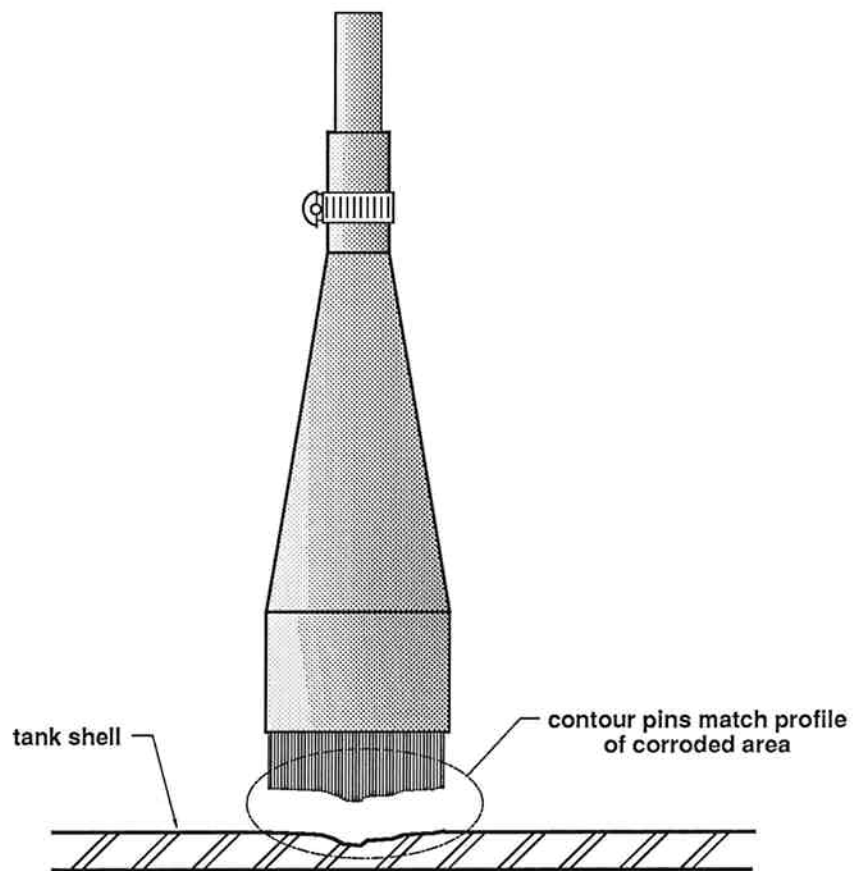
Extensive use of this method on a large number of plants has indicated that 60% of the leaking tanks had a corrosion index greater than 180, whereas the remaining 40% of leaking tanks had index values of greater than 69 but less than 180. Accordingly, an index of less than 69 had virtually a 100% probability of being leak-free.

Both the Warren Rogers and the PACE soil testing methods of evaluating tank integrity focus only on external corrosion but have practical merit even if the results are imperfect

in some cases. It would be almost impossible to be totally accurate by simply conducting soil tests because of the seasonal and yearly variations in soil characteristics that can not be taken into account at the time of sampling. Furthermore contamination of the soil at some time during the tank's service life would be interpreted in either the PACE or Warren Rogers methods as having existed since the time of installation and hence result in a failure prediction which could easily be much much sooner than the actual tank life. There are therefore many unknowns that cannot be accounted for in a soil test, nevertheless these tests are still useful indicators of the tank integrity with respect to failures due to external corrosion.

### Internal Corrosion

The internal condition of a tank can be assessed more readily than the external simply by direct inspection. This however entails partial excavation of the tank, the cutting of the tank and fabrication of a manhole entry, the cleaning out of the tank and purging of the tank to allow for inspector entry. This process therefore has some significant attendant costs. As most internal corrosion problems originate in the area immediately below the fill-pipe there is another in-service method of determining the extent of internal corrosion using what is called a "porcupine" tool. This consists of a cylindrical tool containing many needle-like rods (quills) that are held by friction in the body of the tool. This tool is inserted through the fill pipe with the rod "quills" extended and gently tapped so that the quills will be depressed when they contact the surface forming a profile of the corroded area. When the tool is removed the tank bottom profile can be measured. A schematic of this tool is shown in Figure 10.



**FIGURE 10 - TANK SHELL INTERNAL CORROSION INSPECTION TOOL  
(PORCUPINE)**

## FRP Tanks

Fiberglass reinforced plastic (FRP) tanks are immune to electrochemical corrosion activity. FRP tanks however can deteriorate due to the susceptibility of both the resin and the fiber to corrosive chemicals. Normal soil chemical compositions are not aggressive to FRP tanks and external attack is not considered to be a problem unless the tank is subject

to an acid or alkali spill. Internal corrosion from chemical attack is a greater concern since the FRP resin has limited chemical resistance to fuels compared to steel. Whereas most fuel products do not attack FRP resin, some fuels such as methanol are a concern. Accordingly, the service life of FRP tanks could be impaired by inter-mingling of product or future product development which may not be compatible with the particular resins used in the tank construction. Clearly it has been recognized for over 20 years that the FRP tank is significantly more resistant to soil-side corrosion and to internal corrosion from water accumulation than are steel tanks.\* Most failures of FRP tanks as reported in 1981 API survey are not due to corrosion but a result of punctures by excavation equipment and gauging sticks, or by damage from improper handling.\*\*

## SUMMARY

It is apparent that steel underground tanks are more subject to corrosion than FRP tanks and this applies to aqueous corrosion activity both externally and internally. Although most corrosion caused perforations of steel tanks arises from external corrosion, internal corrosion nevertheless is a factor in a small percentage of tank failures. An assessment of the corrosivity of the external environment can be made by taking appropriate soil samples and testing with either of two well developed methods; namely Warren Rogers Tank Integrity Program and the PACE soil aggressiveness value (SAV) determination method. Corrosion, being a set of relatively complex electrochemical reactions

\* *Evaluation of Corrosion Resistance Fiberglass Reinforced Plastics Versus Conventional Material for Underground Storage Tanks, Ron Skabo, The Hinchman Company, Oct. 1966.*

\*\* *Don't Let Corrosion Get Your Underground Tanks, John H. Fitzgerald, Materials Performance, NACE April 1988, p39*

cannot be totally quantified on an underground tank by soil testing alone, although these two test methods come as close as can be practically expected to predicting tank condition from an external corrosion point of view.

Internal corrosion can be assessed by visual inspection or the use of a tool such as a “porcupine”. In view of existing and impending regulations, owners of underground steel tanks are faced with making upgrading decisions over the next few years to prevent loss of product and contamination of the soil environment. Typical results of recent tank evaluation surveys indicate that about 55% of all steel tanks tested were leak free and therefore candidates for corrosion control upgrading rather than the more costly replacement alternative.\*

\* *Soil Characteristics as a Means of Determining Useful Life of Underground Tanks, Norman A. Kennedy, Underground Storage Tanks - Technology Conference, June 1987.*