

Causes of Underground Corrosion

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Introduction

In any discussion of underground corrosion of iron or steel structures, a number of basic truths must be understood and accepted. These are:

- 1) Corrosion of iron and steel is a natural process.
- 2) All ferrous metals corrode at essentially the same rate.
- 3) Corrosion of iron and steel underground or underwater results in selective and concentrated attack.
- 4) Once leaks start to occur on an iron or steel pipe, they continue to occur at an exponentially rising rate.

Corrosion Is a Natural Process

Underground corrosion of iron or steel pipes is often viewed as an unusual condition which occurs as a result of unusual circumstances and environments. The question is often asked-“will it or won’t it corrode?” In response, we must accept the fact that when iron or steel is placed in underground, we should expect corrosion. The energy imparted to a metal when it is refined wants to be released and the metal wants to revert to the ore from which it was derived. Iron is not found in its refined state in nature. Therefore, an underground iron or steel pipe is essentially in an unstable state and can be expected to eventually become iron ore (rust).

Thus, the question is not one which asks whether or not corrosion will occur, but rather is one which is concerned with the rate of corrosion. How long will it be before the first leak occurs? How long will it be before pipe replacement becomes necessary?”

All Ferrous Metals Corrode at the Same Rate

Tests performed by the National Bureau of Standards at more than 159 sites nationwide over a period of more than 50 years and as reported in “Underground Corrosion,” Circular C-579 by Melvin Romanoff¹ shows that the ferrous metals including cast iron, carbon steel, wrought iron and ductile iron corrode at essentially the same rate underground. The apparent corrosion resistance of cast iron pipe is attributed to the fact that graphitized cast iron can retain its appearance as a pipe even though much of the iron is gone.

Corrosion Is Selective and Concentrated

We shall see that the basic corrosion mechanism of iron underground is electrochemical and that corrosion is not uniformly distributed over the entire metal surface, but occurs only at anodic areas. These anodic areas are relatively small with respect to the cathodic or uncorroding areas. Thus, it has been found that even on severely corroded pipelines on which numerous leaks have occurred, less than 5% of the total surface area of the pipe has been attacked.

Occurrence of Leaks

It has been shown that if the accumulated number of leaks on an underground pipeline or pipeline network are plotted against time, the resulting curve will be an exponentially rising one.² If the scale used for the number of leaks is logarithmic as shown in Figure 1, the resultant plot which can be anticipated on a line without corrosion protection is a straight line. It can be seen that on a logarithmic scale, that the number of leaks rises very significantly. Thus, we can state that once leaks start to occur they not only continue to occur, but they occur at a sharply rising rate.

Basic Mechanisms

In underground corrosion there are two basic mechanisms responsible for corrosion. These mechanisms can be identified as:

- 1) electrolytic corrosion
- 2) galvanic corrosion³

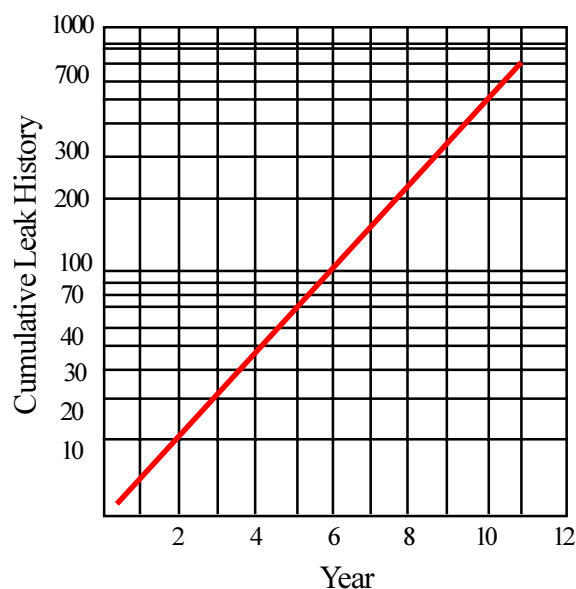


Figure 1 Corrosion Leak History

Electrolytic Corrosion:

Electrolytic corrosion is a result of direct currents from outside sources. These direct currents are introduced into the soil and are picked up by an underground pipe. The locations where the current is picked up are not affected or are provided some degree of corrosion protection. But the locations along the pipe where this current leaves the pipe to enter the soil, those locations are driven anodic and corrosion will result. The corrosion of an iron or steel pipe under this influence will be at the rate of 20 pounds per ampere per year. This type of corrosion is often referred to as stray current corrosion. If the outside source of current is a cathodic protection rectifier on a pipeline belonging to others, the corrosion problem is referred to as an interference problem.

Galvanic Corrosion:

Galvanic corrosion is the self-generated corrosion activity which results when the pipe is placed in the soil.

Differences in potential develop along the pipe or between different pipes. These differences can result from dissimilar metals placed in the soil or they can develop on the same metal as a result of differences within the soil. These potentials generate corrosion currents which leave the metal to enter the soil at anodic areas and return to the metal at cathodic areas. Corrosion occurs at the anodic areas where current leaves the metal to enter the soil.

In both electrolytic corrosion and galvanic corrosion, the corrosion occurs at the anodes. The essential difference is that in electrolytic corrosion, it is the current from the outside source which causes the metal to corrode, whereas in galvanic corrosion, it is the process of corrosion itself, which generates the current. Also, in the electrolytic cell as shown in Figure 2, the anode is the positive (+) electrode. In the galvanic cell, Figure 3, the anode is the negative (-) electrode.

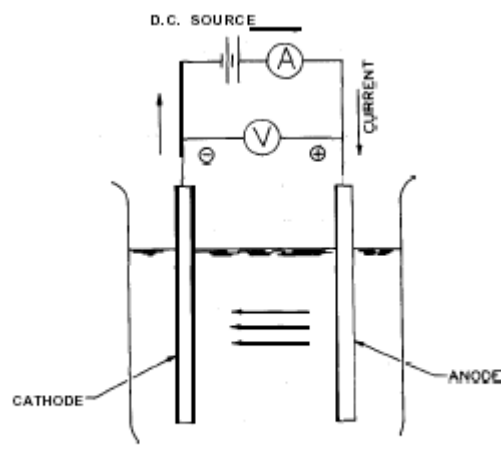


Figure 2. Electrolytic Cell

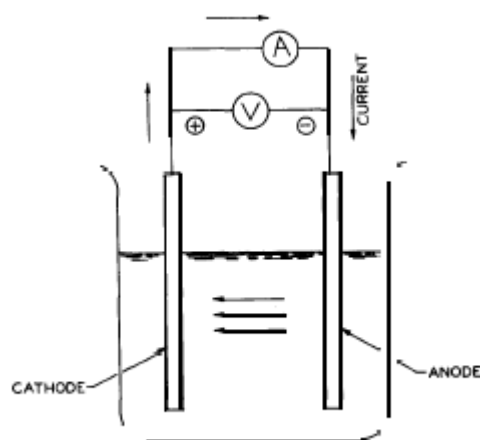


Figure 3. Galvanic Cell

Therefore, if we are to analyze a corrosion problem, it is necessary to understand potential measurements as they apply to underground pipelines.

Pipe-to-Soil Potential Method Of Measuring

The potential measurement used in underground work is referred to as a pipe-to-soil potential. In taking this measurement, a metallic contact is made to the pipeline either through a test wire installed for that purpose or through a probe bar. If there is an above ground riser, contact can be made to the pipeline at that location. This contact is then connected to the negative terminal of a high resistance voltmeter. The positive terminal of that voltmeter is connected to a copper-copper sulfate reference electrode, referred to as a copper sulfate half-cell. This reference electrode is placed in contact with the soil at various locations along the pipeline being investigated. This procedure is shown in Figure 4. The reading on the voltmeter of steel pipe when that pipe is not under cathodic protection can be expected to be less than 1.0 volts, and will usually fall in the range of 350 to 750 millivolts. Because the pipe is connected to the negative terminal of the voltmeter, the pipe-to-soil potential measurement thus obtained is considered as negative and therefore, the readings would be -350 to -750 millivolts. If the pipe is electrically continuous (no insulating or high resistance joints), the point of contact is not significant. The potential measurement is governed by the placement of the reference electrode with respect to the pipeline.

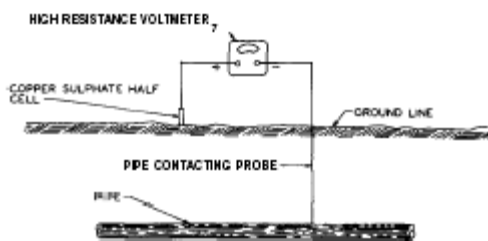


Figure 4. Measurement of Pipe-to-Soil Potential

Pipe-To-Soil Potential Interpretation

A full discussion of pipe-to-soil potential is beyond the scope of this paper. However, these measurements are necessary not only for the determination of the corrosion problem but are required to determine the effectiveness of corrosion control after cathodic protection is applied.

If the corrosion activity is a result of stray currents, and these stray currents are fluctuating as is often the case with D.C. railway equipment, then their presence and influence can be determined from fluctuations in pipe-to-soil potentials. Under electrolytic influences the locations where the potentials are less negative or perhaps positive, are anodic and subject to corrosion. In galvanic corrosion, locations where the potentials are more negative are anodic and subject to corrosion.

Galvanic Corrosion-Dissimilar Metals

It is recognized that different metals placed underground will develop different potentials. A list of the potential of the common metals placed underground is as follows:

<i>Metal</i>	<i>Volts to cucuso:</i>
Magnesium	-1.4 to -1.8
zinc	-1.1
Steel (new)	-0.5 to 0.75
Steel (old)	-0.25 to -0.5
Lead	-0.55
Tinned Copper	-0.35
Copper	-0.25
Steel in concrete	-0.20

The potentials listed above should not be considered to be exact and there can be considerable difference from these values in metals in the field depending upon conditions of both the metal and the environment. When two of these metals are placed underground and are metallically connected to each other, the more negative metal will corrode and the less negative metal will receive protection.

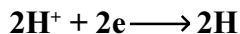
Galvanic Corrosion—Differential Environments

Galvanic corrosion can develop because of differences in the environment contacting the same metal as well as a result of dissimilar metals. Thus, an iron or steel pipe placed underground will be in contact with a variety of different environments along its length and around the circumference. The most important mechanism in this situation is the differential oxygen concentration cell. It is believed that this mechanism is responsible for most of the corrosion encountered underground. When iron corrodes, ferrous ions go into solution at the anodes leaving electrons in the metal as described by the equa-

tion for the anodic reaction:



These electrons migrate through the metal to cathodic areas and combine with the hydrogen ions in solution in the surrounding electrolyte, the hydrogen comes out of solution and remains on the cathodic surfaces as described by the equation for the cathodic reaction:



In most neutral environments encountered underground, the H atoms remain at the cathode, thereby polarizing the cathode. As the cathode is polarized by the formation of hydrogen atoms, the reaction at the anode slows. In some very acid environments, depolarization of the anode occurs because the hydrogen atoms will combine to form hydrogen gas which will evolve. As the gas is evolved at the cathode iron will go into solution at the anode. This type of depolarization rarely occurs in natural environments.

If there is dissolved oxygen in the surrounding environments, this oxygen acts as a cathodic depolarizer by combining and removing the hydrogen to form water or OH ions. As the cathode depolarizes by the removal of hydrogen, iron can go into solution at the anodes, thereby increasing the corrosion. Thus, it is seen that the corrosion rate at the anode is governed by the rate at which oxygen diffuses to the cathode and therefore, this reaction is said to be cathodically controlled. Paradoxically, although oxygen is necessary for this reaction to occur, it is required at the cathode where corrosion does not occur. Locations which are shielded from oxygen become anodes and at these locations corrosion occurs. In this reaction, the anodic areas are small compared to the cathodic areas and corrosion manifests itself in the form of concentrated attack, such as pitting. On pipelines, the bottom of the pipe is usually less accessible to oxygen from the atmosphere, and therefore, the bottom of the pipe becomes anodic with respect to the remainder.

Soil Resistivity

The corrosion currents generated by the various mechanisms described are governed not only by the potentials involved, but by the electrical resistances of the

paths travelled by those currents. Although the exact resistances of those paths are not amenable to measurements, the electrical resistivity of the soil will be indicative of the resistance. Thus, larger corrosion currents are generated in lower resistivity soil than in higher resistivity; or the lower the resistivity of the soil, the greater the probability of corrosion.

Soil resistivity in corrosion work is measured in ohm-cm and measurements are taken using the Wenner four pin method. In this method, four metal pins are placed in contact with the ground in a straight line equally spaced. By determining the change in voltage across the inner pins for current made to flow through the outer pins, the resistivity can be calculated from the formula:

$$P = \frac{191.5 AE}{I}$$

where p = resistivity ohm-cm

A = pin spacing, feet

E = change in voltage across inner pins, volts

I = current through outer pins' amperes

The resistivity thus determined is the average resistivity of the soil between the surface of the ground and a depth equal to the pin spacing.

In the interpretation of soil resistivity measurements, there are various guidelines which have been used for classifying soils in accordance with relative corrosiveness.

One such classification is as follows:

Soil Resistivity Classification:

Resistivity-ohm-cm	Category
0 - 2,000	Very corrosive
2,000 - 5,000	Corrosive
5,000 - 10,000	Moderately corrosive
10,000 - 25,000	Mildly corrosive
Over 25,000	Progressively less corrosive

This classification is not intended to be considered as an exact guide for classifying soils according to corrosiveness. It merely serves to indicate that the corro-

sion rate is lower in soils of higher resistivity. However, it must be appreciated that if a pipe is in the ground long enough, it will develop leaks even in soils of more than 25,000 ohm-cm.

In addition, there is a further complication encountered in the higher resistivity soils. Large variations in resistivity within relatively short distances are often seen in higher resistivity areas. It is not unusual to have variations in resistivity from less than 10,000 to more than 100,000 within 500 feet of pipeline right-of way. These variations in themselves indicate variations in soil composition which can be responsible for the promotion of galvanic corrosion activity.

Summary

We have seen that the corrosion of iron or steel pipe underground is a natural process and that it is selective and concentrated at the anodic areas. All ferrous metals corrode underground at essentially the same rate and that once leaks begin to occur they continue to occur at an exponentially rising rate.

The basic reactions responsible for underground corrosion are, (1) electrolytic and (2) galvanic. In electrolytic corrosion, it is D. C. current from outside sources which is responsible for corrosion. In galvanic corrosion, it is the corrosion of the metal that generates the corrosion current.

Pipe-to-soil potential and soil resistivity measurements are required for determining the corrosion mechanism as well as for determining the probable rate of corrosion. Care must be taken in using and interpreting these measurements.

References

- 1) Romanoff, M.—“Underground Corrosion”—U. S. Department of Commerce National Bureau of Standards Circular 579
- 2) “Corrosion Control Makes Dollars & Sense” Page 36, publication National Association of Corrosion Engineers, October, 1967
- 3) Husock, B.—“Fundamentals of Cathodic Protection” Paper HC-2 Distributed by Harco Corporation, Medina, Ohio