

Corrosion and Cathodic Protection Theory

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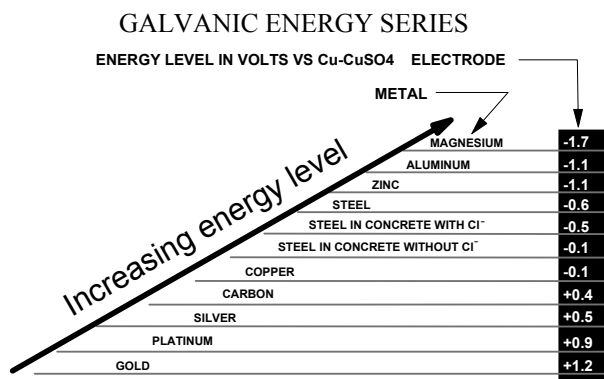
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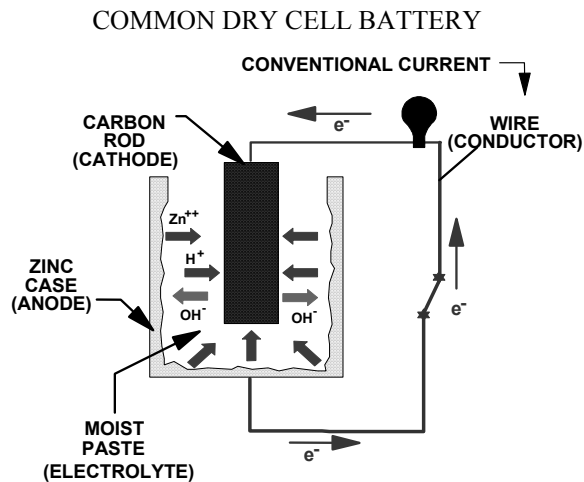
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I. Introduction

Nature has endowed each metallic substance with a certain natural energy level or potential.



When two metals having different energy levels or potentials are coupled together, current will flow. The direction of positive current flow will be from the metal with the more negative potential through the soil to that which is more positive. Corrosion will occur at the point where positive current leaves the metal surface. A dry cell battery is one example of a corrosion cell.



DC railways and other machinery often generate direct current. When this current flows through the soil indiscriminately, it is referred to as "stray" DC. The current may contact and follow a buried metallic structure such as a pipeline, but wherever it leaves that structure to return to its origin, corrosion will occur.

Cathodic protection is an electrical method of preventing corrosion on metallic structures which are in electrolytes such as soil or water. It has had widespread application on underground pipelines, and ever increasing use as the most effective corrosion control method for numerous other underground and underwater structures such as lead cables, water storage tanks, lock gates and dams, steel pilings, underground storage tanks, well casings, ship hulls and interiors, water treatment equipment, trash racks and screens. It is a scientific method which combats corrosion by use of the same laws which cause the corrosion process.

II. Corrosion Mechanism

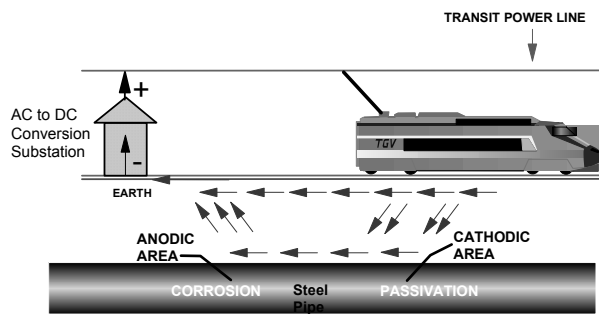
There are two basic mechanisms by which metals in electrolytes corrode

- Electrolytic Corrosion
- Galvanic Corrosion

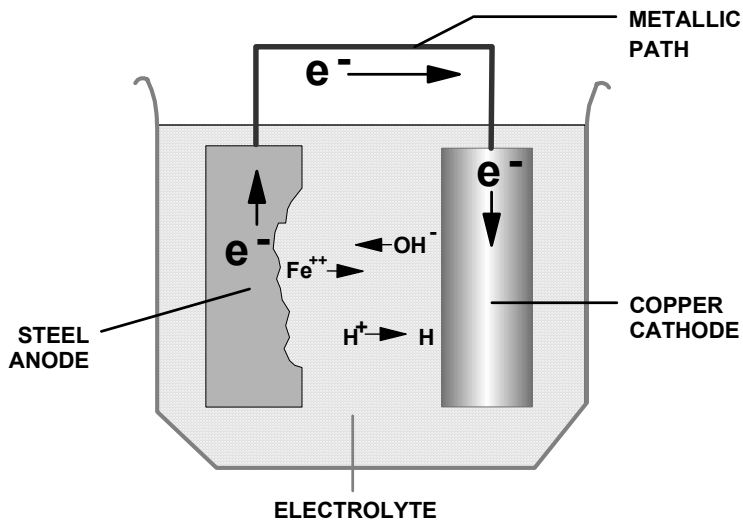
Electrolytic corrosion is a result of direct current from outside sources entering and then leaving a particular metallic structure by way of the electrolyte. Where current

enters the structure, that part is usually unaffected or is provided with some degree of protection. Where current leaves the structure, corrosion occurs. In underground work, this type of corrosion is often referred to as stray current corrosion and results from currents entering the soil from sources of DC such as electric railway systems or DC machinery.

STRAY DIRECT CURRENT CORROSION



Galvanic corrosion is self-generated activity

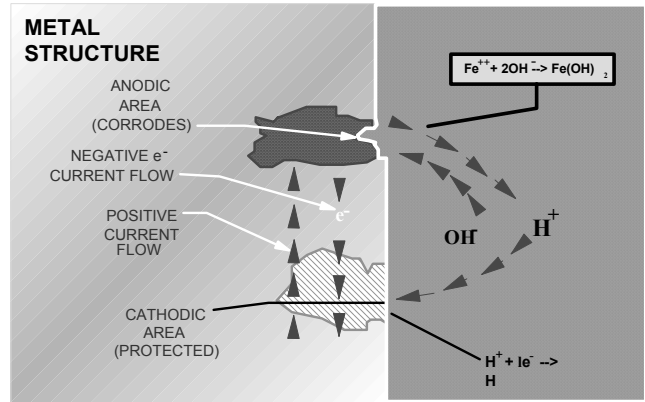


resulting from differences in energy levels or potentials which develop when metal is placed in an electrolyte. These differences can arise from the coupling of dissimilar metals, variations in the electrolyte, non-homogeneity of the metal, or a combination of the above.

BI-METALLIC CORROSION

Current will be generated when two dissimilar metals are electrically connected and immersed in an electrolyte. One of the metals will corrode. The path of the current will be from the corroding metal, through the electrolyte (soil) to the non-corroding metal and then back through the connection (conductor) between the two metals. The corroding metal is the one where the current leaves to enter the electrolyte and is called an anode. The metal that receives the current is called the cathode.

The same metallic structure, when placed in an electrolyte (e.g. soil) can develop differences in potential as a result of metal grain composition, milling imperfections, scratches, threads, etc., being exposed. Those portions will usually be, anodic to the remainder of the surface and will corrode.

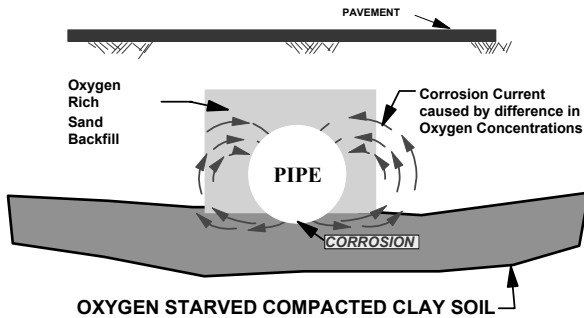


GALVANIC CORROSION OF A SINGLE METAL.

Corrosion can occur due to differences in the electrolyte. These differences may be in the soil resistivity, oxygen concentrations, moisture content and various ion concentrations. The variations produce current flow from one location, through the electrolyte, to another portion of the same metallic structure.

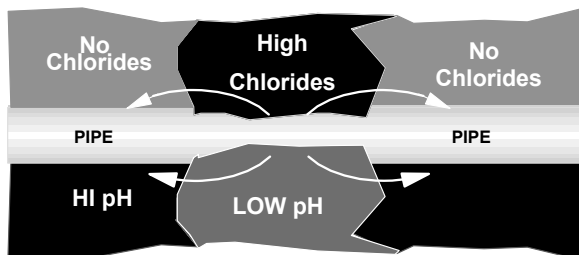
OXYGEN CONCENTRATION CORROSION

Electrolytic corrosion and galvanic corrosion are similar in that corrosion always occurs at the anodic areas. The



essential difference between the two is that in the case of electrolytic corrosion, the external man-made current generates the corrosion; in galvanic corrosion, the natural process of corrosion generates the current. There is also a difference in polarity. In an electrolytic cell, the anode is the positive electrode; in a galvanic cell, the anode is the negative electrode.

CORROSION CAUSED BY DISSIMILAR SOILS



It has been established that electric current can generate corrosion, corrosion, in turn can generate electric current. As indicated by these phenomena, it is then possible to prevent corrosion by use of electrical current. This, then, is the basis for cathodic protection. When direct current is applied with a polarity which opposes the natural corrosion mechanisms, and with sufficient

magnitude to polarize all the cathodic areas up to the open circuit potential of the anodic areas, corrosion is arrested.

The theoretical considerations indicate that the basis for cathodic protection is relatively simple not difficult to understand. However, practical designs for various applications can vary considerably based on the type of structure to be protected and the conditions encountered.

III. Corrosion Control Mechanism

Cathodic protection is an electrical method of preventing corrosion on metallic structures situated in electrolytes. In practical applications, the structures most commonly provided with protection are constructed of iron or steel (including stainless steel) and the electrolytes are most often soil and water. Other metals commonly provided with cathodic protection include, lead sheathed cables, copper and aluminum piping, galvanized steel, and cast iron. Cathodic protection has also been used successfully in unusual electrolytes such as concrete, calcium chloride and caustic soda. However, the vast majority of cathodic protection systems are used to prevent corrosion on steel structures in soil and water. Cathodic protection has become a standard procedure for many structures such as underground storage tanks, pipelines, water storage tanks, ship hulls and interiors, lock gates and dams, water treatment facilities, well casings, trash racks and screens, bridge decks, and steel pilings.

As far back as the Bronze Age, it was observed that metals were not very stable when subjected to their natural environments such as soil and sea water. About 1780, a physiologist, Luigi Galvani, reported on his experiments with metallic

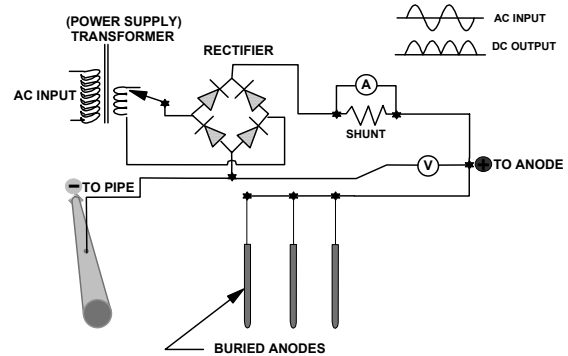
arcs of dissimilar metals. He was studying the muscular structure of the frog. He noticed that when the frogs were suspended on an iron rack by copper hooks, there was a twitching in their leg muscles. One of the foremost physicists of the period, Alessandro Volta, was able to demonstrate that the phenomenon was caused by electricity produced by the dissimilarity of the metals in contact with the biological specimens.

In 1824, Sir Humphry Davy, on contract to the royal Navy, discovered the principle of cathodic protection for the mitigation of natural corrosion processes. He was searching for a method to prevent corrosion of the copper-clad wooden hulls of English ships. He attached billets of zinc to the copper and observed that the zinc would corrode to save the copper. Today, over one and one-half centuries later, corrosion engineers are still using this same method of preventing corrosion damage by applying this same zinc anode cathodic protection to steel ships around the world.

IV. Methods of Application

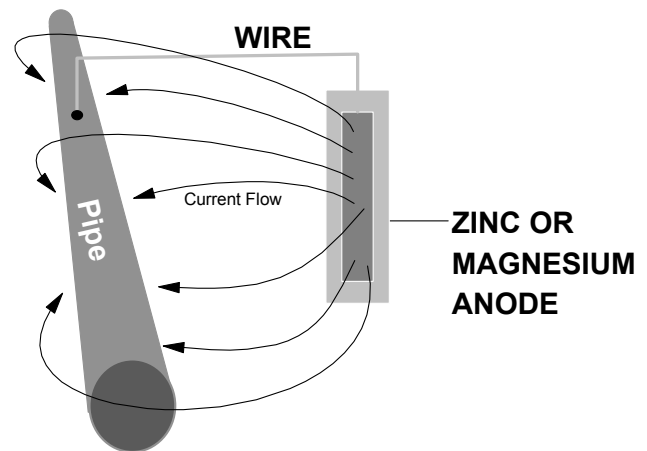
There are basically two methods of applying cathodic protection. One of these methods makes use of anodes which are energized by an external DC power source. In this type of cathodic protection system, anodes are installed in the electrolyte and are connected to the positive terminal of a DC power source and the structure which is to be protected is connected to the negative terminal of that source. Because the power source is almost always a rectifier unit, this type of system is often referred to as a rectifier or impressed current type system.

IMPRESSED CURRENT CATHODIC PROTECTION



The second method of protection makes use of galvanic anodes which have a higher energy level or potential with respect to the structure to be protected. These anodes are made of materials, such as magnesium or zinc, which are naturally anodic with respect to steel structures and are connected directly to these structures.

SACRIFICIAL ANODE CATHODIC PROTECTION



In most cases, the rectifier type system is designed to deliver relatively large currents from a limited number of anodes, and the galvanic anode type system is designed to deliver relatively small currents from a large number of anodes. Each method of applying

cathodic protection has characteristics that make it more applicable to a particular problem than the other. A comparison of those characteristics is as follows:

COMPARISON OF CP SYSTEM CHARACTERISTICS

Galvanic	Rectifier
NO External Power required	External Power Required
Fixed driving voltage	Adjustable Voltage
Fixed Current	Adjustable Current
Limited Current (10 to 50 Milli-amperes Typical)	Unlimited Current (10 to 100 Amperes Typical)
Usually used in lower resistivity electrolytes	Can be Used in almost Any Resistivity Environment
Usually used with small or very well coated structures	Can be Used on Any Size Structure
Low \$/Unit Cost	High \$/Unit Cost
High \$/Sq. Ft. of Metal Protected	Low \$/Sq. Ft. of Metal Protected
Low Maintenance	Higher Maintenance
Does NOT cause Stray Current Corrosion	Stray DC Currents Can be Generated

Regardless of the type of system used, current flows from the cathodic protection anode through the soil to the structure to be protected. Where this current flows onto a structure from the surrounding electrolyte (soil), the potential of the structure is made more negative. Cathodic protection is achieved when this change in potential is sufficient to arrest corrosion.

It would appear that cathodic protection can be achieved merely by the application of current of sufficient magnitude. Although this statement is true, it is deceptively simple

because there are very large differences in the design of cathodic protection systems. These differences result from the infinite variety of structures that are to be protected and from the large assortment of environments in which those structures are located. Because of the large differences in the designs of systems necessary to achieve protection, it is often necessary for existing structures that each system be custom designed for a given location.

In order to prevent corrosion using cathodic protection, current must flow from the electrolyte onto the structure at all locations. If a portion of the structure does not receive current, the normal corrosion activity will continue at that point. If any of the cathodic protection current picked up by the structure leaves that structure to flow back into the electrolyte, corrosion will be accelerated at the location where the current is discharged. As an example, when mechanically coupled piping is used, this can be discontinuous from one pipe section to the next. If a galvanic anode type system is used for protection, it may be necessary to install an anode on each pipe length or to electrically bond across each joint. If one length of pipe is neglected, that length will receive no cathodic protection and the normal corrosion activity will continue. When a rectifier type system is installed on an underground storage tank system, it is even more important that the tank and lines be electrically continuous. If there are non-continuous joints, it is possible for the cathodic protection current to leave the pipe or tank to flow around the electrically discontinuous joint causing corrosion at each point where the current leaves the pipe surface. Similarly, if cathodic protection current is applied to one structure in an area, it is possible for other structures in the neighborhood to be exposed to damage unless proper steps are taken. Potential

measurements are used to determine whether such damaging exposure exists. Just as protection is indicated when the potential of a structure is made more negative, stray current corrosion is indicated when the potential of a structure is made less negative as a result of the application of cathodic protection current.

V. Anode Materials

Galvanic Anodes

Protective current generated by galvanic anodes depends upon the inherent potential difference between the anodes and the structure to be protected. Thus, if the structure is made of iron or steel, any metal that is more active in the electromotive force series can theoretically be used as anode material. In practice, the materials generally used for galvanic anodes are zinc and magnesium. Although aluminum is also a material which is more active than iron, it has not yet proved to be an effective galvanic anode material for underground use because of the polarization films which build up on the aluminum surface as it corrodes, thereby ceasing the generation of protective current. In recent years, some alloys of aluminum have been used successfully in seawater applications and work is progressing on alloys that may prove to be effective in other applications.

It should be noted that galvanic anodes consume themselves in the process of generating protective currents. The rate of consumption is dependent upon the magnitude of current generated as well as the material from which the anode is made. For example, the theoretical consumption rate of zinc is 23.5 lbs. per ampere year and that of magnesium is 8.7 lbs. per ampere year. In actual practice, not all of the metal is consumed in generating current that is

useful for cathodic protection. Some of the metal is consumed in self-corrosion. Zinc is approximately 90% efficient and magnesium is approximately 50% efficient. Therefore, the actual pounds consumed per ampere year of protective current are 26 and 17 lbs. for zinc and magnesium respectively.

In underground applications, these anodes are normally surrounded with a special backfill. The backfill is usually a mixture of gypsum, Bentonite and sodium sulfate. This special backfill serves a number of purposes. First, it provides a uniform environment for the anode, thereby making the corrosion of the anode uniform; second, the backfill decreases the anode-to earth resistance; third, it retains moisture and thereby maintains a lower resistance; and fourth, it acts as a depolarizing agent.

Impressed Current Anodes

When a rectifier type system is used, the current is derived from an outside source and is not generated by the corrosion of a particular metal as is the case with galvanic anodes. However, materials used as energized anodes do corrode. Thus, junk pipe and steel rails that were at one time used extensively as anode materials in rectifier type systems, corrode at the rate of 20 lbs. per ampere year. Even a relatively small rectifier system, with a capacity of only 10 amperes, would consume 2000 lbs. of steel in 10 years. Therefore, longer life anode materials were sought. The materials that are used almost universally today are graphite, high silicon cast iron and precious metal oxide coated titanium. In underground work, special coke breeze backfills are usually used for the purpose of providing a uniform environment around the anode and for lowering the anode-to-earth resistance.

VI. Examples

Underground Coated Structures

The economics favoring cathodic protection of cross country pipelines are so overwhelming, particularly on high pressure gas and oil lines, that practically every new line of consequence is provided with cathodic protection almost immediately after completion. The Department of Transportation has passed Federal legislation requiring that all oil, gas and gas products pipelines be cathodically protected and that the level of protection meets designated standards and regulations.

New structures are generally provided with a good, high resistivity coating that is applied with techniques that leave almost negligible amounts of the surface exposed to the soil. However, it is recognized that a coating, no matter how good or how well applied, is never perfect.

The corrosion protection afforded by the coating must be supplemented with cathodic protection in order to achieve complete mitigation of corrosion. It is important to understand that coated structures develop leaks within a shorter period of time than do uncoated structures. This is true even though the total metal loss on a coated structure is appreciably less than on a bare structure. All of the corrosion activity is concentrated at the holidays or breaks in the coating rather than evenly dispersed over the entire surface, thus accelerating the corrosion rate at the holiday locations.

Fortunately for the structure owner, coating and cathodic protection work very well together. When a tank or pipe is coated with one of the high quality materials and closely controlled application techniques that are available today, a relatively small magnitude

of current can provide complete cathodic protection for tanks and their associated piping.

Although protection of cross country pipelines and existing rural tank farms is usually provided with the rectifier type systems, the use of such systems in congested areas is often very difficult because of the many interference problems created on nearby structures. Therefore, in congested areas, sacrificial anode type systems are more often used.

One example was of a well coated 10,000 gallon underground storage tank located in Detroit, Michigan. It was amply protected with one anode installed on one end of the tank with a total current output of less than 10 milli-amperes of current. The fact that sacrificial anodes have been installed on over 200,000 well-coated underground storage tanks without a single corrosion related product discharge is a testament to the effectiveness of this approach.

In many instances, spacing of anodes can be extended to 100 - 500 feet or more on small diameter buried piping depending on the quality of the coating and environmental conditions. As a consequence, many companies in recent years have established programs in which magnesium anodes are installed on pre-selected spacings as the well-coated piping is laid.

Underground Bare Structures

The problems presented in attempting to provide cathodic protection for existing bare structures are much more difficult than those on coated structures. The major difficulty arises because of the much greater magnitude of current required. On a well-coated underground storage tank, it is not unusual to be able to provide protection with

one or two galvanic anodes while it is not uncommon to have several rectifier units in a large complex tank farm.

Because of the much greater current requirement, interference problems can be created on other nearby underground utility systems. On systems using sacrificial anodes, the number of anodes required is similarly much greater on bare structures than on coated.

We have seen one example where one anode was sufficient to provide protection for a coated 10,000 gallon tank. On the other hand, a poorly coated or bare 10,000 gallon tank can require in excess of 1.5 amps to achieve effective corrosion control. For one bare UST piping system in Ohio consisting of 1,200 feet of 3" diameter pipe, 2 amperes of current was required for full corrosion

control. If magnesium anodes were selected for use, over 60 anodes would be required.

VII. Conclusion

Cathodic protection is a highly adaptable and effective means of preventing corrosion on a variety of underground or underwater structures. There are basically two types of systems: namely, galvanic and impressed current. Each has characteristics which make it more adaptable' under given circumstances. Cathodic protection designs can differ considerably depending upon the coating, the configuration of the structure, the environment and the presence of neighboring structures. When a system is designed, installed and maintained properly, cathodic protection is one of the most effective and economical methods of preventing corrosion.