PREVENTION OF EXTERNAL CORROSION IN PIPELINES

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Dehradun
May, 2008

PREVENTION OF EXTERNAL CORROSION IN PIPELINES

A dissertation submitted in partial fulfillment of the requirements for the Degree of
Bachelor of Technology

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UNIVERSITY OF PETROLEUM & ENERGY STUDIES
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CERTIFICATE

This is to certify that the work contained in this dissertation titled **“Prevention of External Corrosion in Pipelines”** has been carried out by **Mr. Pranav Singh & Mr. Vipul Singh Rawat** under my supervision and has not been submitted elsewhere for a degree.

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ABSTRACT

Pipe that is buried under ground or water has a tendency to have external corrosion which is very critical from both point of view technical as well as economical. External corrosion of buried metallic mains may arise from the nature of the ground surrounding them, contact with other buried metallic structures or from the pick up and discharge of stray d.c. electric earth currents, for example such as may occur with electric traction systems. Significant corrosion will not normally arise from the flow of alternating electric currents (a.c.) in the soil.

To overcome this problem of corrosion and prevent our piplines for safe supply we are using two principal methods of preventing external corrosion of pipelines-**Cathodic Protection** technique and **Coating.** In recent installations coatings & CP have normally been used together in a complementary fashion, since high quality coatings substantially reduce the CP current requirements & application of a functioning CP system allows some relaxation in the requirement for 100% holiday free coatings.

Cathodic protection is the prevention of corrosion by making a metal, which would ordinarily behave like an anode and corrode, behave like a cathode and be free from corrosive attack. Essentially, CP is predetermining the anode in the corrosion cell, or making a large corrosion cell to overcome the other smaller corrosion cells. In cathodic protection this is achieved in one of two basic ways .The first way galvanic series and second basic method Impressed current cathodic protection. Structures commonly protected are the exterior surfaces of pipelines, ships' hulls, jetties, foundation piling, steel sheet-piling, and offshore platforms .Cathodic protection is also used on the interior surfaces of water-storage tanks and water-circulating systems.

ACKNOWLEDGEMENT

First and foremost, we are thankful to **University of Petroleum & Energy Studies** for giving us opportunity to carry out our major project on "**Prevention of External Corrosion in Pipelines**".

We are indebted to our mentor,**Mr. Rajeshwar Mahajan (Senior Lecturer, College of Engineering)** & **Mr. A. K. Das (Adjunct Professor, College of Engineering)**, for his constant support and guidance during this study. We would like to express our sincere gratitude for his patience and encouragement throughout this work, without which this work would not have been possible.

We are extremely grateful to the entire **UPES faculty** for their significant contribution to my academic and intellectual development.

At last we would like to thank all of our colleagues for making our stay at UPES memorable.

Date:

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NOMENCLATURE

CP	Cathodic protection
NACE	National association of corrosion engineers.
PE	Poly ethylene
Psi	Pounds per square inch
FBE	Fusion bonded epoxy
DC	Direct current
HVDC	High voltage direct current
mm	milllimetres
cm	centimeters
ft	feet
^{0}C	Celsius
^{0}F	Faherenheit
MMO	Mixed metal oxides
LIDA	Linear distributed anodes
PVC	Poly vinyl chloride
ASTM	American society of testing materials
Amp	Ampere
PCP	Permanent cathodic protection
TCP	Temporary cathodic protection
HT	High tension
ROW	Right of way
GI	Galvanic Iron
TLP	Test lead post

CHAPTER 1

INTRODUCTION

Pipe that is buried under ground or water has a tendency to have external corrosion which is very critical from both point of view technical as well as economical . External corrosion of buried metallic mains may arise from the nature of the ground surrounding them, contact with other buried metallic structures or from the pick up and discharge of stray d.c. electric earth currents, for example such as may occur with electric traction systems. Significant corrosion will not normally arise from the flow of alternating electric currents (a.c.) in the soil.

To overcome this problem of corrosion and prevent our piplines for safe supply we are using two principal methods of preventing external corrosion of pipelines-**Cathodic Protection** technique and **Coating.**

The first practical use of cathodic protection is generally credited to Sir Humphrey Davy in1820.

The most rapid development of cathodic protection system was made in the United States of America to meet the requirements of the rapidly expanding oil and natural gas industry which wanted to benefit from the advantages of using thin-walled steel pipes for underground transmission. For that purpose the method was well established in the United States in 1945.

In the United Kingdom, where low-pressure thicker-walled cast-iron pipes were extensively used, very little cathodic protection was applied until the early 1950s. The increasing use of cathodic protection has arisen from the success of the method used from 1952 onwards to protect about 1000 miles of wartime fuel-line network that had been laid between 1940 and1944. The method is now well established.

Cathodic protection can, in principle, be applied to any metallic structure in contact with a bulk electrolyte. In practice its main use is to protect steel structures buried in soil or immersed in water. Structures commonly protected are the exterior surfaces of pipelines, ships' hulls, jetties, foundation piling, steel sheet-piling, and offshore platforms .Cathodic protection is also used on the interior surfaces of water-storage tanks and water-circulating systems. However, since an external anode will seldom spread the protection for a distance of more than two or three pipe-diameters, the method is not suitable for the protection of small-bore pipework. Cathodic protection has also been applied to steel embedded in concrete, to copper-based alloys in water systems, and, exceptionally, to lead-sheathed cables and to aluminium alloys ,where cathodic potentials have to be very carefully control.

In recent installations coatings & CP have normally been used together in a complementary fashion, since high quality coatings substantially reduce the CP current requirements & application of a functioning CP system allows some relaxation in the requirement for 100% holiday free coatings.

The desirable characteristics of a pipeline coating according to NACE Standard RP0169-96[1] includes following:

- The coating should have a high electrical resistance & high dielectric strength.
- The coating should exhibit good adhesion to the pipe.
- The coating should have been reasonably easy to apply & the application process should not change the properties of the pipe.
- The coating must have an effective moisture barrier.
- The coating should be resistant to chemical & physical damage degradation during installation & service.
- The coating should be reasonably easily to repair in the field.
- The use of coating should not present any environmental or health risks.

Pipeline coatings have been used for more than 70 years & numerous system have been developed. The coating systems that are currently being applied include the following:

- Coal tar enamels containing embebbed glass fibre mats.
- Fusion-bonded epoxy coatings.
- Multilayer; FBE under Extruded polyethylene & polypropylene coatings.
- Mill-applied tape system.
- Extruded polyethylene & polypropylene coatings.

Of above listed coating system Extruded polyethylene & polypropylene coatings, Fusion-bonded epoxy coatings and Multilayer; FBE under Extruded polyethylene & polypropylene coatings are reportedly currently experiencing increasing acceptance by customers & their future use should therefore expand.

Prevention of external corrosion should be achieved by a system of coating and/or sheathing, with the addition, where appropriate, of cathodic protection. An external coating alone should not be considered to be adequate corrosion protection for buried steel mains.

Buried PE mains and some mains coating materials may suffer degradation by attack form substances in contaminated ground. Such degradation may be avoided by suitable route planning.

PE mains may also suffer degradation from prolonged exposure to direct sunlight.

CHAPTER 2

CORROSION PROCESS

Corrosion process are the chemical reactions that takes place at the surface of a metal and obey well-established chemical laws. The fact that the corrosion is a surface phenomenon means that its course may be controlled by the properties of corrosion product. The metal compound formed may act as a barrier layer increases with time : this is frequently observed in the reactions of metals with gaseous environments. If , however corrosion product may be removed from the site of reaction , the corrosion rate cannot be expected to diminish with time . This is the case soluble corrosion products are formed by the corrosion of certain metals and aqueous solutions.

All metals are prone to corrosive attack if the environment is sufficiently aggressive, e.g. noble metals are unaffected by most media, but they can be dissolved in aqua regia.

In practice, corrosion reactions are most undesirable as they effectively destroy metal or render it useless. For instance , steel girders will lose their strength & ultimately fail if rusting takes place extensively , water tanks made from steel will leak if only minute areas are destroyed by corrosion. It will be appreciated that the economic losses resulting from corrosion are very large & the methods of combating it are all expensive.

2.1 PRINCIPLES OF OPERATION

Understanding the principles of Cathodic protection systems is based upon understanding the nature of the corrosion process.Corrosion is deterioration of essential properties in a material due to reactions with its surroundings.In the most common use of the word, this means a loss of an electron of metals reacting with water or oxygen. The corrosion of metals is an electrochemical process. That is, it is an electrical circuit where the exchange of electrons (electricity) is conducted by chemical reactions in part of the circuit. These chemical reactions occur at the surface of the metal exposed to the electrolyte. Oxidation reactions (corrosion) occur at the surface of the anode and reduction reactions occur at the surface of the cathode. Corrosion control systems which relocate these oxidation reactions, by making the protected structure a cathode in a larger corrosion cell, is called a “cathodic” protection system.” The cathodic protection anodes are installed to become the anode in this larger corrosion cell and provide the location for all oxidation reactions in the cell. To describe the principles of operation of cathodic protection in detail, the exact nature of the corrosion process must be described in detail.

2.1.1 Corrosion cell

Corrosion is the deterioration of a material through reaction with its environment. In the case of a metal, this deterioration occurs mainly through an electrochemical process. The electrochemical process consists of four distinct parts: anode, cathode, electrolyte, and metallic path. These four parts constitute what is called the "corrosion cell". Electrochemical corrosion occurs only when all four parts of the corrosion cell are present. To understand the operation of a cathodic protection system, it is extremely important to understand these four parts of the electrochemical corrosion cell.

2.1.2 Anode

The most obvious part of the corrosion cell is the anode. This is the location where corrosion occurs. The anode is the point in a corrosion cell where electricity is passed by chemical means from the surface of the metal to the electrolyte. This chemical reaction is an oxidation reaction, which is characterized by the metal loosing an electron and combining with another element, usually oxygen. In the case of steel, the resulting material is iron oxide (rust).

2.1.3 Cathode

The second part of the corrosion cell is the cathode. This is the location where protection occurs. The cathode is the point in a corrosion cell where electricity is passed by chemical means from the electrolyte to the surface of the metal .This chemical reaction is a reduction reaction, which is characterized by the metal passing electrons to the electrolyte.

ANODE	CATHODE
An electrode where oxidation reactions (corrosion) occurs	An electrode where reduction reactions (protection) occurs
Antonym - Cathode	Antonym - Anode

2.1.4 Anode/Cathode Relationship

An electrode becomes either an anode or a cathode in an electrochemical corrosion cell depending upon its electrical potential compared to the other electrode. This electrical potential difference is the electromotive force of the cell and is the voltage difference between the anode and the cathode. The electrode which is more electrically active, or more negative in voltage, undergoes the corrosion, so by definition is the anode. The electrode that is more noble (less negative in potential) passes electrons to the electrolyte (reduction reactions) and by definition is the cathode and does not undergo corrosion (oxidation reactions). As previously discussed, there are four distinct parts to the electrochemical corrosion cell, all four parts must be present for a complete circuit to exist and for current to flow (corrosion to occur).

2.1.5 Electrolyte

The third part of the corrosion cell is the electrolyte. The electrolyte is the location where ions flow. The electrolyte is any material in contact with both the anode and the cathode that will allow ions to migrate. The electrolyte is the part of a corrosion cell which allows oxidation and reduction reactions to occur. The electrolyte includes the source of elements or atoms that are required for ion transfer and from the metal electrodes (anode and cathode).

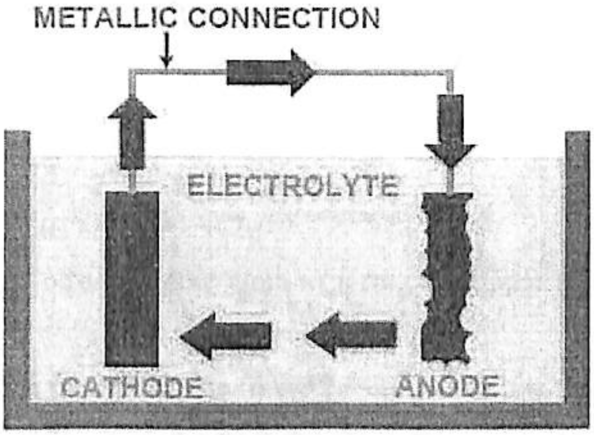
2.1.6 Metallic Path

The fourth part of the corrosion cell is the metallic path. The metallic path completes the circuit and allows the electrons to flow. The metallic path is any metal that contacts both the anode and the cathode and allows electrons to flow. This electron flow must be present for electrochemical corrosion to occur. In the case of a tank or pipeline, this can be the tank or pipe itself, or it can be a metallic bond to different metallic structure.

ELECTROLYTE	METALLIC PATH
Any soil or liquid adjacent to and in contact with the anode and the cathode that allows ions to migrate (flow)	Any conductor that allows electrons to flow from the anode to the cathode

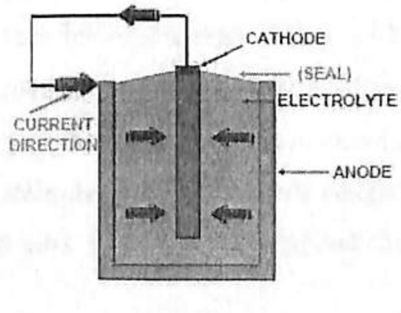
Again, all four parts of the corrosion cell must be present for electrochemical corrosion to occur. When all four parts are present, a closed circuit condition exists, and current will flow through this circuit. Corrosion only occurs at the anode of the cell, which is where the oxidation reactions occur. A familiar example of the corrosion cell is the common dry cell battery. In this case, two different metals, one being an anode and one being a cathode, are placed in contact with a continuous electrolyte, and when a metallic path is supplied to the circuit, current flows

Figure 2-1. The Corrosion Cell



The corrosion reaction should be considered as a cyclic phenomenon where each of the components of the cell must be present and functioning in order for the overall electrochemical corrosion reaction to proceed. If any one of the components of the electrochemical cell are removed or if the individual reactions at either the anode or the cathode can be prevented from occurring then the entire corrosion process can be prevented.

Figure 2-2. Corrosion Cell, The Dry Cell Battery



2.1.7 Anode Reaction

At the anode the metal atoms give up one or more electrons and become metal ions. In chemical shorthand the general formula for this reaction is written:

$$M_0 \text{ -> } M+^{n+} + ne-$$

M_0 represents a metal atom such as iron or copper in a metallic structure. The arrow represents the direction in which the reaction is occurring. The symbol M+ represents a metal ion. Metal ions formed in the corrosion reaction leave the metal structure and enter the environment (electrolyte). The symbol e- represents the negatively charged electron released by the formation of the metal ion. The free electron that is formed in the corrosion reaction remains within the metal structure. For a specific anodic reaction such as occurs in the corrosion of copper the reaction would be written:

$$Cu_0 \text{ -> } Cu{+}{+} + 2e-$$

This represents the reaction of one copper atom to form one copper ion with a charge of +2 and two electrons.

Note that there is no change in total charge (0 = +2 +-2). All metals can react to form metal ions and electrons. It is characteristic of anodic reactions that metal ions and electrons are produced.

2.1.8 Cathode Reaction

At the cathode there are many possible reactions. The simplest common cathodic reaction is the reaction of hydrogen ions, which are present in water solutions, with electrons to form hydrogen gas. In chemical shorthand this reaction is written:

$$2\ H+ +2e- \text{ -> } H_2$$

This represents the reaction of two hydrogen ions (2H+) with two electrons (e-) to form two hydrogen atoms, which then combine to form one molecule of hydrogen (H_2) gas. As in the case of anodic reactions, there is no change in net charge in this reaction (+2 + -2 = 0).

Another common reaction at the cathode is the reaction of electrons with dissolved oxygen and the breakdown of water into hydroxyl ions. In chemical shorthand this reaction is written:

$$O_2 + 2H_2O + 4e- \text{ -> } 4OH-$$

represents the reduction of dissolved oxygen (O_2) in alkaline electrolytes where oxygen and the breakdown of two water molecules ($2H_2O$) results in the formation of four hydroxyl ions (4OH-).

2.1.9 Other Cathodic Reactions

In other cathodic reactions, different ions may react with electrons, but the important characteristic of every cathodic reaction is the rebonding (gaining) of electrons, which is the main characteristic of a reduction reaction. Metal ion reduction and metal deposition may also occur. Note that there is no direct involvement of the metal itself in the cathodic reaction, except that if metal ions are present, they may be reduced (gain their electron(s) back) or deposited. The metal does not become an ion, does not lose an electron, and cannot combine with another atom or element (oxidize or rust). Although the cathodic reaction must occur for the corrosion reaction to proceed there is no corrosion occurring at the cathode. This reduction reaction is normally called protection; since the metal is protected from becoming an ion, it is protected from corrosion. This process also results in many factors which would otherwise slow the corrosion rate: the reduction of hydrogen ions (which causes pH to change in the alkaline direction); the formation of hydroxyl ions (which also causes pH to change in the alkaline direction); the breakdown of water (which causes an increase in resistivity in the electrolyte); and the formation of a hydrogen coating on the cathode (which causes an increase in the cathode to electrolyte resistance).The electrons formed at the anode flow through the metallic electron path and are re-bonded at the cathode. The electrolyte provides the ions necessary for the cathodic reaction and serves to dissolve the metal ions formed at the anode. The most common electrolyte is water or a water based solution. The water may be tap water,seawater, water held in the pores of a soil or water which has precipitated from the air as rain or dew. It is important to note that corrosion and cathodic protection current discussed in this publication and NACE International publication is conventional or positive current flow.

2.2 TYPES OF CORROSION

Basically, there are four ways corrosion can occur. Corrosion can occur through a chemical reaction or three general types of electrochemical reactions. The three general types of electrochemical reactions that occur depend on the cause of the potential difference between the anode and the cathode. This potential difference can be caused by differences in the environment, differences in the metal, or by external electrical sources of DC current. Understanding this principle leads to an understanding of the principles of operation of cathodic protection systems. Each of these three types of corrosion will be explained in detail, with examples of each. These three types are general corrosion, concentration cell corrosion (electrochemical cell caused by differences in the electrolyte), galvanic corrosion (electrochemical cell caused by differences in the metal), and stray current corrosion (electrochemical cell caused by external electrical sources).

2.2.1Concentration Cell Corrosion

- Dissimilar Environment
- Oxygen Concentration
- Non Homogeneous soil
- Biological effect

2.2.2 Galvanic Corrosion

- Dissimillar Metals
- Old to New sindrom
- Dissimilar Alloys
- Stress Metallic Section
- Temperature

2.2.3 Stray Current Corrosion

- DC Transist system
- HVDC Electric Transmission Line
- Cathodic Protection system

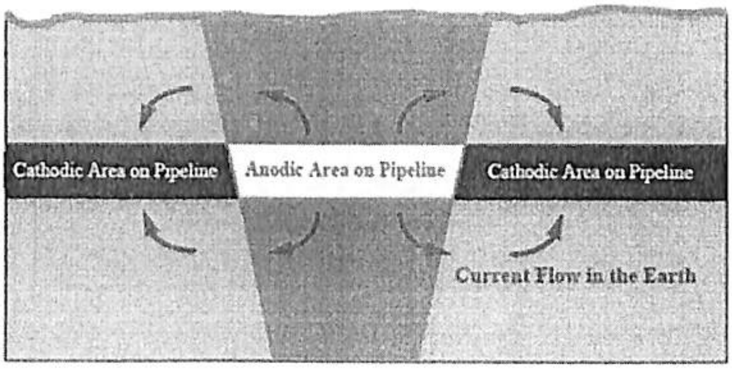


Fig 2.3Concentration cell caused by different environment

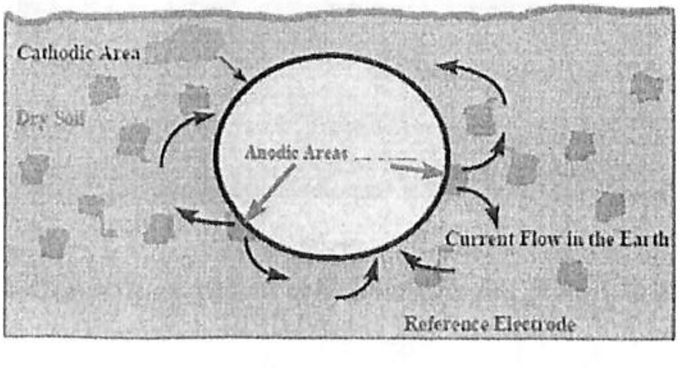


Fig 2.4 Concentration cell caused by Non Homogeneous soil

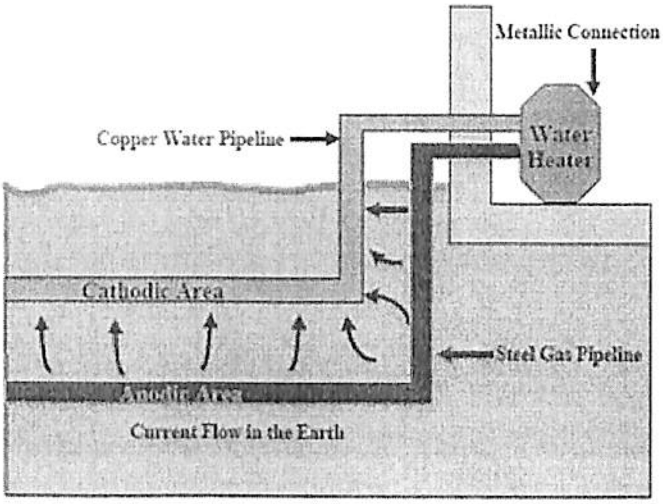


Fig 2.5 Galvanic corrosion cell caused by different metals

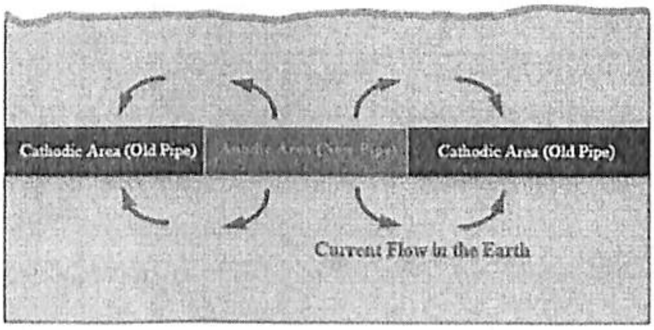


Fig 2.6 Galvanic corrosion cell caused by old & new steel

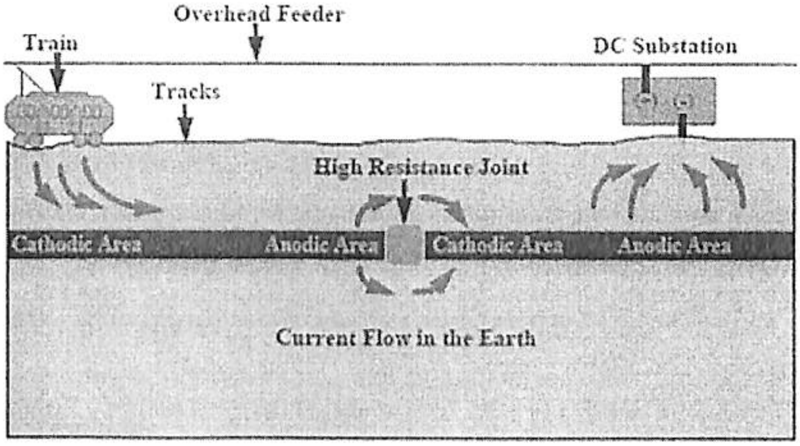


Fig 2.7 Stray Current corrosion cell caused by a DC transit system

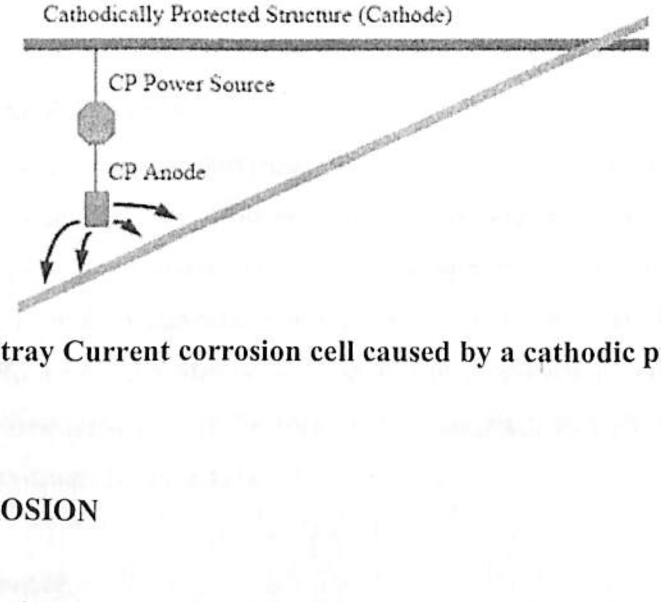


Fig 2.8 Stray Current corrosion cell caused by a cathodic protection

2.3 RATE OF CORROSION

Since almost all corrosion is an electrochemical reaction, anything that affects the speed of a chemical reaction or the amount of current flow will affect the rate of corrosion. Ohms law is applicable to the electrical portion of the corrosion cell. The rate of corrosion is directly proportional to the amount of current that flows in the electrochemical corrosion cell. If the current can be measured, an exact calculation of the metal loss can be made. This means that a measurement in amps or milliamps can be mathematically calculated in kilograms (pounds) per amp year. One amp year is one amp flowing for a period of one year. Different metals have different consumption rates.

2.3.1 Electrical Effects on the Rate of Corrosion

Any factor that affects the amount of current flowing in a circuit will affect the rate of the electrical portion of the electrochemical reaction (corrosion). Following is a description and example of the factors affecting the rate of the electrical portion of corrosion.

2.3.1.1 Potential Difference.

The potential difference between the anode and the cathode is electromotive force and can be measured as voltage. The greater this difference, or voltage, the greater the potential of corrosion. The voltage is directly proportional to the current, and therefore the corrosion, in an electrochemical cell. If the voltage is doubled, and all other factors remain the same, the amount of corrosion doubles.

2.3.1.2 Resistivity of the Electrolyte.

The resistivity of the electrolyte is normally a significant factor in determining the rate of corrosion. This is an uncontrollable characteristic of the soil or water (the electrolyte). The definition of an electrolyte is a material that will allow ions to migrate, and the resistivity is the rate at which it allows ions to migrate. Resistivity is the inverse of the conductivity and is measured in ohm centimeters. Resistivity is inversely proportional to current, and therefore to corrosion, in an electrochemical cell. If the resistivity is doubled, and all other factors remain the same, the amount of corrosion is cut in half.

2.3.1.3 Contact Resistance.

The contact resistance of the anode to electrolyte and of the cathode to electrolyte has the same effect as resistivity, since it is a measure of resistance. The lower the resistance, the greater the current (corrosion). If the contact resistance of the anode or the cathode is doubled, and all other factors remain the same, the amount of corrosion is cut in half. Note that if the contact resistance of both the anode and the cathode is doubled, the amount of corrosion is only one-fourth of its original value.

2.3.1.4 Coating of the Structure.

Coating of the structure normally raises the contact resistance of the anode and the cathode since most coatings are dielectric in nature (non-conductive). The coating of a structure may affect the ion migration rate at the anode and at the cathode. Slowing the migration rate corresponds to slowing the corrosion rate. Structure coatings may also affect other environmental factors such as the temperature, pH, and ion concentration.

2.3.1.5 Polarization of the Structure.

Polarization is the change of the electrode potential as a result of the electrochemical current flow and usually results in the formation of a film on the electrode surface called a "polarization film." Polarization film consists partly of a thin film of hydrogen on the cathode surface. This polarization film and other changes have beneficial effects at the cathode. The layer of hydrogen acts as an additional coating, water is driven away from the surface of the cathode, ion concentration in the electrolyte is reduced, the contact resistance of the electrode to electrolyte is raised, and essentially, corrosion cell current no longer flows or is reduced to a small fraction of its previous value.

2.3.1.6 Amount of Current Flow.

The amount of current flow directly influences the rate of corrosion. Corrosion can be determined from the amount of current flow. Each metal has definite characteristics in the number of electrons given up in the oxidation process and the number of atoms in a kilogram (pound) of the metal. This can, therefore, be translated to kilograms (pounds) per amp. The normal unit of measure encompasses a one year period—kilograms (pounds) per amp-year.

2.3.1.7 Chemical Effects on the Rate of Corrosion.

Any factor that affects the speed of a chemical reaction will affect the rate of the chemical portion of the electrochemical reaction (corrosion). Following is a description and example of the factors affecting the rate of the chemical portion of corrosion.

Temperature is a complex external variable. Generally, as temperature increases, corrosion increases. However this also depends on availability of oxygen. The corrosion rate of iron in a system closed to the atmosphere has been shown to increase almost linearly with temperature from about 40^0C to 160^0C (105^0F to 320^0F). However, in an open system, the corrosion rate increases up to about 80^0C (175^0F) and then decreases. It should also be noted that the pH of a liquid will become more acidic as the temperature is raised, also affecting the corrosion rate. For example, 25 parts-per-million alkalinity water at a pH of 9.4 at 26.7^0C (80^0F), has a pH of 8.0 at 93.3^0C (200^0F).

2.3.1.8 Ion Concentration.

Ion concentration has an effect similar to pH, except that the corrosion rates of some metals are affected by the presence of certain ions.

2.3.1.9 Electron Concentration.

High concentrations of free electrons in the electrolyte around the cathode can inhibit corrosion by that saturation reaching the maximum ion migration rate of the environment. Very low concentrations of free electrons in the electrolyte around the cathode may increase the corrosion rate by the chemical nature of equilibrium, where the electrons readily migrate into the environment.

2.3.2.0 pH of the Electrolyte.

The pH of the soil or water electrolyte in an electrochemical corrosion cell affects the rate of the corrosion by speeding or slowing the chemical reactions at the anode and/or the cathode. The pH of an electrolyte is basically the concentration of hydrogen ions. A pH below 4 increases the corrosion rate of mild steel. At a pH of 3 the corrosion rate increases tremendously. Amphoteric metals also show an increase in the corrosion rate in alkaline environments. Aluminum and lead are examples of amphoteric metals.

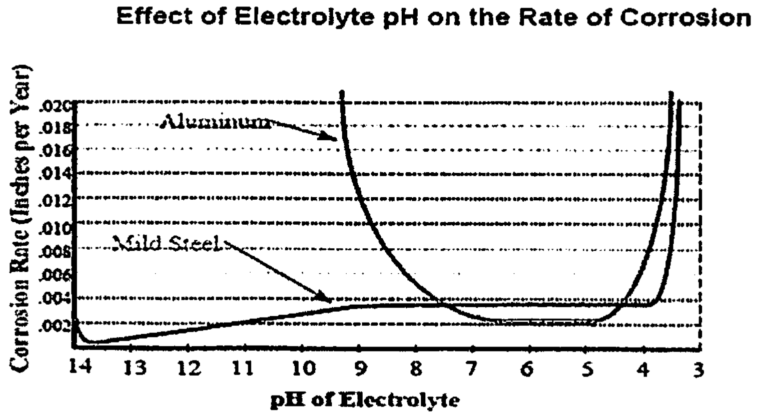


Fig 2.9 Effect of electrolyte pH on rate of corrosion

2.3.2.1 Polarization of the Structure.

Polarization acts as an additional coating, and affects pH levels and ion concentration in the electrolyte adjacent to the structure.

2.4 Area Relationships

The relative size of the anodic area and the cathodic area can greatly affect the rate of corrosion, especially under stray current conditions. When the anodic area is very small, and the cathodic area is large, the corrosion is concentrated and generally becomes more severe. Under stray current conditions, this size relationship is extremely critical. The current density at the cathode under stray current conditions can be extremely high, resulting in failure of the structure in anextremely short period of time.

2.5 Galvanic Series

The two major factors affecting the rate of corrosion in an electrochemical corrosion cell are the electrical characteristics of the electrolyte (resistivity), and the voltage difference between the anode and the cathode. The resistivity of the electrolyte is normally not a controllable characteristic, but it is measurable. The voltage or potential of the metal anode and cathode is also a measurable characteristic. The voltage measured is the voltage difference between the two electrodes. Since this voltage is dependent only on a voltage difference, there must be a reference that all other electrodes can be measured against, to give a relational table, or series, of the potential of any given electrode. As earlier stated metals all have different potentials, and any given metal has different potentials in different electrolytes. For an electrode to be used as a reference to measure other electrodes, the metal and the electrolyte in contact with the metal must be specified. Once this is done, the electrode becomes a reference electrode .Many types of reference electrodes have been used. In the laboratory the hydrogen/hydrogen (hydrogen electrode, hydrogen electrolyte) is common. For field use, the copper/copper sulfate (copper electrode, fully saturated copper sulfate electrolyte) is in common use, except in salt water, where silver/silver chloride (silver electrode, silver chloride electrolyte) is used and must be adjusted by the factor or the chloride contact of the electrolyte. These references are merely stable electrodes with a known potential used to measure the potential of unknown electrodes. Using these references, the potential value of any metal in any electrolyte can be recorded for future reference and This series can then be used to determine which electrode will be the anode (and corrode) in an electrochemical corrosion cell.

Galvanic Series

GALVANIC SERIES OF METALS: METAL OR ALLOY REFERENCE:	SILVER/SILVER CHLORIDE	SATURATED CALOMEL	COPPER/COPPER SULFATE
ELECTROLYTE	FLOWING SEAWATER	SEAWATER	NEUTRAL SOILS AND WATER
Pure Magnesium		-1.60 to -1.64	-1.75
Standard Magnesium			-1.55
Zinc		-0.98 to -1.04	-1.10
Aluminum Alloy	-0.79	-0.77 to -1.00	-1.05
Pure Aluminum			-0.80
Low-Carbon Steel (clean and shiny)	-0.61	-0.60 to -0.72	-0.50 to -0.80
Low-Carbon Steel (rusted)			-0.20 to -0.50
Cast Iron (not graphitized)	-0.61	-0.60 to -0.72	-0.50
Lead		-0.18 to -0.23	-0.50
Low-Carbon Steel (in concrete)			-0.20
Brass			
Copper, Brass, Bronze	-0.36		-0.20
High-Silicon Cast Iron			-0.20
Mill Scale on Steel			-0.20
Carbon, Graphite, Coke	+0.25		+0.30

Table 2.1 Galvanic series

CHAPTER 3

COATING

Coatings are one of the most important for underground corrosion control. Generally, all underground metallic structures, except ground rods are coated. Proper selection and use of coatings are important. The emphasis here is on the selection of coating for the temperature and environment expected. First attempts to control pipeline corrosion relied on the use of coating materials, with the reasoning that if the pipeline metal could be isolated from contact with the surrounding earth, no corrosion could occur. It involves **primer, enamel** and **wrapping.**

A coating would be completely effective as a means to stopping corrosion if:

- The coating material is an effective electrical insulator.
- It can be applied with no breaks and remain so during the backfilling process.
- It is an initially perfect film that remains so with time.

How much primer for a mile of a pipe?

Multiply pipe O.D. by 23/4 to get gallons of primer per miles.

How much coal-tar enamel for a mile of pipe?

For an average cover of 3/32 inch, multiply O.D. of pipe by 0.6.The answer is in tons of enamel per mile.

How much wrapping for a mile of pipe?

For 14-in. to 48-in. pipe multiply O.D. by 15 to get the number of squares feet of wrapping per mile.For pipe sizes of 123/4 in. and smaller, add 1 to the nominal size of the pipe and multiply by 15.

3.1 COATING DEFECTS

Coating defects are also called Holidays. These defects may result from:

- Skips by the coating machine
- Manufacturing applications
- Pinholes in the coating film as applied
- Cracks from excessive mechanical or thermal stresses
- Scrapes or gouges caused during subsequent handling of the coated pipe
- Penetration by rocks, clods or debris in the backfill surrounding the pipe
- Distorting stresses exerted on the coating by certain soils having a very high shrinkage rate upon drying
- Penetration by growing roots
- Action of solvents in soil surrounding the pipeline
- Action of bacteria in the soil surrounding the pipeline
- Damage from subsequent construction on other facilities making it necessary to uncover the pipeline
- Any other action that may damage the coating film

3.2 TYPES OF COATING USED FOR PIPELINE PROTECTION

- Asphalt/Coal tar:1940 to 1970
- Tape wrap(two layer):1960 to present
- Two-layer extruded polyethylene: 1960 to present

- Fusion-bonded epoxy:1975 to present
- Three-layer polyotefin:1986 to present
- Composite coating:1990 to present

3.3 COATING AND LINING

Metallic pipes and, where practicable, other components of a mains system and its associated installations, should have the required corrosion protection factory applied before delivery to site. This will permit proper pre-treatment and application of protection materials under controlled conditions.

A short length at the ends of steel pipes may be left unprotected, to facilitate field welding. These areas should be given temporary protection, to prevent corrosion during transport and storage.

3.4 ROUTE PLANNING

At the route planning stage, consideration should be given to the avoidance of the more obvious corrosion hazards, for example contaminated or naturally aggressive ground, routing to avoid stray d.c. Earth current areas and paralleling of high voltage overhead a.c. power lines or pylons. Where there is doubt about the suitability of ground, soil resistivity measurements should be made to determine the extent to which the ground may be corrosive.

3.5 EXTERNAL COATINGS FOR STEEL MAINS

3.5.1 Factory coated pipes

The external coating should provide protection against long-term electrical, chemical and mechanical degradation. It is especially important that the coating be resistant to damage during transport and pipe laying operations. The coating system should adhere strongly to the pipe and satisfactorily resist cathodic disbonding.

3.5.2 Field applied pipe coatings

Selection and application of field-applied coatings should be compatible with any factory-applied coating.

The area to be coated should be cleaned (preferably by grit blasting), primed and coated without delay. All joints should be inspected before commencing the coating procedure.

Where wrapping tape is employed, particular care is needed to ensure that it is applied in accordance with the manufacturer's instructions without wrinkles, with consistent overlap and with a sound seal between the tape layers. The material should adequately overlap existing pipe coatings, which should be clean and dry prior to application and adhere strongly to it.

3.5.3 Coating of other below-ground components

It is important that all below ground components, forming part of a cathodically protected system, should be coated to a common standard. Valves etc., installed below ground level, should be so coated even though housed in chambers.

Any in-service coating damage should be repaired. The complex shape of some components may require consideration of coating materials other than those recommended for pipes. It may be advantageous to use mastics, in conjunction with tapes or brush/spray-applied materials based, for example, on an epoxy resin or synthetic rubber.

3.5.4 Post-construction inspection

On completion of main laying and backfill, a Pearson-type survey should be carried out to locate any areas of coating damage on the buried main. Any damage so found should be repaired.

3.5.5 External coatings for ductile iron mains

To inhibit corrosion, a snug fitting polyethylene sheath or sleeve should be applied, totally enclosing the pipe and joint, to separate it from the surrounding soil. The sleeve should be firmly tied around the main at 1 m intervals. As an alternative, factory applied coatings with separate joint sheath or protection may be used. In aggressive ground, it may be necessary to adopt a higher level of factory-applied coating with cathodic protection.

3.5.6. PE pipe

Although resistant to a wide range of inorganic substances, there is a possibility that certain aromatic and aliphatic hydrocarbon compounds may degrade PE. Most lubricating and hydraulic oils, chemical solvents and certain gas conditioning fluids fall into this category. The mechanism of attack is one of absorption of the chemical leading to a softening of the polyethylene and a subsequent adverse effect on properties such as strength and stiffness. PE pipe and fittings affected in this way may not be suitable for fusion.

3.6 BACKFILL

Backfill around the main should be free from organic material and stones, which might damage the pipe or its coating system. Backfill of a known aggressive nature should not be placed within a depth of 150 mm above the pipe.

3.7 ABOVE GROUND COMPONENTS

External protection of above ground equipment should be compatible with the protection systems used on other parts of the main.

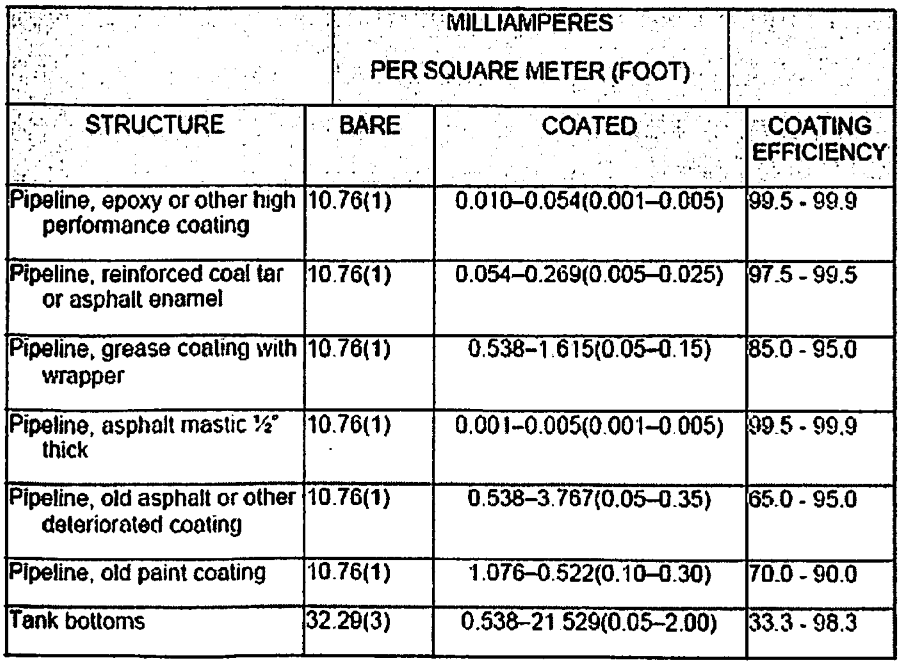
PE and pipe coatings are degraded by prolonged exposure to direct sunlight and the stabilizing compounds, which are included in their composition, only retard the degradation process. Where pipes may be subjected to intense prolonged sunlight, they should be protected from direct exposure.

CHAPTER 4

INTRODUCTION TO CATHODIC PROTECTION.

Cathodic protection is an electrochemical method used to prevent or control corrosion of buried or submerged metallic structures. CP systems are active systems that rely on the application of electric current to control corrosion. If current is interrupted, corrosion will progress at a normal rate for the material/environment combination; if supplied current is inadequate for complete protection, corrosion will progress at a reduced rate. After a CP system is installed and adjusted to provide adequate protection, currents and potentials should remain relatively stable; changes in currents or potentials indicate a problem.

Cathodic protection is the prevention of corrosion by making a metal, which would ordinarily behave like an anode and corrode, behave like a cathode and be free from corrosive attack. Essentially, CP is predetermining the anode in the corrosion cell, or making a large corrosion cell to overcome the other smaller corrosion cells. In cathodic protection this is achieved in one of two basic ways .The first way is by using the galvanic series (Table shown above), to select a more active metal, install that metal in the electrolyte and provide a metallic path. This method is called ***Sacrificial cathodic protection,*** or ***galvanic cathodic protection.*** The galvanically more active metal (anode) is installed to sacrifice itself to protect the structure (cathode). The voltage (and resultant current) is merely the potential difference of the two different types of metal. The second basic method of cathodic protection is applying a source of DC current that forces the current to flow from an installed anode(s) to the structure, causing the entire structure to be a cathode. This method is called ***Impressed current cathodic protection***. A rectifier, solar cell, battery, generator, or some other DC power supply is installed in the circuit. The selection of anode material is free from the galvanic series considerations and anodes are chosen which are economical, or metals which have a small weight loss per ampere year of current .The current required for cathodic protection depends upon the metal being protected and the environment. To achieve these protective potentials, current must flow from the anode to the structure being protected. The amount of current required to protect a given structure is proportional to the area of the structure that is exposed to the electrolyte. Therefore, current requirements are usually given as current densities in units of amperes or milliamperes (0.001 amperes) per square meter (foot) of exposed surface. Coatings are dielectric in nature, and to some degree, isolate the structure from the electrolyte. For coated structures, the amount of current required is much lower than for bare structures, as only those areas where the coating has been damaged or has deteriorated require or will receive current .The coating efficiency is the percent of the structure that is effectively isolated from the electrolyte. Efficiencies of coatings can vary greatly due to the type of coating, quality of surface preparation, quality of application, structure handling, structure installation, backfill techniques, and backfill material used. Coatings efficiencies normally range from about 80 percent up to 99.7 percent. Current requirements for coated structures are best determined by actual testing after the structure is installed. The current densities required for cathodic protection depend on the metal being protected and the environment.



	MILLIAMPERES PER SQUARE METER (FOOT)		
STRUCTURE	BARE	COATED	COATING EFFICIENCY
Pipeline, epoxy or other high performance coating	10.76(1)	0.010–0.054(0.001–0.005)	99.5 - 99.9
Pipeline, reinforced coal tar or asphalt enamel	10.76(1)	0.054–0.269(0.005–0.025)	97.5 - 99.5
Pipeline, grease coating with wrapper	10.76(1)	0.538–1.615(0.05–0.15)	85.0 - 95.0
Pipeline, asphalt mastic ½" thick	10.76(1)	0.001–0.005(0.001–0.005)	99.5 - 99.9
Pipeline, old asphalt or other deteriorated coating	10.76(1)	0.538–3.767(0.05–0.35)	65.0 - 95.0
Pipeline, old paint coating	10.76(1)	1.076–0.522(0.10–0.30)	70.0 - 90.0
Tank bottoms	32.29(3)	0.538–21.529(0.05–2.00)	33.3 - 98.3

Table 4.1 Coating Efficiency of Different Structure

Current required for cathodic protection is supplied by the corrosion of an active metal.Sacrificial anode systems depend upon the differences in corrosion potential that are established by the corrosion reactions that occur on different metals or alloys. For example, the natural corrosion potential difference of iron referenced to a copper/copper sulfate reference electrode is commonly found to be between -0.4 and -0.6 volts DC. The natural corrosion potential of zinc referenced to a copper/copper sulfate reference electrode is about -1.1 volts. Thus, if the two metals are electrically connected, the potential difference between the iron and the zinc is approximately 0.5

to 0.7 volts DC, and the corrosion of the zinc becomes the source of current and prevents corrosion of the iron cathode.. Zinc, magnesium, and aluminum alloys all have potentials that are sufficiently more negative than iron or steel and may be useful for the protection of those structures in many environments. Other metals such as copper and copper alloys have a lower potential than iron or steel and are easily protected by steel (and many other metals). Materials such as aluminum alloys that have a higher potential than iron or steel are more difficult to protect, but even aluminum alloys can be effectively protected by magnesium alloys or commercially pure magnesium. In the process of providing electrons for the cathodic protection of a less active metal, the more active metal (anode) corrodes. The more active metal (anode) is sacrificed to protect the less active metal (cathode). The amount of corrosion is dependent on the metal being used as an anode and is directly proportional to the amount of current supplied. Another factor is the anode efficiency, which accounts for the anode's self-corrosion rate and the corrosion rate for the amount of cathodic protection current. To provide a uniform electrolyte around an anode in soil, maintain moisture, and lower the resistance of anode-to-earth, a special backfill is used. This backfill is normally 75 percent gypsum, 20 percent bentonite, and 5 percent sodium sulfate. The anodes in galvanic cathodic protection systems must be periodically inspected and replaced when consumed. In many cases, when the sacrificial anodes have failed, the entire system is replaced with an impressed current system.

4.1 SACRIFICIAL ANODE

These cathodic protection systems are fundamentally very simple. The simplest systems consist of an anode fabricated from an active metal such as zinc that is directly connected to the structure in an area where it will be exposed to the same environment as the structure being protected. This type of system is widely used in the protection of ships and waterfront structures.

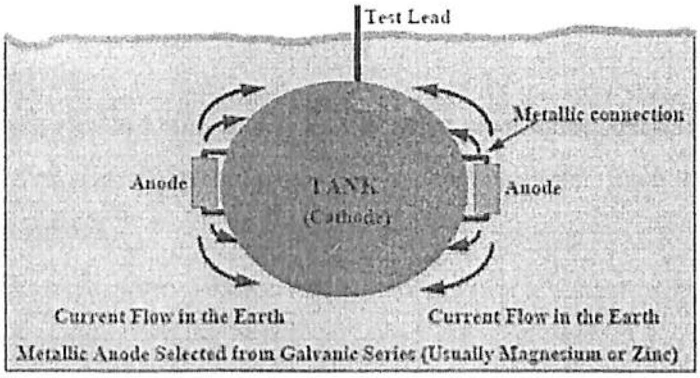


Fig 4.1 Direct Attachment Galvanic (Sacrificial) Cathodic Protection System

For the protection of underground structures such as pipelines, the anodes are not usually attached directly to the structure, but are placed in the soil, evenly distributed a short distance from the pipeline, and are connected to the pipeline by a wire, usually through a test station. This type of sacrificial anode system is shown in Figure 4.1. The application of galvanic anodes is limited by the small potential difference (normally less than 1 volt DC) that can be obtained. Galvanic systems generally can only be economically used on small or well-coated structures in low resistivity electrolytes. Since the amount of cathodic protection is dependent on the current density supplied to the protected structure, the electrolyte resistivity determines the amount of current that the limited voltage will supply. The amount of metal exposed to the electrolyte determines the amount of current required. Uncoated (bare) structures may require an exorbitant number of anodes for adequate protection. In higher resistivity electrolytes, the small anode-structure voltage difference would yield (Ohms law) an extremely small amount of anode current, hence requiring a large amount of anodes. High purity magnesium anodes have the highest potential available, butin high resistivity soil there would not be sufficient current to protect a structure unless it had a very good coating.

4.1.1 Galvanic anode type

There are three materials that are commonly used as galvanic anodes: magnesium, aluminum alloy, and zinc. Each material has different grades or types available. Each type is available in a multitude of sizes and shapes.

4.1.1.1. Magnesium Anodes

Magnesium is the most commonly used sacrificial anode material for the protection of buried structures. Magnesium anodes are also used for the protection of the interiors of water tanks and heaters, heat exchangers and condensers, and waterfront structures. Magnesium anodes are available as castings and extrusions weighing from 0.45 kilograms to over 90.72 kilograms (1 to over 200 pounds) and in a wide variety of shapes In addition, magnesium alloy anode material is available as a "ribbon" anode that consists of a 10 gauge steel wire surrounded by standard alloy magnesium 9.5 millimeters by 19 millimeters (3/8-inch by 3/4-inch). Two different anode compositions are commonly used. They are the standard alloy and a commercially pure or "high potential" alloy. The high purity alloy has the highest electrical potential available for any sacrificial anode, approximately - 1.75 volts DC to copper/copper sulfate in soil. The standard alloy has the next highest electrical potential available, approximately -1.55 volts to copper/copper sulfate in soil. The composition of each alloy is given in The consumption rate for magnesium is 4 kilograms (8.8 pounds) per amp year. The efficiency for providing cathodic protection, considering the self-consumption rate, is higher for the standard alloy than the high purity alloy. For design purposes, the efficiency of both types is 50 percent. It is important that replacement anodes be of the same type as the originals, as the design of the system is dependent on the anode material used, unless replacement of the entire system is incorrect type could lead to insufficient protection.

Compositions of Zinc Anodes

ELEMENT	STANDARD ALLOY	SEAWATER ALLOY
Aluminum	0.005% max	0.10% 0.50%
Cadmium	0.003% max	0.03% - 0.15%
Iron	0.00014% max	0.005% max
Lead	0.003% max	0.006% max
Copper	-	0.005% max
Silicon	-	0.125% max
Zinc	Remainder	Remainder

Composition of Magnesium Anodes

ELEMENT	STANDARD	HIGH POTENTIAL
Aluminum	5.3 - 6.7%	0.1% max
Manganese	0.15% min	0.5 - 1.3%
Zinc	2.5 - 3.5%	
Copper	0.2% max	0.02% max
Silicon	0.1% max	
Iron	0.003% max	0.03% max
Nickel	0.002% min	0.001% max
Other Metals	0.3% maxi	0.3% max total 0.05% max. each
Magnesium	Remainder	Remainder

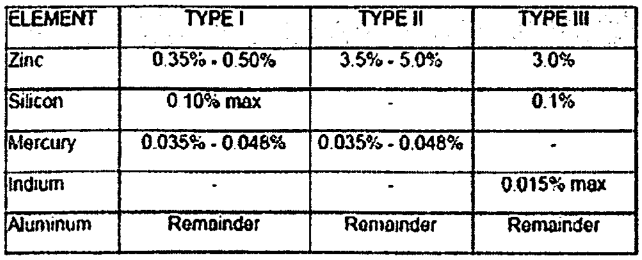
Table 4.2 Compositions of Zinc and Magnesium

4.1.1.2. Zinc Anodes.

Zinc anodes are commonly available in weights from 2.27 kilograms to 113.4 kilograms (5 pounds to 250 pounds) in the form of plates, bars, and rods. Zinc is also available as ribbon anodes in 16-millimeter by 22.2-millimeter (5/8-inch by 7/8-inch), 13-millimeter by 14.3- millimeter (1/2-inch by 9/16-inch), and 8.7-millimeter by 11.9-millimeter (11/32-inch by 15/32-inch) sizes, each with a 2.5-millimeter (1/10-inch) diameter galvanized steel wire core. Zinc anodes are most commonly used in immersion service either in fresh or salt water. They are, however, occasionally used in the protection of buried structures when special circumstances are encountered, usually in soil resistivities below 2,000 ohm centimeters with extremely well coated structures. Two zinc anode compositions are commonly available. They are a standard alloy formulated for use in fresh water and soil and an alloy specially formulated for use in seawater. The composition of these alloys is given . As is the case for magnesium alloy anodes, consumed zinc anodes should be replaced with zinc anodes of the same type and size as those originally installed, unless the entire anode system is replaced. Anodes of the incorrect type could lead to insufficient protection. The electrical potential of zinc anodes is approximately -1.10 volts DC to copper/copper sulfate in soil. In some fresh waters, the potential can reverse at temperatures above 58.3 °C (140 °F); consequently, zinc should not be used in those cases. The consumption rate for zinc is 10.6 kilograms (23.5 pounds) per amp year. The efficiency is greater for zinc than magnesium. For design purposes, the efficiency of zinc is 90 percent.

4.1.1.3. Aluminium Galvanic Anodes

Aluminium galvanic anodes are a more recent development than either zinc or magnesium alloys. Their primary use is in the protection of structures in seawater. However, they have occasionally been used in fresh water or in soil. When the original anodes used are aluminum alloy and their performance has been satisfactory, they should be replaced with anodes of the same type.



ELEMENT	TYPE I	TYPE II	TYPE III
Zinc	0.35% - 0.50%	3.5% - 5.0%	3.0%
Silicon	0.10% max	-	0.1%
Mercury	0.035% - 0.048%	0.035% - 0.048%	-
Indium	-	-	0.015% max
Aluminum	Remainder	Remainder	Remainder

Table 4.3 Composition of Galvanic anodes

ESTIMATED ANODE CURRENT OUTPUT IN MILLIAMPERES (mA) (SEE NOTE)

			ELECTROLYTE RESISTIVITY (OHM-CM)							
ANODE MATERIAL	SIZE(INCHES)	WEIGHT (POUNDS)	500	1000	2000	4000	8000	16000	32000	64000
High Purity Magnesium	3x3x5	3	127	64	32	16	8	4	2	1
High Purity Magnesium	2.75x2.75x26	9	242	121	61	30	15	8	4	2
High Purity Magnesium	3.75x3.75x60	40	413	206	103	52	26	13	6	3
High Purity Magnesium	3x3x78	42	456	228	114	57	29	14	7	4
Magnesium	3x3x5	3	102	51	25	13	6	3	2	1
Magnesium	2.75x2.75x26	9	194	97	48	24	12	6	3	2
Magnesium	3.75x3.75x60	40	330	165	83	41	21	10	5	3
Magnesium	3x3x78	42	365	182	91	46	23	11	6	3
Zinc	3x3x5	3	42	21	11	5	3	1	1	0
Zinc	2.75x2.75x26	9	81	40	20	10	5	3	1	1
Zinc	3.75x3.75x60	40	138	69	34	17	9	4	2	1
Zinc	3x3x78	42	152	76	38	19	10	5	2	1

Note: For protection of well-coated steel (single vertical anode, 3 meters (10 feet) from structure).

Table 4.4 Available voltage for cathodic protection of anodes.

4.1.2 Advantages and Disadvantages of Galvanic Anode Systems

Advantages

- Economically feasible when installed with the structure.
- Very little operation or maintenance requirements (very small chance of premature failure or breakdown).
- Extremely small possibility of overprotection (which may cause coating damage or hydrogen embrittlement).
- Small likelihood of stray current causing interference damage to other metallic (foreign) structures.

Disadvantages

- Small driving voltage available (limited potential difference).
- Extremely small current available in higher resistivity electrolytes.
- Not economically feasible to install or replace anodes on large or extensive existing structures.

4.1.3 Installation of Galvanic Anodes.

Galvanic anodes used to protect buried structures are normally buried a short distance from the structure and connected to the structure using an insulated copper wire. Chemical backfill material is almost always used around sacrificial anodes in soil. The backfill may be installed dry, as a water slurry, or as part of a prepackaged unit. The special backfill is used to provide a uniform electrolyte, maintain moisture, and lower the resistance to earth to allow the anode to produce the required electrical current in an efficient and reliable manner. This backfill is normally 75 percent gypsum, 20 percent bentonite, and 5 percent sodium sulfate. The anode should be 3 to 5 m away from pipeline and top of anode should be lowered in such a manner that anode top should be at the bottom of pipe.

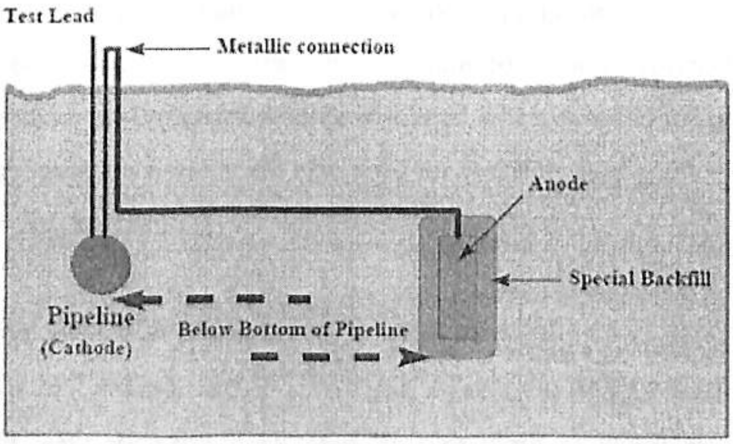


Fig 4.2 Galvanic Anode Installation

Galvanic anodes used in immersion service are usually either directly attached to the surface being protected, or are suspended adjacent to it. When replacement of such anodes is necessary, they should be replaced using the same anodes as were originally used. All mounting hardware should be carefully inspected and repaired or replaced as necessary to insure that the anodes remain in place and that electrical contact is maintained.

4.1.3.1 Galvanic Anode Connection to Structure.

Electrical contact between the galvanic anodes and the structure being protected is vital to the protection of the structure. In directly attached systems, this contact is achieved through the mounting system. The anodes are either directly welded or bolted to the structure. For anodes suspended in water, contact with the structure is achieved either through the mounting system or through insulated copper jumper wires that are welded to both the anode core and to the structure being protected. In systems where the anodes are not directly mounted on the structure being protected, connection is normally achieved using an insulated copper wire. The wire is either cast into the anode during manufacture or welded to the anode core. Connection to the structure usually is achieved by welding the wire to the structure. When additional wire is required for the connection, wire of the proper size using type TW insulation is usually used. Thermite welding is widely used in installation, maintenance, and repair of cathodic protection systems. The process can be used to connect wires to the structure or anode cores or to connect two or more wires together. All connections and splices should be insulated when exposed to soil or water to prevent loss of good electrical contact. Clamps are also used for connection of anode wires to the structure; or, more commonly, for splicing.

4.1.3.2 Procedure for Thermite welding:

- Excavate a pit over the pipeline to expose the pipline top surface at the location of thermite welding care shall be taken that cable to pipe joint is not made up on the seam or circumferential weld.
- Cut and open the coating on the pipeline with care and without damaging the pipeline for a size of 50mmx50mm.
- Clean the surface of the pipe to white metal finish using sand paper .Depending up on size of cable select the model of cad weld material i.e. CA-15 or CA-32 and mould.

- Place the mould on the exposed area and pour the cad weld material .Before pouring the cad weld material put the disc inside the mould for holding the cad material. Ignite using the gun and wait for 2 minutes as cool down period.
- Conduct Megger test at 500/1000 volts for all the cables before installation to ascertain the healthiness of the cables.
- Place a plastic funnel 75 mm ID (approx) around the exposed area such that about 5mm wide coating remains in side of plastic funnel .Place M-seal around it to prevent leakage of encapsulation materials.
- Fill the conical mould from the top by using mixture of Epoxy-Dobefill-60 and hardener. Allow the epoxy hardener to set and test the insulation by holiday detector.

4.1.4 Galvanic Test Stations.

Test stations are included in galvanic anode cathodic protection systems on buried structures to facilitate inspection of the system. The test stations may be located above the surface in connection boxes or in subsurface test stations mounted flush on grade. Typical test stations are shown in figures

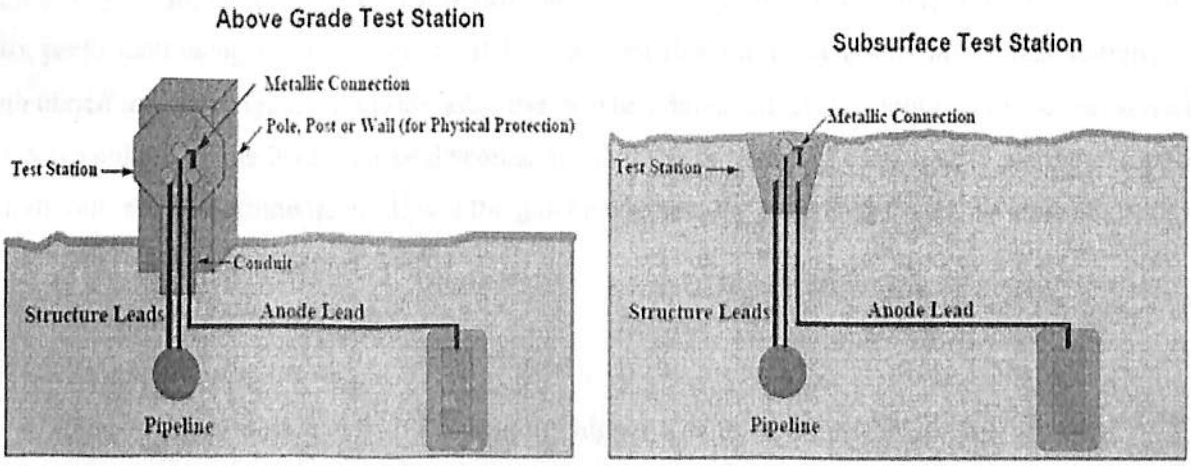


Fig 4.3 Sacrificial Anode Above Grade and Subsurface Station

Test stations are used to conduct many different tests in cathodic protection systems. For galvanic anode systems, the most common test station measures the potential of the structure nearest the anode, the potential of the structure farthest from the anode, the potential of the anode, and the amount of current being supplied by an anode or group of anodes. The connections in this type of test station are shown in Figure

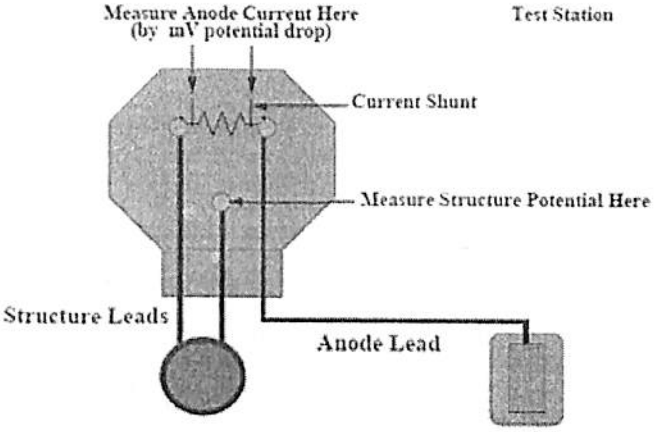


Fig 4.4 Potential-Current Test Station Connections

Normally, a test station has three wires. Some test stations may not have current shunts, may not have a separate structure potential measurement lead, may have multiple anode leads, may just have one structure lead (anodes connected directly to structure), or there may be multiple anodes with a single lead. Other types of test stations are described in the sections that describe the various tests performed using the test stations. It is important that the connections in the test stations be maintained in their original condition after use or when damaged. If the identities of the test station leads are unknown, the leads can be disconnected and the potential of each lead to a copper/copper sulfate reference electrode taken. Using the galvanic series, the leads may be easily identified:

- High purity magnesium -1.75
- Standard magnesium -1.55
- Structure leads -0.2 to
- Zinc -1.2, aluminum -1.1 -0.8 or slightly higher if with other anodes are still attached

4.1.4.1 Procedure for Test Station installation

Test station should provided along the pipeline ROW for monitoring the performance of the CP system considering following parameters:

- At anode ground bed.
- At both sides of all cased crossings.
- At all insulating joints
- At crossing of AC/DC electrical traction system.
- At grounding cells, Surge diverters & polarization locations.
- At HT overhead line (66kV&above) crossings and selected locations where HT overhead line is in the vicitinity of the pipeline
- Drastic changes in soil resistivity.
- At measuring points for pipeline current.
- In the vicinity of DC networks or grounding system where interference problems are suspected.
- At crossings/parallel running of other pipelines structures.
- At both sides of major river crossings

The Test stations with the galvanic anodes shall have provision for link variable(resistors) insertion to limit the anode output current.

The test stations shall be installed with the front of test station facing the pipeline.

Test station connection schemes are as follows:

Purpose	Type
Pipe to soil measurement	A
Galvanic anode installation	B
Foreignpipeline crossing	C
Cased crossing with uncoated casing	D
Insulating Joint	E
HT Line crossing	F

4.1.5 Procedure

- Excavate 1mx1mx1m where the foundation is to cast.
- Prepare PCC for height of 50mm.
- Place TLP bend (bottom) above PCC.
- Take MS shuttering and place it in right position.
- The PCC (M-15) mixture shall be constantly rammed for proper compaction.
- Remove the shuttering after 24 hrs.
- The foundation shall be cured by proper curing for minimum 7 days.
- Place the TLP boxes on the studs of the bend cast in concrete foundation and tighten the bolts.
- All cables used shall be armored (except-anode cable) and of copper conductor.
- The bolts shall be distorted by hitting with a heavy hammer to make the installation vandal proof and also to ensure that the installation becomes theft proof.
- Bottom cable entry of test station foundation shall be closed/sealed by using Bitumen compound to prevent from water

4.1.6 Precautions

- Cables used shall be off sufficient length so as to reach termination point without any joint .Provide sufficient stack for future maintainance purpose.
- All the connections should be checked for proper tightening.
- Cable core ferrules are to be provided at end before final termination
- Cable should be neatly dressed inside the trench and to be terminated inside test station.
- In case of location, where sacrificial anode is to be installed, the same should be taken parallel and the anode cable to be terminated at test station.

4.1.7 Procedure for cable laying and termination

There shall be no joints in a single run of cable.

- The cable shall be laid at a depth .75mm inside the station/plant area and at 1.5m outside station/plant area with a layer of 75mm of sand or soft soil.
- Cable tags for buried cables/PVC ferrule are attached to each cable at termination point for identification of individual cable.
- Termination of cable is to be made by crimping of cable to proper sized copper lugs .Before crimping each strand of cable conductor and the inner surface lug is cleaned by fine sand paper to remove existing oxide film Then the conductor is inserted inside the lug and it is crimped by crimping tool.
- All underground cables shall be enclosed by GI pipe of appropriate size while passing through road/rail crossings.
- Cables shall be neatly arranged in trenches in such a manner that crisscrossing is avoided and final take off to equipment is facilated.

4.2 IMPRESSED CURRENT CATHODIC PROTECTION

As in galvanic anode systems, impressed current systems supply current for cathodic protection of a metal surface. However, in the case of an impressed current system, the protective current is supplied by a rectifier (or other DC power source) instead of by the natural potential difference of the anode to the structure. As shown in Figure the potential difference between the anode and cathode is forced from a non-reactive anode bed by the action of additional energy from a rectifier to force the electron flow that would be normally produced in the corrosion reaction. The energy for the "electron energy pump" action of the rectifier is provided by ordinary alternating current. The effect of these electrons at the structure being protected is the same as that derived from the sacrificial anode type of cathodic protection system. However, the anode material serves only as a source of electrons and anodic (oxidation) electrochemical reactions.In practice, materials such as graphite, high silicon cast iron (HSCI), platinum or mixed metal oxide, are used for impressed current cathodic protection system anodes because they are slowly consumed (they have a very low kilogram (pound) per amp year weight loss). To provide a uniform electrolyte, a lower resistance to earth, and venting of gases and acids, a special backfill is used. This earth contact backfill is normally coke breeze or calcined fluid petroleum coke. Anodes in impressed current systems must be periodically inspected and replaced if consumed or otherwise damaged. As is the case for any electrical equipment, rectifiers used for impressed current cathodic protection systems require preventive maintenance and recurring operational checkouts to ensure proper operation. Impressed current system anode leads must have a special insulation to preclude the copper lead wire from becoming part of the anode system. Since the power source is forcing everything connected to the positive terminal to act as an anode (and corrode) any defect or nick in the insulation of the anode lead wire would result in copper metal loss ending in failure of the anode system.

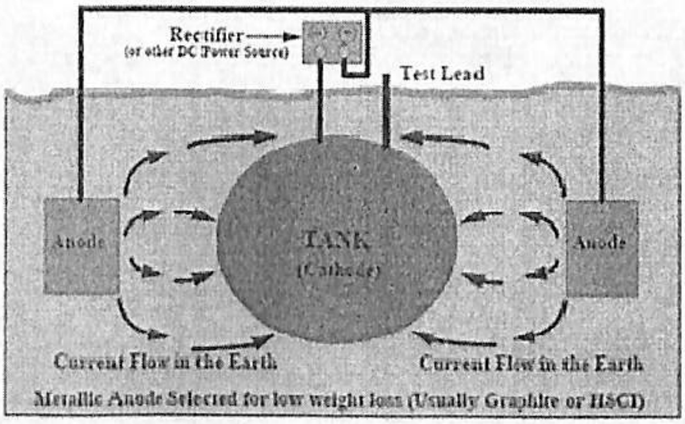


Fig 4.5 Potential-Current Test Station Connections

Impressed current systems are fundamentally the same as galvanic anode systems in their operation, except that in impressed current systems a rectifier or other direct current power source is used to increase the potential of the electrons from the anodes to provide the desired protective current. Thus, as shown in Figure 2-24, in addition to an anode and a connection to the structure being protected, an impressed current cathodic protection system uses a rectifier or other power source. A battery, solar cell, direct current generator, or thermoelectric generator may be used as a power source. However, nearly all impressed current cathodic protection systems use alternating current or solar powered rectifiers as a power source.

4.2.1 Impressed Current Rectifiers

Rectifiers used for cathodic protection commonly use an adjustable step down transformer, rectifier stacks, a shunt to measure output current, meters to indicate output current and voltage, circuit breakers, lightning arresters, and transformer tap connections, all in one case. The function of the rectifier is to convert alternating current into controlled (pulsating) direct current. A typical pole mounted rectifier for cathodic protection service is shown in Figure

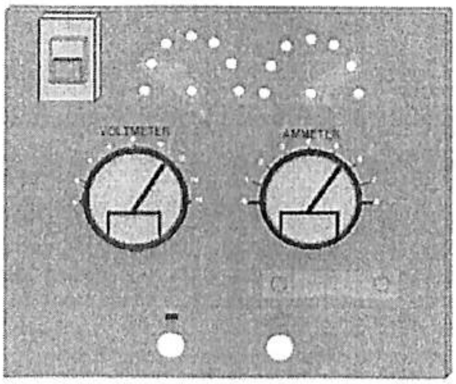


Fig 4.6 Impressed Current Cathodic protection System Rectifier

4.2.1 Impressed Current Anode Materials:

The anodes of an impressed current system provide the means for the protective current to enter the electrolyte. Since the anodes form the corroding part of the system, the best material is one that has a low rate of weight loss per ampere-year . The most commonly used materials for impressed current anodes are graphite and high-silicon cast iron. Aluminum is sometimes used in water storage tanks. In areas where heavy icing is not a problem, high silicon cast iron anodes are used instead of aluminum for lower long-term cost .Platinum coated titanium or niobium anodes and mixed metal oxide anodes are becoming more prevalent as impressed current anode material.

Before the 1970s, there were only three types of anodes primarily used for impressed current groundbeds—high silicon cast iron, graphite, and scrap steel. As technology progressed, so did the types of materials that are commonly used by corrosion personnel. The materials have specialized applications and, when installation and operating costs are assessed, very few anodes can be used universally for any type of application and still achieve a desirable design life. In most soils, anodes evolve oxygen and the anode oxidizes as the current is discharged. In chloride containing soils or water, anodes evolve chlorine gas that forms hydrochloric acid, and the anodes break down chemically. The whole purpose of this explanation is to point out that some anodes perform well in the presence of oxygen and others in the presence of acids.

Electrochemical Equivalents Of Common Structural Metals

	WEIGHT LOSS
METAL	KILOGRAMS (POUNDS) PER AMPERE YEAR
Carbon (Graphite)	1 (2.2)
Iron	9.1 (20.1)
Aluminum	2.9 (6.5)
Lead	33.9 (74.5)
Copper	10.3 (22.8)
Zinc	10.7 (23.6)
Magnesium	4 (8.8)
Nickel	9.6 (21.1)
Silver	35.2 (77.6)
Tin	19(42)

Table 4.5 Electrochemical equivalents of common structure of metals.

4.2.3 High Silicon Cast Iron:

Cast iron anodes are produced in two alloy types with the principal addition of chromium, developed in 1959, to improve the life in chloride soils and water. The principal reason for superior cast iron performance is the formation of a silicon oxide (SiO_2) film that forms on the anode surface, reducing the rate of oxidation, and retarding the consumption rate. They have good electrical properties, and the resistance of the alloy is 72 micro-ohms per cubic centimeter at 20 °C. To be successful in soils, the anodes are backfilled with metallurgical or petroleum coke breeze to reduce the anode resistance and increase the effective anode surface area. Even when the anodes are pre-packaged in coke breeze filled canisters, filling the annular space between the canister and the soil with additional coke breeze is a recommended practice. In seawater, the anode will discharge current at very low voltages and, therefore, does not require backfill. Manufacturers of cast iron anodes developed cable-to-anode connection procedures which distributors are required to follow. Therefore, there has been a lower incidence of connection failures, compared to graphite anodes. The anodes exhibit superior conductivity and experience very little change in resistance with time, unless the anode is damaged. The high tensile strength of the metal is an asset in some circumstances, except that their very low elongation makes them brittle and subject to fracture from severe mechanical and thermal shock.

Cast iron anodes are manufactured in a wide variety of dimensions, shapes, and weights. Refer to Table 2-13 for a description of the various sizes. A proprietary type of cast iron anode, originally manufactured from "off-specification" corrosion resistance piping, is called a tubular anode. This uses the ASTM 518 Grade 2 chromium alloy and has demonstrated since 1971 to have superior resistance to "end effect," common to anodes with poor connection resistance values.

Cast Iron Composition

		ASTM 518	
Element		Grade 1	Grade 2
Silicon		14.2 - 14.75%	14.2 - 14.75%
Manganese		1.5% max.	1.5% max.
Chromium		-	3.25 - 5.0%
Carbon		0.75 - 1.15%	0.75 – 1.15%
Copper		0.50% max.	0.50% max.
Iron		Balance	Balance
Consumption Rate	Soil	0.45 kg (1 lb)/amp-year	0.34 kg (0.75 lb)/amp-year
	Seawater	8.4 kg (18.5 lb)/amp-year	0.11 kg (0.25 lb)/amp-year

Table 4.6 Cast iron composition

4.2.4 Graphite Anodes:

Graphite rods have been used as an impressed current material for many years. The basic configurations consist of round or square rods, manufactured from a slurry of powdered petroleum coke and coal tar resin. The coal tar is used as a bonding agent to hold the graphite particles together and then baked for a month at high temperatures to fuse the mixture. This process increases the resistance to oxidation and subsequent breakdown. There are many types of graphite compositions and the type used for cathodic protection ground beds is one of the most porous. The porosity allows moisture penetration to eventually migrate to the connection, causing failure at the cable connection. A denser anode is expensive; therefore, the porosity is reduced by impregnating the rods with an inexpensive filler of linseed oil, microcrystalline wax, or a phenolic-based resin. There is controversy concerning the best type of filler and even whether filler really reduces moisture penetration over long periods of time. Some fillers have caused deep well anode ground beds to become fouled and develop a high circuit resistance when the anodes have been driven at high current density levels .It is very important to have a proper anode-to-cable connection with any anode material. For years, the manufacturers of graphite anodes had no specification for a proper anode lead wire connection. This led to varying procedures and numerous failures attributable to poor material, poor workmanship, and no quality control parameters prior to shipment. Many users have developed their own assembly standards that make graphite anodes a customized and consequently, more expensive product than it could be if an industry standard existed. Additional specification details should include:

- Type of container - lead, brass, molten, compression.
- Connection depth/diameter – 76 mm (3 in), 102 mm (4 in), 127 mm (5 in), centered.
- Connection sealant - thermoplastic, thermosetting (epoxy).
- Cable sealant - TFE tubing, shrink cap, encapsulation.
- Impregnation - wax, linseed oil, resin.
- Sizes - 3"x30", 3"x60", 4"x40", 4"x80".

Graphite should not be operated at current densities exceeding 10.76 amperes per square meter (1 ampere per square foot) in soil or 2.70 amperes per square meter (0.25 amperes per square foot) in water. Unfortunately, graphite is brittle and may be easily damaged during transportation, either bare or packaged. Special handling and padding is necessary to prevent cracking and breaking.

4.2.5 Aluminum Anodes:

Occasionally, aluminum is used as an impressed current anode for protecting the interior of water tanks. Because it is relatively inexpensive compared to other impressed current materials, anodes are provided in ½- inch-diameter by ten-foot-long screwed-rod sections. These are for use in tanks where seasonal icing usually destroys the anode lead wire connection, requiring annual replacement. This type of anode system does not contaminate potable water, but the consumption rate of 4.1 kilograms (9 pounds) per amp-year limits the cost effectiveness on the basis of cost per year of service compared to other anode systems.

4.2.6 Types of Impressed Current Anode Beds:

The types of impressed current anode beds are dependent on the placement, orientation, and depth of the anodes. Impressed current anode beds are normally placed in remote earth, and distribute current over long distances of the protected structure (pipelines, tank farms, distribution systems etc.). Distributed impressed current ground beds are sometimes used for small structures (valves, tanks), and the anodes are evenly distributed along the structure to be protected, each anode protecting a small portion of the whole structure. Distributed impressed current systems are commonly used to protect the interiors of water storage tanks, both ground level and elevated structures. The remote type of ground bed can be installed near the surface, either horizontally or vertically, or they can be installed deep. Distributed systems are installed like the previously discussed sacrificial anodes, with the addition of a continuous header cable which connects the anodes to the rectifier (or other power source) and a structure lead from the power source to the protected structure.

4.2.6.1 Vertical Remote Impressed Current CP Systems :

These systems are commonly used for pipelines in remote areas. This is usually the most economical choice when there are not other utilities in the area and there is sufficient room to locate the anodes remote from the structure. Vertical placement of the anodes in the earth tends to lower the total resistance to earth of the system (versus horizontal). The distance to remote earth varies according to the resistivity of the earth, usually 91 to 213 meters (300 to 700 feet). Soil resistivity testing should be done in the area of a proposed anode bed to locate an area of low resistance to place the anodes. Care must be taken to ensure that that low resistance area is not continuous to the protected structure. Poor current distribution may occur if this condition occurs. In some cases, the best location for an anode bed may be in higher resistivity earth. The resistance of the anode bed can be lowered by adding additional anodes, using longer anodes, or by increasing the spacing of the anodes.

4.2.6.2 Horizontal Remote Impressed Current CP Systems:

These systems are commonly used for pipelines in remote areas where a rock stratum is located near the surface or where other soil conditions would require horizontal installation to ensure the anode is in a uniform environment. This is usually the most economical choice when there are not other utilities in the area, there is sufficient room to locate the anodes remote from the structure, and there is a rock strata near the surface. Horizontal placement of the anodes in the earth tends to raise the total resistance to earth of the system (versus vertical). The distance to remote earth varies according to the resistivity of the earth, usually 91 to 213 meters (300 to 700 feet).

Soil resistivity testing can be done in the area of a proposed anode bed to locate an area of low resistance to place the anodes. Care must be taken to ensure that the low resistance area is not continuous to the protected structure. Poor current distribution may occur if this condition occurs. In some cases, the best location for an anode bed may be in higher resistivity earth. The resistance of the anode bed can be lowered by adding additional anodes, using longer anodes, or by increasing the spacing of the anodes. The anodes may have individual leads connected to a header cable or they may be installed on a continuous cable.

4.2.6.3 Distributed Impressed Current CP Systems:

These systems are commonly used to protect small structures. This is usually the most economical choice when the structure is small or the anodes cannot be placed in remote earth. This type of anode bed is used to protect water tank interiors, ground level tank bottoms, underground storage tanks, or a short pipeline. Anodes are distributed along the pipeline, or around the surface of the tank (interior for water tanks, exterior for underground tanks). The distance from the structure is normally 1.5 to 3 meters (5 to 10 feet), and the distance between anodes is normally double that distance (3 to 6 meters [10 to 20 feet]). In some cases, the anode is continuous, and is placed in a grid pattern on tanks, or along the side of a pipeline.

4.2.6.4 Deep Remote Impressed Current CP Systems:

These systems are commonly used to protect large structures in built up areas. This is usually the most economical choice when the structure is large, in an area with many other utilities, or the anodes cannot be placed near the surface. This type of anode bed is used to

protect pipeline distribution systems, aboveground tank farms, and pipelines in built-up areas. The anodes are placed in remote earth by drilling deep below the surface. The typical deep anode bed is 30.5 meters (100 feet) to the top anode, and from 61 to 183 meters (200 to 600 feet) to the bottom anode. The anodes can be on individual leads, spaced on a continuous cable, or be a continuous anode wire. This type of anode bed can have a much higher current capacity than typical surface anode systems. This type of system minimizes interference to other metallic structures. This system requires special consideration for backfill, cable insulation, and venting.

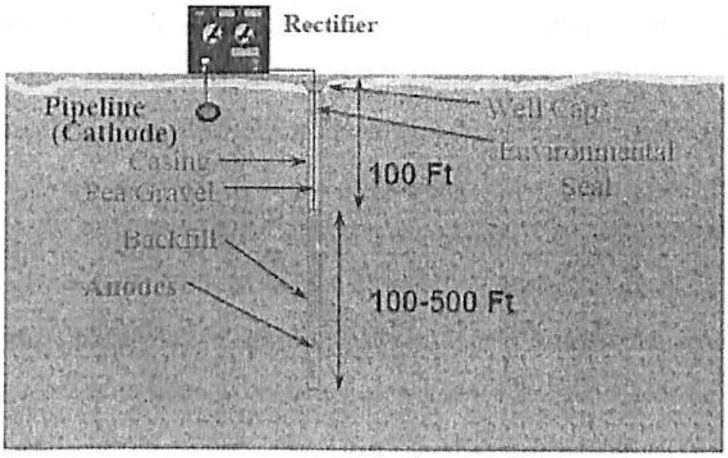


Fig 4.7 Deep Remote Impressed Current Cathodic Protection System

4.2.7 Advantages and Disadvantages of Impressed Current Anode Systems

Advantages:

- Economically feasible when installed on existing structures.
- Large voltage available (potential difference limited only by the size of power supply).
- Large current available, even in very high resistivity electrolytes.
- Can provide sufficient current to protect very large, poorly coated, or uncoated structures.

- Economically feasible to replace anode system when required.

Disadvantages:

- Significant operation and maintenance requirements.
- Relatively large chance of premature failure or breakdown.
- Possibility of stray current causing interference damage to other metallic (foreign) structures

4.2.8 Impressed Current Test Stations

Test Stations for structures with impressed current cathodic protection systems normally are merely contact points for the positive connection of a voltmeter to allow for potential testing. Normally, there are two wires to the test station to permit test lead verification and redundancy. Also, impressed current systems require the same test stations as galvanically protected structures for casings, isolations, and bonding, with a higher likelihood for interference bonds. Any location where the structure is assessable could be considered a test station. These locations could be where a pipeline goes through a valve pit, low level drain pit, high level drain pit, exposed crossing a ditch, goes aboveground for a valve or meter, or enters a building or any other location where it is exposed.

Test stations should be installed wherever the structure is inaccessible to allow the ability to test the cathodic protection system(s). Examples of such areas include paved areas and structures under concrete slabs. In these cases, the test stations provide a contact point for the reference electrode as well as test leads to the structure.

4.3 PERMANENT CATHODIC PROTECTION

The permanent cathodic protection will have Mixed Metal Oxide(MMO)strip also known as LIDA(linear distributed) anodes and LIDA single. The LIDA single anodes shall be centre connected sealed tubular type. These anodes shall be of noble metals. Mixed Metal oxide coated titanium(having Ti substrate composition conforming to ASTM B338 Grade-I and Grade-II).The LIDA anodes shall be dimensionally stable.

The characteristics of anode single bed are as follows:

Shape and Dimension	1,000mm (+) or (-) 5mm long 25mm (+) or (-)mm wide 3mm (+) or (-)mm thick
Weight	0.27Kgs (+) or (-) 0.020kgs
Operating current density (with Carbonaceous Backfill)	75 Amp/m^2
Current output (with Carbonnaceous backfill)	3 Amp/m^2
Electrical Resistivity	$6x10^{(-5)}$ ohm cms
Type of Joint	Epoxy splicing
Contact Resistence of Anode to cable joint	9x $10^{(-5)}$ ohm (maximum)
MMO Coating thickness	> 6 gms /m^2
Anode Consumption Rate	1mg/amp.yr
Type of Cable	XLPE PVC 10mm^2
Length of Cable	As required to reach JB
Design Life	40 years

The anode to be installed at a distance of 5m (minimum) apart and shall be electricically remote to the pipeline (to be ascertained by calculations).Normally the nearest part of anode for shallow horizontal/vertical type of anode beds shall not be less than 100m from the pipeline. However , the actual distance will be as per site conditions. For deep well anode bed the first anode should be at least more than 15 m deep and the actual depth shall be as per Approved design. However for deep well anode bed instead of LIDA single anodes LIDA string anodes shall be used.

Each anode to cable joint shall be tested for it's electrical contact resistance & it's value in ohm shall be recorded..

First anode to cable joint shall be subjected to accelerated ageging test& destructive test to determine pullout strength of cable to anode joint as well as effectiveness of the joint insulation.

4.3.1 Petroleum Coke Breeze

Lubricated calcined petroleum coke breeze backfill material for use with LIDA single(MMO) anodes in (PCP) system shall have a carbon content of 91.77% minimum and bulk density of 74 pounds per cubic ft. Zero percent shall be retained by a screen size of 16 mesh.

The coke breeze shall have low resistence carbon lubricant added for lowering the combined resistance while developing the pumping qualities. Earth contact resistance shall be 0.1 ohm cm at 150 psi.

Typical Backfill composition

CARBON	**91.71%**
VOLATILES	**00.700%**
ASH	**2.230%**
SULPHUR	**5.85%**
SILICON	**0.060%**
IRON	**0.020%**
MOISTURE	**0.00%**

Table 4.7 Typical backfill composition

Typical Physical Analysis

Bulk Density	**54 lb/cuft**
Real Density	**0.2gm/ml**
Porosity	**40.8%**

Table 4.8 Typical physical analysis.

4.3.2. AC operated auto/manual transformer rectifier unit:

The CP transformer Rectifier unit scheme for protection, monitoring, control, metering and indication shall be designed to meet requirements of tthis specification. The control shall be achieved using thyristors and fully solid state logic only.

Transformer shall be double wound, air cooled type with an electrostatic shield between the windings. The transformer insulation shall be class F. The winding size shall be based on maximum current density.

Rectifier shall be silicon type of approved make with adequate cooling arrangement and with moisture and humidity resistant finish. It shall be mounted on spindles or other suitable supports. It shall have configuration suitable for full wave rectification. Adequate filtering in the form of L-C filtering circuit shall be provided on output side to smoothen out the D.C output to limit ripple content to less than 5% at rated output.

The input and output of rectifier shall be protected by fast acting fuses of suitable ratings. Lightning Arres/Surge suppressors shall also be provided across D.C output terminals and A.C input terminals to protect the rectifier against the surges. Each diode and SCR shall be provided with suitable surge suppressers.

4.4 CP SYSTEM MAINTENANCE.

System performance can be monitored by measuring the supplied current, by measuring the potential of the structure, or (preferably) by a combination of the two methods. Scheduled maintenance may include inspection and adjustment of equipment items, such as current rectifiers or anodes; unscheduled maintenance may include troubleshooting and repair of items identified as defective during scheduled inspections, such as anode beds or electrical conductors.

4.5 CP PROGRAM ELEMENTS.

A CP program includes:

- Corrosion control by cathodic protection design.
- Corrosion control during in-house and contracted job orders, work orders,sand projects.
- Use of CP to eliminate electrochemical reactions (corrosion).
- Use of protective coatings to reduce CP current requirements.
- Failure analysis and initiation of corrective actions on corrosion failures caused by materials, design, construction, or the environment.
- Historical records and documentation required for demonstration of compliance and efficient operations and maintenance of CP

4.6 APPLICATIONS.

Facilities that may employ cathodic protection in a corrosion control program include:

- Underground fuel storage tanks and ground level tank bottoms.
- Fuel distribution systems.
- Elevated and ground level water storage tank interiors.
- Potable water distribution systems.
- Natural gas distribution systems.
- Compressed air distribution systems.
- Fire mains.
- Sewage lift stations.

- Steel sheet pile seawalls, pier support/fender piles, and other submerged steel structures.
- Concrete reinforcing steel.

4.7 BENEFITS.

For utilities, there are two choices:

- install and maintain CP; or
- periodically replace the utility when the leak failure rate becomes an operational (or financial) burden.

Properly installed and maintained cathodic protection systems dramatically reduce life cycle costs by indefinitely extending a utility's lifetime. They also reduce the government's potential liability from premature failure of utilities, such as gas line explosions and jet fuel leaks. Environmental cleanup, transportation, and disposing of contaminated soil, monitoring requirements, and other costs connected to a "reportable" (over 3,785 liters [1,000 gallons]) leak can cost the government over one million dollars. Notices of Violation (NOV) can carry stiff fines and penalties. CP is essential to maintaining any metallic structure in a corrosive environment at the lowest life cycle cost.

CHAPTER 5
CONCLUSION

External Corrosion is the main cause of the degradation of steel pipeline system that is buried under the earth . First attempt to control pipeline corrosion relied on the use of coating materials, with the reasoning that if the pipeline metal could be isolated from contact with the surrounding earth, no corrosion could occur. Cathodic protection is the most efficient method of protecting metallic pipe from such corrosion . We use two types Cathodic protection viz. Sacrificial Anode System and Impressed Current Cathodic protection . Sacrificial Anode system we use mainly for shorter period of time to check the behavior of the soil and pipe after that we go for impressed current cathodic protection because it is cheaper. So while deciding type of Cathodic protection economics plays a major role including other technical factor.

In recent installations coatings & CP have normally been used together in a complementary fashion, since high quality coatings substantially reduce the CP current requirements & application of a functioning CP system allows some relaxation in the requirement for 100% holiday free coatings.

To make corrosion prevention system more effective, we apply both Coatings and Cathodic Protection.

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