CATHODIC PROTECTION OF UNDERGROUND STEEL PIPELINES BY USING SACRIFICIAL ANODES

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CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

For most of us, corrosion is defined as the destruction or deterioration of a metal because of reaction with environment that is often called rust and is a curse we have to endure helplessly. Corrosion is electrochemical processes in which a current leaves a structure at the anode site, passes through an electrolyte, and reenters the structure at the cathode site. Differences in potential at different points along the pipe begin to develop. For example, because it is in a soil with low resistivity compared to the rest of the line, current would leave the pipeline at that anode site, pass through the soil, and reenter the pipeline at a cathode site. These potentials generate corrosion currents which leave the pipe to enter the soil at certain selective locations. Corrosion then occurs at these selective locations of the pipe structure. Internal or external corrosion of underground pipelines in soil or water results in selective and concentrated attacks at coating defects. There is no need to replace a complete piece of pipe if corrosion can be controlled at these selective locations (Gibala, R., Tireell, M., and Wert, C., 1993).

Corrosion is a very serious problem. Three areas in which corrosion are important are in economic, improved safety and conservation of resources. The leakage of hazardous materials from a transport pipeline represents not only the loss of natural resources but also the potential for serious and dangerous environmental impact, and human fatalities. While pipelines are designed and constructed to maintain their integrity, diverse factors (e.g., corrosion) make it difficult to avoid the occurrence of leakage in a pipeline system during its lifetime.
On the other hand, internal pipeline events that increase the risk of failure include the generation of defects due to corrosion or erosion and fatigue due to fluctuating pressure or temperature conditions. Although the transmission pipeline safety record has been improving over time, and human casualties, property loss, and environmental damage resulting from pipeline incidents are infrequent, when they do occur the consequences can be significant. For example, a 1999 liquids pipeline incident in Bellingham, Washington, resulted in the release of 277,000 gallons of gasoline into a stream in the middle of the city (Pipeline Rupture and Subsequent Fire 1999, Pipeline Accident Report. 2002 Washington) The gasoline ignited, killing three, injuring eight, and causing.

To solve this problem, cathodic protection provides a valuable extra precaution against corrosion attack. This method only required simple installation which is anodes made from electrically dissimilar metals are buried in the ground near the pipeline, which acts as the anode, and the corrosive action of ground water is thereby arrested, the anodes being sacrificially consumed (British standard code of practice Cathodic Protection. 1973). To protect the pipeline from corrosion with effectively we must have good knowledge in corrosion.

By following the useable concept of the corrosion mechanism, it easier to understand various conditions to be described which cause active corrosion cells on pipeline. The corrosion process as normally encountered in pipeline work is basically electrochemical in nature and that the presence of oxygen in some form is necessary. The amount of metal that will be removed is directly proportional to the amount of current flow. After we applied the cathodic protection by using sacrificial anode to the underground steel pipe, the general result is the original anode (steel pipe) became as cathode and some other metal for example magnesium will became anode (National Research Council. 1988. Washington DC).
1.2 PROBLEM STATEMENT

Corrosion of underground steel pipeline is as a result of an electrochemical reaction. Corrosion is an electrochemical process in which a current leaves a structure at the anode site, passes through an electrolyte, and reenters the structure at the cathode site areas which corrosion is important is in economic, safety, and conservation of resources. In addition to the cost of replacements (direct losses), corrosion costs also include (indirect losses); lost of production shutdown or failure, lost of product for example oil, gas, water due to corroded pipe system, loss of efficiency and high cost of fuel and energy as the result of leakage of corrode pipes.

Cathodic protection is the most important of all approaches to corrosion control. One of the types of cathodic protection is sacrificial anode or galvanic cathodic protection. Corrosion occurs through the loss of the metal ions at anodic area to the electrolyte. Cathodic areas are protected from corrosion because of the deposition of hydrogen or other ions that carry current (Sandoval, A., Beruvides, M., Wiesner, T.F. 2001). By using the sacrificial anode technique the steel pipe will protected from corrosion but other metal that we used will be corrode. In designing this method we must analyze parameters such as factor affecting corrosion, the amount of anode and rate of corrosion.
1.3 OBJECTIVES OF STUDY

The objectives of this study are:

(i) To design the cathodic protection for underground steel pipeline.
(ii) To investigate the effects of cathodic protection for underground steel pipeline.
(iii) To determine the corrosion rate of the pipeline by using weight loss method due to type of sacrificial anode used, and effect of coating to the steel pipe.
(iv) To analyze the corrosion type occurs to the pipe structure.

1.4 SCOPES OF PROJECT

The scope of this study includes:

(i) Sacrificial anode technique will be used to the underground steel pipeline.
(ii) Analysis of the soil pH.
(iii) Designing the test rig at the site and sample preparation
(iv) Analyze of the parameters; coating and type of anode that effecting cathodic protection
(v) Analysis of corrosion rate based on weight loss method
(vi) Surface morphology examination using Scanning Electron Microscope
CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

Corrosion is defined as the destructive result or deterioration of a metal or alloy or its properties because of a reaction with environment. Metal atoms in nature are present in chemical compounds. The same amount energy needed to extract metal from their minerals is emitted during the chemical reaction that produces corrosion. Corrosion returns the metal to its combined state in chemical compounds that are similar or even identical to the minerals from which the metals were extracted. Corrosion also has been called extractive metallurgy in reverse. Underground steel pipeline is one of equipment that subject to corrosion. For example are domestic water pipes, where corrosion attacks mostly on the internal and external of the surface of pipe.

2.2 FACTORS AFFECTING CORROSION

In electrochemical corrosion requires four primary factors which is an anode, a cathode, an electrolyte and physical contact (National Association of Corrosion Engineers, 1984. Houston).

(i) Anode: The anode gives up electrons to the circuit and corrodes.

(ii) Cathode: The cathode receives electrons from the circuit by means of a chemical or cathode, reaction. Ions that combine with the electrons produce a by-product at the cathode.

(iii) Physical contact: The anode and cathode must be electricity connected, usually by physical contact, to permit the electrons to flow from anode to cathode.
Corrosion also can be affected by the factor below (National Association of Corrosion Engineers, 1984. Houston).

(i) Temperature effects: Increasing the temperature of a corrosive system will increase the corrosion rate because the kinetics energy is increase.

(ii) Potential difference (EMF): when two metals exposed to same environment with different potential, the metal higher in the series of Standard Electrode, $V^\circ$ (V), will corrode and protect the lower metal in series.

(iii) Surface Condition: The cleanliness of the surface, existence of surface films and presence of foreign matter can exert a very strong influence on the initiation and rate of corrosion.

(iv) Heat treatment: Many of the final mechanical and corrosion resistance strongly influenced by its thermal history or heat treatment.

(v) Environmental impurities: Environment impurities are extremely important factors.

(vi) Time: The extents of corrosion naturally increase with increase time.

(vii) Pressure: Variation in pressure encountered in most liquid systems have little if any effect on the rate of corrosion, unless the pressure simply retains a corrosive species in the environment, e.g., oxygen in heated water.

(viii) Concentration: When there are differences in concentration or pH of corrosive in liquid contact with a metal surface, a corrosion cell usually will develop between the zones exposed to the different solutions.

(ix) Differential aeration: A surface, one part of which is exposed to an aerated liquid while another part is exposed to a liquid with less aeration, will corrode if there is an electrical path through liquid.
2.3 MECHANISM OF CORROSION

Corrosion theorists are obliged to take into account considerations of the infinitely small and necessarily complex activities on the molecular and at the ionic, electronic and atomic levels. Figure 2.1 shows an illustration of corrosion cells. Three basic kind of corrosion can be listed as chemical, electrochemical and physical. For example, a common representation of the corrosion reaction maybe expressed with respect to iron, water and oxygen in this chemical reaction (National Association of Corrosion Engineers, 1984. Houston).

\[ Fe + H_2O + \frac{1}{2}O_2 \rightarrow Fe(OH)_2 \]  

(2.1)

This indicates that the initial reaction of iron with oxygen in pure water is to form ferrous hydroxide. Corrosion would not occur if one of these elements is absent entirely. Corrosion involves both an anodic and cathodic reactions. The anodic reaction involves metal dissolution (corrosion) (R. Roberge. 1999). For corroding metals, the anodic reaction invariably is of the form:

\[ M \rightarrow M^{n+} + ne^- \]  

(Loss of electrons)  

(2.2)

Examples in addition equation (2.2) are

\[ Fe \rightarrow Fe^{2+} + 2e^- \]  

(2.3)

\[ Mg \rightarrow Mg^{2+} + 2e^- \]  

(2.4)

\[ Zn \rightarrow Zn^{2+} + 2e^- \]  

(2.5)

The cathodic reaction or oxidation consumes (gain electrons) the electrons and the cathodic reaction depends on the type of environment:

(i) In acid environments:

Hydrogen evolution

\[ 2H^+ + 2e^- \rightarrow H_2 \]  

(2.6)
(ii) Neutral & Alkaline

\[ O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \quad (2.7) \]

For example reaction Eq.(2.2), defined as the anodic reaction, is an oxidation in which M valence increase from 0 to 2+, liberating electrons, e, while Eq.(2.6), defined as cathodic reaction, is a reduction in which the oxidation state of hydrogen decrease from +1 to 0, consuming electrons (Jones, D.A., Uhling, H.H, Revie R.W 1982).
2.3.1 Corrosion of Steel

Corrosion of steel is an electrochemical reaction followed by a chemical reaction: Anodic reaction (Bayliss, D.A and Deacon, D.H.1985):

\[ Fe \rightarrow Fe^{2+} + 2e^- \]  

(2.8)

The corrosion reactions can be illustrated using chemical terminology as follow equation (2.8). This is simple way of describing the process where iron is removed as charged particle called ions (Fe^{2+}) and electron(e-) carry current to balance the electric charge. Clearly a balancing reaction must occur at the cathode and under ordinary natural exposure conditions this can be represented as follows:

Cathodic reaction:

\[ \frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^- \]  

(2.9)

In short, hydroxyl ions are produced at the cathode. These two reactions can combined in a chemical equation (2.10):

\[ Fe + \frac{1}{2}O_2 + H_2O \rightarrow 2OH^- + Fe^{2+} \]  

(2.10)

The ferrous and hydroxyl ions react together to form ferrous hydroxide:

\[ 2OH^- + Fe^{2+} \rightarrow Fe(OH)_2 \]  

(2.11)

This is simple form of rust which unstable and is eventually oxidized (i.e. react with oxygen) to form the familiar reddish brown rust, chemically denoted FeOOH. This is the form of rust usually produced in air, natural water and soils. However, under acidic conditions hydrogen is produced at the cathode and the corrosion product may be Fe_{3}O_{4} (magnetite).
2.3.2 \textbf{Forms of Corrosion}

Figure 2.2 shows forms of corrosion that occur to the metal structure. The several types or forms of corrosion are: (Jones, D.A., Uhling, H.H, Revie R.W. 1982)

(i) General corrosion: General corrosion or rusting is the most familiar form of steel corrosion. It can be considered a uniform corrosion process in which numerous micro corrosion cells are activated at the corroded area. The cells could be minute grains where the boundary tends to be the anode, for example in atmospheric exposures, oxygen in the air is the usual oxidizing agent, and the water necessary for the reaction is readily available in the form of rain, condensation (dew, for example), or humidity (water vapor in the air). In the rusting of ordinary steel, the corrosion product (rust) does not form an effective barrier to further corrosion, but permits reactants to penetrate to the steel surface beneath and continue the rusting cycle.

(ii) Pitting corrosion: A non-uniform, highly localized form of corrosion that occurs at distinct spots where deep pits form. (A pit is a small electrochemical-corrosion cell, with the bottom of the pit acting as the anode.) Chloride-induced corrosion is of this type and can be seen frequently in structures exposed in coastal areas.

(iii) Galvanic corrosion: When two metals of different electrochemical potential are joined or coupled electrically in the presence of moisture or an aqueous solution, one will act as the anode and corrode; the corrosion of steel when it is in contact with copper is a familiar example. This principle is used to advantage when steel is protected by galvanic methods (for example, galvanized steel or the use of other sacrificial anodes).

(iv) Stress-corrosion: Under stress, corrosion processes proceed much faster and can lead to brittle failure as corrosion tends to be localized. Corrosion of this kind can occur in prestressing tendons in concrete.

(v) Crevice corrosion: This form occurs when moisture and contaminants retained in crevices accelerate corrosion.
2.4 UNDERGROUND CORROSION

Most of the corrosion of underground metal is as a result of an electrochemical reaction. Corrosion occurs through the loss of the metal ions at anodic area to the electrolyte. Cathodic areas are protected from corrosion because of the deposition of hydrogen or other ions that carry current (Turner, J.M. 1993)

2.4.1 Effect of Resistance on Corrosion Current Flow

For corrosion cell that involving a single anode and a single cathode that having a potential between them, the amount current flow will be governed by apparent resistance in the anode cathode circuit. This can be considered as comprising two parts. The first one is Ohmic resistance of materials in the circuit and the effect of the
polarization (hydrogen) film on cathode. The lower the apparent of the resistance, the higher current flow by Ohm’s law and the greater the metal loss.

Ohmic resistance includes resistance in the metallic path between the anode and the cathode, the resistance of the path through the electrolyte (soil or water) between the anode and cathode and the resistance of corrosion product films on the metal surface. On pipeline, the metallic circuit resistance usually will be very low because it normally passes through a relatively short section of the pipeline by itself but that occur resistance of the path through electrolyte that is function of the resistivity of the soil.

At a given electrolyte resistance, the areas of anodes and cathodes are important. That includes the size of anode or cathodes, the higher the contact resistance between it and the electrolyte. For example, coating of good quality can interpose a very high resistance into circuit.

**Figure 2.3**: The flow of direct current between anodic and cathodic areas on a section of buried pipe.

Figure 2.3 shows that the flow of direct current between anodic and cathodic areas on a section of buried pipe. Direct current flow on a typical corroding structure. The structure that labeled (C) is cathodic area and no corrosion at pipe surface that labeled with (B). The current flow through the pipe steel from cathodic area back to anodic area to complete a circuit labeled as (A). At the anodic area, current leaves the steel to enter the surrounding earth, steel is being corroded at the surface labeled as (D) current flow through earth from anodic area to cathodic area. There is a direct current flowing from anodic areas into the soil and onto the cathodic area, and back through the pipe itself to complete the circuit. The amount of current flowing is limited by such factor as the resistivity of the environment and the degree of the polarization at anodic and cathodic areas (National Association of Corrosion Engineers, 1984. Houston).

2.5 FACTOR AFFECTING UNDERGROUND CORROSION

2.5.1 Soil Resistivity

Soil resistivity depends on the natural ingredient the amount of salt dissolved in the soil and moisture content. For the cathodic protection applications, galvanic anodes are used generally in those cases where relatively small increments of current are required in areas where soil resistivity is low that enough to permit obtaining the desired current with a reasonable number of anodes (Bashi, S.M., Mailah, N.F., Mohd M.A. 2003). Table 2.1 shows that the effect of soil resistivity to the corrosion rate. The corrosion rate is increase when the soil resistivity is increase.

2.5.2 Soil pH Value

The main factor that affects underground corrosion process is the soil pH value. The more acidic the soil is, the higher the corrosion rate. Table 2.2 shows that the effect of pH value to the corrosion rate. This pH ranges generally from 5 to 10 in soil. pH for indicates value, where lower value considered acidic and higher value is alkaline (Bashi, S.M., Mailah, N.F., Mohd M.A. 2003).
Table 2.1: Relationship Soil Resistivity and Corrosion Rate

<table>
<thead>
<tr>
<th>Soil resistivity (Ohm – meter)</th>
<th>Type of corrosion rate (Mils/year)</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt; 25</td>
<td>Severely corrosive (&gt;13)</td>
</tr>
<tr>
<td>26-30</td>
<td>Moderately corrosive (9-12)</td>
</tr>
<tr>
<td>51-100</td>
<td>Mildly corrosive (4-9)</td>
</tr>
<tr>
<td>&gt;100</td>
<td>Low corrosive (&lt;4)</td>
</tr>
</tbody>
</table>

Source: National Power Energy conference (PEcon) 2003

2.5.3 Aeration

It is a measure of the availability of oxygen to the metal and is dependent on particle size distribution. Corrosion increase with the increase of aeration.

2.5.4 Moisture

Moisture depends on season, location of the soil type, ground water level and particle size. Corrosion increases with higher moisture contents due to higher salt solubility.

2.5.5 Others factor

It is difficult to classify the other factors such as temperature, bacterial or interference current effects as they are a combination of many factors. If it is only contributed 10 percent of the total corrosion rate in many cases, then it can be neglected.
Table 2.2 Effect pH Range on Corrosion Rate

<table>
<thead>
<tr>
<th>Type of soil</th>
<th>pH value range</th>
<th>Corrosion rate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Extremely acid</td>
<td>&lt; 4.5</td>
<td>Highest</td>
</tr>
<tr>
<td>Very strongly acid</td>
<td>4.5 to 5.0</td>
<td></td>
</tr>
<tr>
<td>Strongly Acid</td>
<td>5.1 to 5.5</td>
<td></td>
</tr>
<tr>
<td>Medium Acid</td>
<td>5.6 to 6.0</td>
<td></td>
</tr>
<tr>
<td>Slightly Acid</td>
<td>6.1 to 6.5</td>
<td></td>
</tr>
<tr>
<td>Neutral</td>
<td>6.6 to 7.3</td>
<td>Least</td>
</tr>
<tr>
<td>Mild Alkaline</td>
<td>7.4 to 7.8</td>
<td></td>
</tr>
<tr>
<td>Moderately Alkaline</td>
<td>7.9 to 8.4</td>
<td></td>
</tr>
<tr>
<td>Strongly Alkaline</td>
<td>8.5 to 9.0</td>
<td></td>
</tr>
<tr>
<td>Very strongly Alkaline</td>
<td>9.1 &gt;</td>
<td>Higher</td>
</tr>
</tbody>
</table>

Source: National Power Energy conference (PEcon) 2003

2.6 CORROSION OF UNDERGROUND STEEL PIPELINES

Pipelines carrying oil, gas and water are surely the most considerable assets buried in soils. Some pipe lines deteriorate slowly and in certain cases pipeline life has been targeted at 70 years or more. Apart from the quality of the construction, coatings,
CP systems, and so forth, the factors which affect pipeline life include nature of the product, nature of the environment, operating conditions and quality of maintenance.

Some conditions can establish anodes and cathodes on pipeline to allow the corrosion cell exists. Those conditions are responsible for active corrosion can be of immeasurable value when designing and installing pipeline systems (Darowicki, K., Bohdanowicz, W and Walaszkowski, J. 2001).

(i) Dissimilar metal corrosion cells

Different metal are used in pipeline construction provided there is an electrical contact between them and also in contact with common electrolyte (soil or water). This is simplest example for the dissimilar metal corrosion cell. Any two dissimilar metals may be expected to have an electrical potential between them. The magnitude of this potential and which of the metal will be anodic (corroded) will normally depends on the position of the metals in the electromotive force series (EMF) in Table 2.3 or galvanic series.

(ii) Corrosion resulting from dissimilar soils

A steel pipeline passing through dissimilar soils also can establish corrosion cells. This because the potential of the pipeline metal with respect to its environment can vary differences in the electrolyte composition. For example in Figure 2.4, the potential of the pipeline metal respect to the electrolyte represented by soil A is slightly different from the potential of the same metal to the electrolyte represented by soil B. The pipe in soil A is anodic compare to soil B and it will corrode (National Association of Corrosion Engineers, 1984. Houston).
(iii) New pipe and Old pipe.

This conditions is very closed related to dissimilar metal corrosion when new steel pipe is join together with old steel pipe. Figure 2.5 shows examples of occurrence of galvanic corrosion cells. The new piece of pipe, exposed to same corrosion conditions, and usually this new section will corrode sooner than expected. This is because the potential of new steel is different from that of old rusted steel. The new steel is anodic and it will corroded.
Figure 2.5 Dissimilar Steel Pipes Galvanic Corrosion Cells

Source: National Association of Corrosion Engineers, corrosion Basics 1984

Table 2.3 Standard Electrochemical Series for Some Common Metals and Reactions

<table>
<thead>
<tr>
<th>Reaction</th>
<th>Standard Reduction Potential V (SHE)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Au^3+ + 3e^- = Au</td>
<td>+1.498</td>
</tr>
<tr>
<td>Pt^2+ + 2e^- = Pt</td>
<td>+1.200</td>
</tr>
<tr>
<td>Pd^2+ + 2e^- = Pd</td>
<td>+0.987</td>
</tr>
<tr>
<td>Ag^+ + e^- = Ag</td>
<td>+0.799</td>
</tr>
<tr>
<td>Hg^2+ + 2e^- = 2Hg</td>
<td>+0.788</td>
</tr>
<tr>
<td>O_2 + 2H_2O + 4e^- = 4OH^-</td>
<td>+0.401</td>
</tr>
<tr>
<td>Cu^2+ + 2e^- = Cu</td>
<td>+0.337</td>
</tr>
<tr>
<td>2H^+ + 2e^- = H_2</td>
<td>0.000</td>
</tr>
<tr>
<td>Pb^2+ + 2e^- = Pb</td>
<td>−0.126</td>
</tr>
<tr>
<td>Sn^{2+} + 2e^- = Sn</td>
<td>−0.136</td>
</tr>
<tr>
<td>Ni^{2+} + 2e^- = Ni</td>
<td>−0.250</td>
</tr>
<tr>
<td>Co^{2+} + 2e^- = Co</td>
<td>−0.277</td>
</tr>
<tr>
<td>Cd^{2+} + 2e^- = Cd</td>
<td>−0.403</td>
</tr>
<tr>
<td>Fe^{2+} + 2e^- = Fe</td>
<td>−0.440</td>
</tr>
<tr>
<td>Cr^{3+} + 3e^- = Cr</td>
<td>−0.744</td>
</tr>
<tr>
<td>Zn^{2+} + 2e^- = Zn</td>
<td>−0.763</td>
</tr>
<tr>
<td>Al^{3+} + 3e^- = Al</td>
<td>−1.662</td>
</tr>
<tr>
<td>Mg^{2+} + 2e^- = Mg</td>
<td>−2.363</td>
</tr>
<tr>
<td>Na^+ + e^- = Na</td>
<td>−2.714</td>
</tr>
<tr>
<td>K^+ + e^- = K</td>
<td>−2.925</td>
</tr>
</tbody>
</table>

Source: British standard code of practice CP 1021 1973
2.7 CATHODIC PROTECTION

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. It’s also can be defined as reduction or eliminations of corrosion by making the metal a cathode by means of an impressed current or attachment to a galvanic anode. Current flows because of a potential difference between the anode and cathode. The anode potential is more negative than the cathode potential, and the difference is the driving force for the corrosion current. The total system is anode, cathode, electrolyte, and metallic connection between anode and cathode is termed a corrosion cell. For corrosion to occur, the following conditions are required (Gibala, R, Tireell, M, Wert, C. 1993).

(i) Electrodes.
   An anode and cathode must be present.

(ii) Electrical potential.
    An electrical potential between the anode and cathode must be present. Several conditions may cause this potential.

(iii) Conductive path.
    A metallic conductive path electrically connecting the anode and cathode must exist. In the case of a metallic pipeline, the pipe itself is this conductive path.

(iv) Electrolyte.
    The anode and cathode are immersed in an electrically conductive electrolyte that is ionized. Usual soil moisture or water fulfills this condition.

(v) Current.
    When these conditions exist, an electric current will flow, and where the current leaves a metallic object, metals will be consumed.

Cathodic protection reverses the current flow by installing ground beds of sacrificial anodes. No longer does the current leave the structure. Now the structure receives current flow, inhibiting corrosion. The structure is the cathode, and thus, the term cathodic protection.
2.7.1 Types of cathodic protection systems

Cathodic protection is a method to reduce corrosion by minimizing the difference in potential between anode and cathode. This is achieved by applying a current to the structure to be protected (such as a pipeline) from some outside source. When enough current is applied, the whole structure will be at one potential; thus, anode and cathode sites will not exist. Cathodic protection is commonly used on many types of structures, such as pipelines, underground storage tanks, locks, and ship hulls. There are two main types of cathodic protection systems: sacrificial anode and impressed current (Denny, A.J, Uhling, H.H., R W Revie. 1985).

(i) Galvanic systems or sacrificial anode

A galvanic cathodic protection system makes use of the corrosive potentials for different metals. Without cathodic protection, one area of the structure exists at a more negative potential than another, and corrosion results. If a much less inert object (that is, with much more negative potential, such as magnesium anode) is placed adjacent to the structure to be protected, such as a pipeline; and a metallic connection (insulated wire) is installed between the object and the structure, the object will become the anode and the entire structure will become the cathode. That is, the new object corrodes sacrificially to protect the structure. Thus, the galvanic cathodic protection system is called a “sacrificial anode cathodic protection system” because the anode corrodes sacrificially to protect the structure. Galvanic anodes are usually made of either magnesium or zinc because of these metals higher potential compared to steel structures. Figure 2.6 shows those cathodic protections with sacrificial anode.

(ii) Impressed current systems.

Impressed current cathodic protection systems use the same elements as the galvanic protection system; only the structure is protected by applying a current to it from an anode. The anode and the structure are connected by an insulated wire, as for the galvanic system. Current flows from the anode through...
the electrolyte onto the structure, just as in the galvanic system. The main difference between galvanic and an impressed current system is that the galvanic system relies on the difference in potential between the anode and structure, whereas the impressed current system uses an external power source to drive the current. The external power source is usually a rectifier that changes input alternating current (AC) power to the proper direct current (DC) power level. The rectifier can be adjusted, so that proper output can be maintained during the system’s life. Impressed current cathodic protection system anodes typically are high-silicon cast iron or graphite. Figure 2.7 shows those cathodic protections by impressed current

![Diagram](image)

**Figure 2.6** Cathodic protections with sacrificial anode

Source: Uhling, H.H. and Revie, R W. 1985
2.7.2 Cathodic Protection Systems by Sacrificial Anode

As mentioned before, the corrosion cell resulting from dissimilar metals in contact. In a corrosion cell, one metal will be act as anode that respect to the other and it will corrodes. So, by using the sacrificial anodes technique, very strong anodic metal is connected to the pipeline. This metal will corrode and in so will discharge current to the pipeline. In a corrosion cell, current flows from the anode through the electrolyte to the cathode. Cathodic protection methods attempt to control the direction of the corrosion current. A sacrificial anode is an anode electrically connected to the system to be protected. The basic idea is to force certain parts to be cathodic or anodic with respect to the other in order to control the current direction. If a sacrificial anode is chosen that is anodic to every metal in the pipeline system, the anode will corrode while the pipeline is protected (Roberge, P.R. 1999).

A prime example of a sacrificial system is the use of magnesium anodes in connection with the pipeline system. The magnesium is buried in the ground within the
same electrolyte as the pipeline. The pipeline and the anode are electrically connected, and as the magnesium corrodes, the pipeline is protected. The magnesium should be alloyed to prevent passive layering. A passive layer is an oxide film that forms naturally on the surface of most metals.

This passive layer becomes a protective coating on an anode and prevents further corrosion. If the sacrificial anode does not corrode, the protection current is not produced. If this happens, the pipeline will begin to corrode. In the other words, sacrificial anode operates by employs reactive metals that have different natural potentials caused direct current to flow when both are electrically connected. Usually three major sacrificial metals Magnesium, Zinc, and Aluminum, .This because in standard electromotive force series, magnesium, zinc and aluminum is more anodic compare to steel.

The sacrifice anode also can be described as a metal which will have a voltage difference concerning the corroding structure and will discharge current that will flow through the environment to the structure. The amount of electricity that can be obtained from sacrificial anode depends on the electrochemical equivalent of the metal used and efficiency of working anode. For the galvanic couple between dissimilar metals in the galvanic series, the more noble metal is cathodically protected, while the more active is dissolved. At the active sacrificial anode, electrons will flow to the cathodic structure (Bayliss D.A, Deacon D.H 1990). The anodic section at the cathode structure for example will produce.

\[ Fe \rightarrow Fe^{2+} + 2e^- \]  (2.12)

It’s reduced by the surplus of electron provided by the sacrificial anode and at the same times, the reduction of dissolved oxygen by reaction

\[ O_2 + 2H_2O + 4e^- \rightarrow 4OH^- \]  (2.13)

Or the evolution of hydrogen by reaction is accelerated
Figure 2.8 shows compares between natural condition corrosion and with cathodic protection applied. In galvanic or sacrificial anode technique, two metals or alloys are galvanically coupled, and the more active of the two in the galvanic series will act as sacrificial anode and cathodically protect the other.

2H₂O + 2e⁻ → H₂ + 2OH⁻  \hspace{1cm} (2.14)

For soil use, aluminum, magnesium and zinc are used as sacrificial anode. Usually magnesium anode is used almost in soil. This is because it’s very active anodic corrosion potential which is sufficient to overcome the large soil resistivity than are often prevent.

Figure 2.9 shows a simplified polarization diagram for the galvanic couple between a sacrificial anode of \(E_{corr(a)}\). The two are polarized to the same “short-circuit”

Figure 2.8 Comparism between Natural Condition Corrosion and with Cathodic Protection Applied.

Source: Jones, D.A .1993