

CATHODIC PROTECTION OF UNDERGROUND STEEL PIPELINES BY USING  
SACRIFICIAL ANODES

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Thesis submitted in fulfilment of the requirements for the award of the degree of  
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Faculty of Mechanical Engineering  
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**UNIVERSITI MALAYSIA PAHANG**  
**FACULTY OF MECHANICAL ENGINEERING**

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CATHODIC PROTECTION OF UNDERGROUND  
STEEL PIPELINES BY USING SACRIFICIAL  
ANODES

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**BORANG PENGESAHAN STATUS TESIS♦**

JUDUL: **CATHODIC PROTECTION OF UNDERGROUND STEEL  
PIPELINE BY USING SACRIFICIAL ANODES**

SESI PENGAJIAN: 2009/2010

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*For my beloved Family Members,  
Especially my Parents  
And unforgettable all my friends...  
May Allah bless you..!!*

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## ABSTRACT

Underground corrosion may cause serious damage to the underground steel pipelines structure. Cathodic protection (CP) method is the most important in order to prevent underground corrosion. In this project, Cathodic Protection by using sacrificial anodes technique will be used to the underground steel pipeline. In this project a study of the performance of magnesium and zinc anodes have been carried out. Besides that, in order to know the effect of coating to the corrosion rate, the specimens of steel pipe have been coats using paint. All of the specimens were buried in the soil with depth 0.2m, pH 5.49. Each sample undergoes underground exposure for 28 days before the surface morphology investigation was conducted using Scanning Electron Microscope (SEM). After the exposure period, cleaning process for all specimens follows prior to the final analysis. Corrosion rates were calculated using weight loss methods for all of the specimens. Magnesium sacrificial anode gives better protection to the steel pipe compare to the zinc anode. The result of the corrosion rate for cathodically protected coated steel pipe by using magnesium anode was lowest which is 0.80 mpy compared to the cathodically protected coated steel pipe with sacrificial zinc anode, the corrosion rate is 2.32 mpy. The result for coated steel pipe without using any anode is 2.71 mpy. The magnesium anode performance yield similar result to the cathodically protected for uncoated steel pipe. The corrosion rate for coated steel pipe is around 0.80 mpy to 2.71 mpy which is lowest compare to corrosion rate for uncoated steel pipe is around 9.86 mpy to 15.68 mpy. Surface morphology examinations indicate the type of corrosion occurred on the steel pipe was uniform corrosion and galvanic corrosion. In conclusion, the conjoint use of cathodic protection and coating takes advantage of the most attractive features of each method of corrosion control. Magnesium anodes proves to be more practical anode in applying Cathodic Protection for underground steel pipelines.

## ABSTRAK

Kakisan di bawah tanah boleh memberi kesan yang serius terhadap struktur paip besi. Perlindungan katodik adalah penting dan wajar dalam mengawal kakisan di bawah tanah. Di dalam projek ini, perlindungan katodik dengan menggunakan teknik anod tekorban telah dijalankan. Selain itu, untuk mengetahui kesan lapisan di permukaan paip besi terhadap kadar pengurangan, sampel paip besi telah dilapis menggunakan cat. Semua sampel telah ditanam di dalam tanah dengan kedalaman 0.2m, pH 5.49. Sampel dibiarkan di dalam tanah selama 28 hari sebelum analisis morfologi permukaan dijalankan dengan menggunakan "Scanning Electron Microscop (SEM)". Selepas biarkan selama 28 hari, sampel dibersihkan sebelum analisis akhir dijalankan. Kadar pengurangan dikira menggunakan kaedah kehilangan berat untuk setiap sampel. Anod magnesium memberi perlindungan terbaik kepada paip besi dibandingkan dengan anod zink. Kadar pengurangan untuk paip besi yang di cat serta diberi perlindungan katodik menggunakan magnesium anod adalah paling rendah iaitu 0.80 mpy di bandingkan dengan paip besi yang di cat serta diberi perlindungan katodik menggunakan magnesium anod. Kadar pengurangan untuk paip yang di cat tanpa diberi perlindungan katodik ialah 2.71 mpy. Prestasi magnesium anode adalah sama apabila perlindungan katodik di aplikasikan kepada paip besi yang tidak dilindungi dengan cat. Pemeriksaan morfologi permukaan menunjukkan jenis kakisan yang terbentuk adalah kakisan umum dan kakisan "galvanic". Kesimpulannya, kombinasi perlindungan katodik dan cat memberi kelebihan dalam mencegah pengurangan. Magnesium anod membuktikan ia lebih sesuai untuk digunakan sebagai anod dalam perlindungan katodik untuk paip bawah tanah.

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## LIST OF SYMBOLS

|                |                                 |
|----------------|---------------------------------|
| $V$            | Potential Energy or Voltage     |
| $\Omega$       | Ohm                             |
| $m$            | Metre                           |
| $cm$           | Centimetre                      |
| $g$            | gram                            |
| $g/cm^3$       | Density                         |
| $mpy$          | mils per year                   |
| $I$            | Impressed current               |
| $I_G(sc)$      | Short circuit galvanic current  |
| $I_{corr(sc)}$ | Short circuit corrosion current |
| $E_{corr}$     | Corrosion potential             |
| $E_{corr}$     | short-circuit potential         |
|                | Local mean stress               |
| $\Omega/m$     | Soil Resistivity                |
| %              | Percentage                      |
| $^{\circ}C$    | Degree Celsius                  |

**LIST OF ABBREVIATIONS**

|       |                                  |
|-------|----------------------------------|
| CP    | Cathodic Protection              |
| Zn    | Zinc                             |
| Al    | Aluminium                        |
| Mg    | Magnesium                        |
| Fe    | Ferrous                          |
| Si    | Silicon                          |
| Cu    | Copper                           |
| H     | Hydrogen                         |
| O     | Oxygen                           |
| $e^-$ | Electron                         |
| ASTM  | American Standard Testing Method |
| EMF   | Electromotive force series       |
| AC    | Alternating current              |
| DC    | Direct current                   |
| SEM   | Scanning Electron Microscope     |
| HCL   | Hydrochloric Acid                |
| T     | Time                             |
| A     | Surface Area                     |
| W     | Mass Loss in grams               |
| D     | Density                          |

## 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., Tirell, 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).

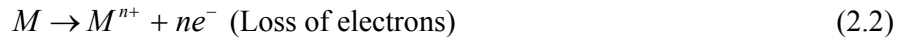
- (i) Temperature effects: Increasing the temperature of a corrosive system will increase the corrosion rate because the kinetics energy is increase.
- (ii) Potential difference (EMF): when two metals exposed to same environment with different potential, the metal higher in the series of Standard Electrode,  $V^\circ$  (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

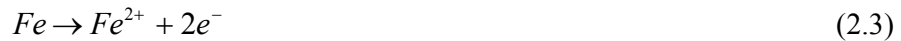
Corrosion theorists are obliged to take into account considerations of the infinitely small and necessarily complex activities on the molecular and at the ionic, electronic and atomic levels. Figure 2.1 shows an illustration of corrosion cells. Three basic kind of corrosion can be listed as chemical, 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).



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:



Examples in addition equation (2.2) are



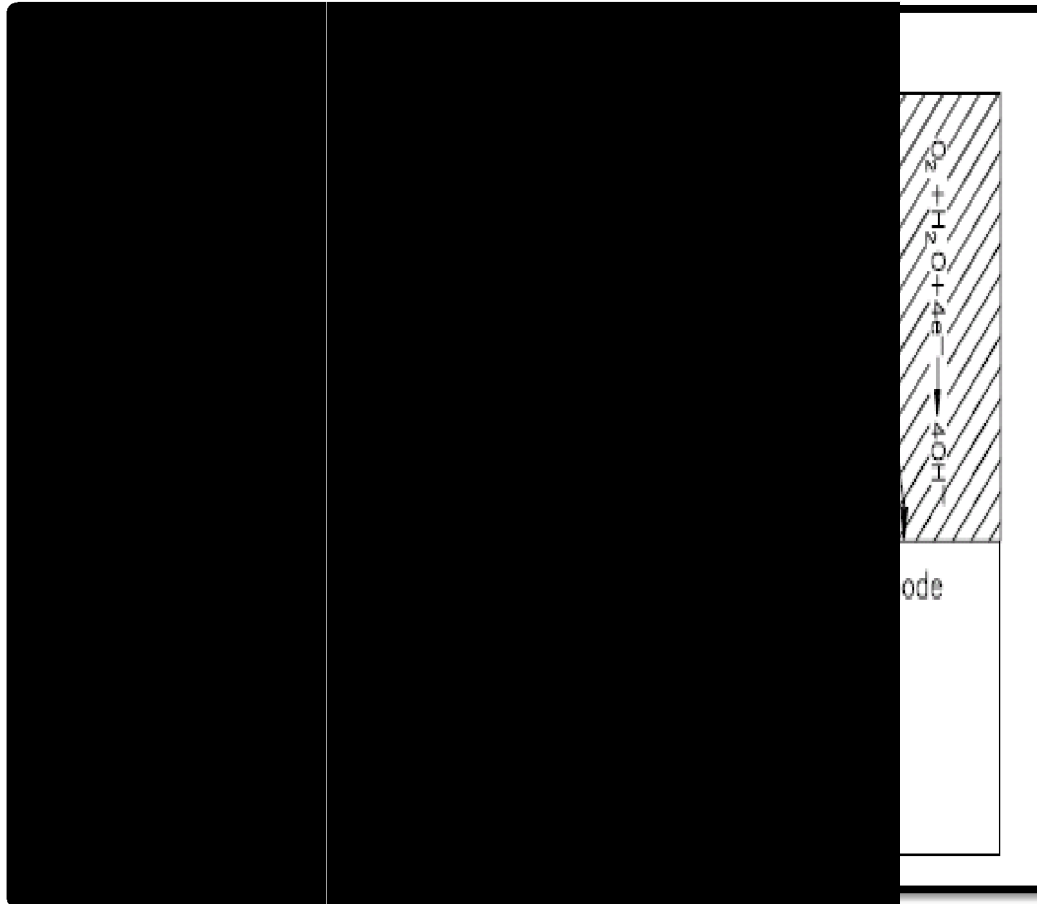
The cathodic reaction or oxidation consumes (gain electrons) the electrons and the cathodic reaction depends on the type of environment:

- (i) In acid environments:

Hydrogen evolution



(ii) Neutral & Alkaline



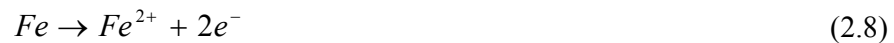
**Figure 2.1:** An illustration of corrosion cells

Source: Jones, D.A., Uhling, H.H, Revie R.W 1982

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):

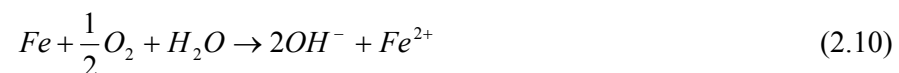


The corrosion reactions can be illustrated using chemical terminology as follow equation (2.8). This is simple way of describing the process where iron is removed as charged particle called ions ( $Fe^{2+}$ ) and electron( $e^{-}$ ) carry current to balance the electric charge. Clearly a balancing reaction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

Cathodic reaction:



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



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

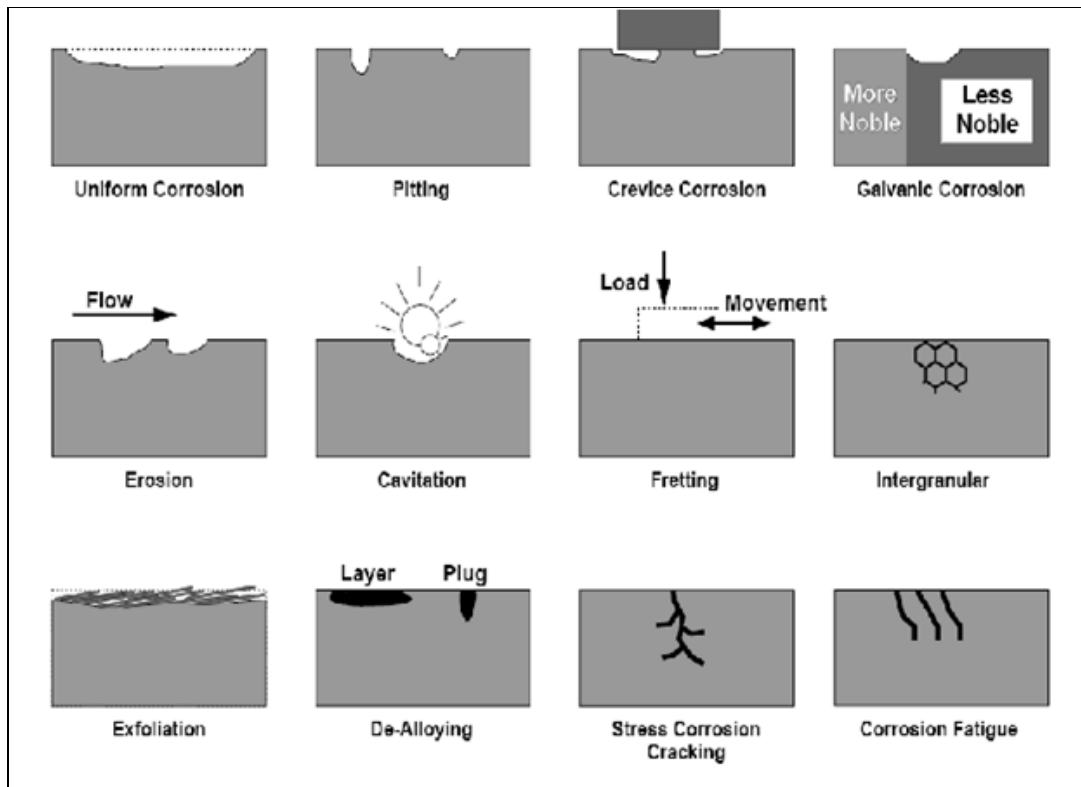


This is simple form of rust which unstable and is eventually oxidized (i.e. react with oxygen) to form the familiar reddish brown rust, chemically denoted  $FeOOH$ . This is the form of rust usually produced in air, natural water and soils. However, under acidic conditions hydrogen is produced at the cathode and the corrosion product may be  $Fe_3O_4$  (magnetite).

### 2.3.2 Forms of Corrosion

Figure 2.2 shows forms of corrosion that occur to the metal structure. The several type 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.



**Figure 2.2:** Forms of Corrosion

Source: Roberge, P.R. 1999

## 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)

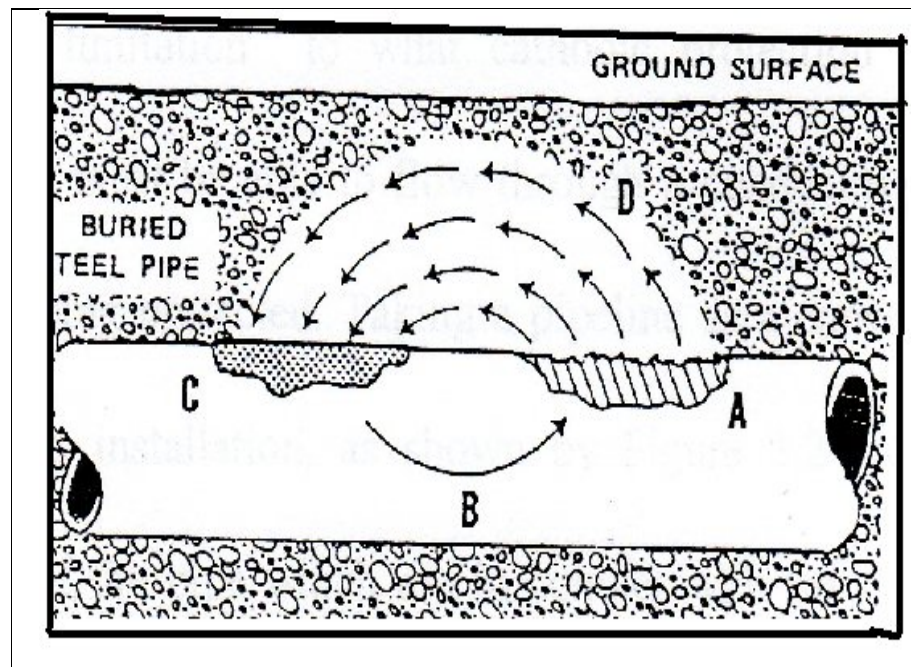
### 2.4.1 Effect of Resistance on Corrosion Current Flow

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.

Source: (National Association of Corrosion Engineers, 1984. Houston).

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

| <b>Soil resistivity</b><br>(Ohm – meter) | <b>Type of corrosion rate</b><br>(Mils/year) |
|--|--|
| < 25                                     | Severely corrosive ( >13 )                   |
| 26-30                                    | Moderately corrosive (9-12)                  |
| 51-100                                   | Mildly corrosive (4-9)                       |
| >100                                     | Low corrosive ( <4 )                         |

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

| Type of soil           | pH value range | Corrosion rate |        |
|------------------------|----------------|----------------|--------|
| Extremely acid         | < 4.5          | Highest        |        |
| Very strongly acid     | 4.5 to 5.0     |                |        |
| Strongly Acid          | 5.1 to 5.5     |                |        |
| Medium Acid            | 5.6 to 6.0     |                |        |
| Slightly Acid          | 6.1 to 6.5     |                |        |
| Neutral                | 6.6 to 7.3     |                |        |
| Mild Alkaline          | 7.4 to 7.8     |                |        |
| Moderately Alkaline    | 7.9 to 8.4     |                |        |
| Strongly Alkaline      | 8.5 to 9.0     |                |        |
| Very strongly Alkaline | 9.1 >          |                | Higher |

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.

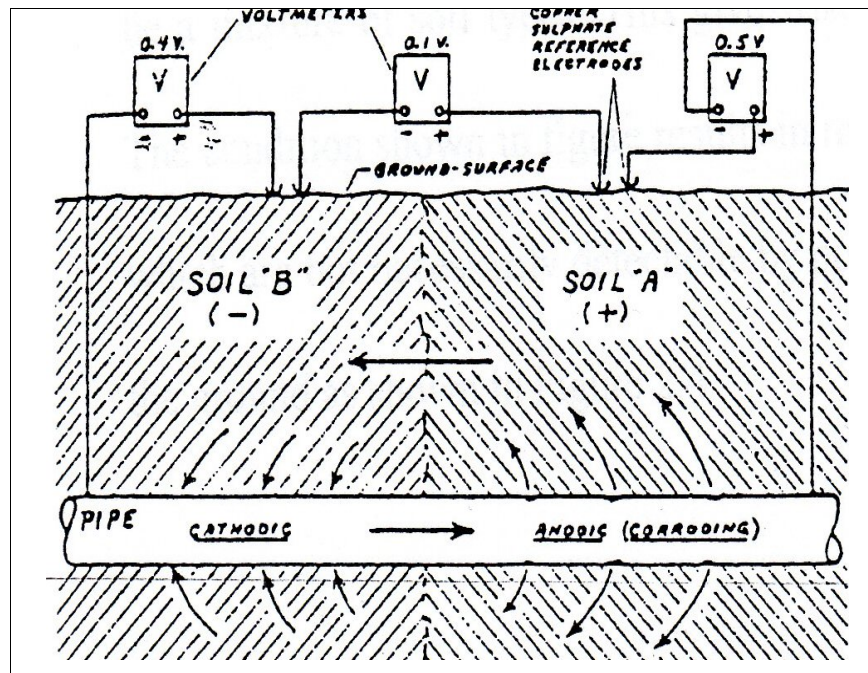
Some conditions can establish anodes and cathodes on pipeline to allow the corrosion cell exists. Those conditions are responsible for active corrosion can be of immeasurable value when designing and installing pipeline systems (Darowicki, K., Bohdanowicz, W and Walaszkowski, J. 2001).

(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).

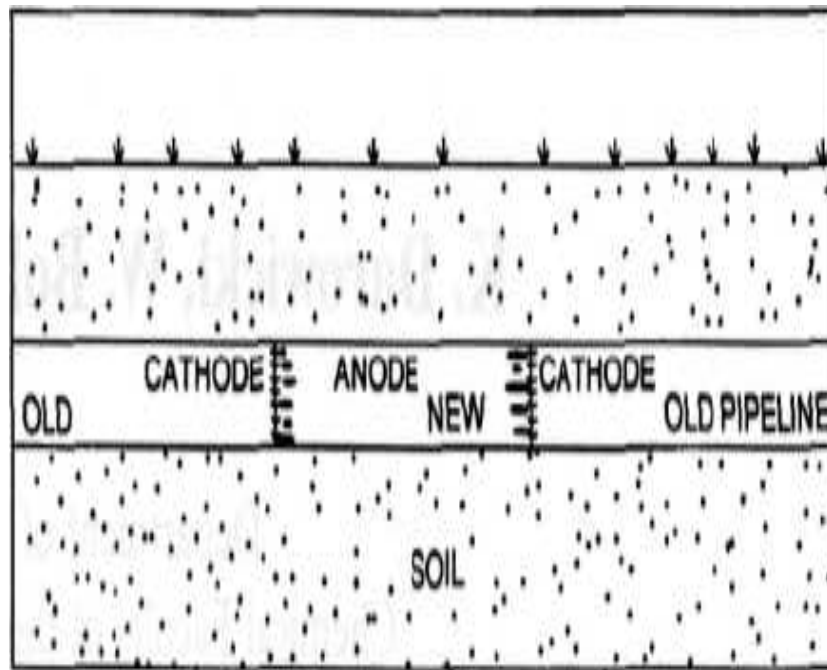


**Figure 2.4** Corrosion from Dissimilar soils

Source: National Association of Corrosion Engineers, corrosion Basics 1984

(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

|                                     | Reaction   | Standard Reduction Potential V (SHE) |
|-------------------------------------|--|--------------------------------------|
| ↑<br>Noble                          | $\text{Au}^{3+} + 3e^- = \text{Au}$                      | +1.498                               |
|                                     | $\text{Pt}^{2+} + 2e^- = \text{Pt}$                      | +1.200                               |
|                                     | $\text{Pd}^{2+} + 2e^- = \text{Pd}$                      | +0.987                               |
|                                     | $\text{Ag}^+ + e^- = \text{Ag}$                          | +0.799                               |
|                                     | $\text{Hg}_2^{2+} + 2e^- = 2\text{Hg}$                   | +0.788                               |
|                                     | $\text{O}_2 + 2\text{H}_2\text{O} + 4e^- = 4\text{OH}^-$ | +0.401                               |
|                                     | $\text{Cu}^{2+} + 2e^- = \text{Cu}$                      | +0.337                               |
|                                     | $2\text{H}^+ + 2e^- = \text{H}_2$                        | 0.000                                |
|                                     | $\text{Pb}^{2+} + 2e^- = \text{Pb}$                      | -0.126                               |
|                                     | $\text{Sn}^{2+} + 2e^- = \text{Sn}$                      | -0.136                               |
|                                     | $\text{Ni}^{2+} + 2e^- = \text{Ni}$                      | -0.250                               |
|                                     | $\text{Co}^{2+} + 2e^- = \text{Co}$                      | -0.277                               |
|                                     | $\text{Cd}^{2+} + 2e^- = \text{Cd}$                      | -0.403                               |
|                                     | $\text{Fe}^{2+} + 2e^- = \text{Fe}$                      | -0.440                               |
| $\text{Cr}^{3+} + 3e^- = \text{Cr}$ | -0.744   |                                      |
| Active<br>↓                         | $\text{Zn}^{2+} + 2e^- = \text{Zn}$                      | -0.763                               |
|                                     | $\text{Al}^{3+} + 3e^- = \text{Al}$                      | -1.662                               |
|                                     | $\text{Mg}^{2+} + 2e^- = \text{Mg}$                      | -2.363                               |
|                                     | $\text{Na}^+ + e^- = \text{Na}$                          | -2.714                               |
|                                     | $\text{K}^+ + e^- = \text{K}$                            | -2.925                               |

Source: 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, Tirell, 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).

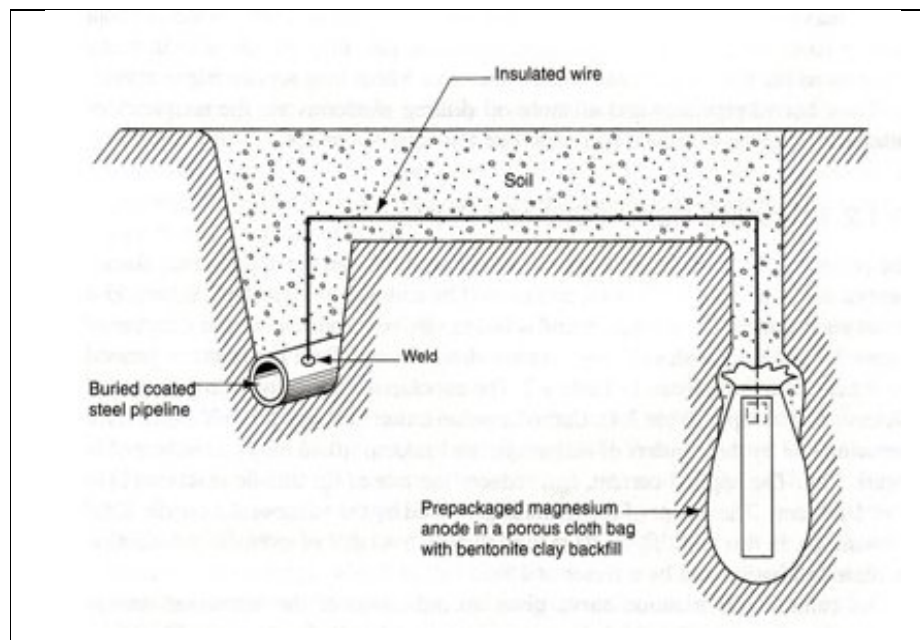
#### (i) Galvanic systems or sacrificial anode

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

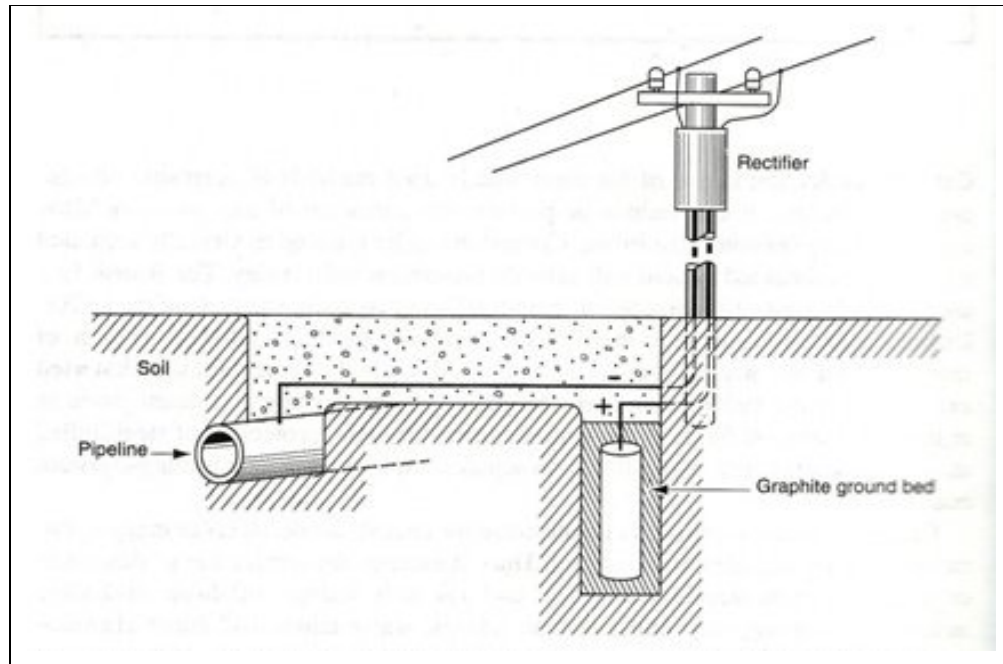
the electrolyte onto the structure, just as in the galvanic system. The main difference between galvanic and an impressed current system is that the galvanic system relies on the difference in potential between the anode and structure, whereas the impressed current system uses an external power source 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



**Figure 2.6** Cathodic protections with sacrificial anode

Source: Uhling, H.H. and Revie, R W. 1985





**Figure 2.7** Cathodic protections by impressed current

Source: Uhling, H.H. and Revie, R W. 1985

### 2.7.2 Cathodic Protection Systems by Sacrificial Anode

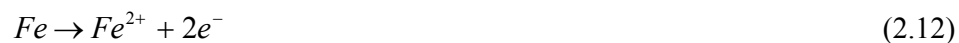
As mentioned before, the corrosion cell resulting from dissimilar metals in contact. In a corrosion cell, one metal will be act as anode that respect to the other and it will corrodes. So, by using the sacrificial anodes technique, very strong anodic metal is connected to the pipeline. This metal will 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.



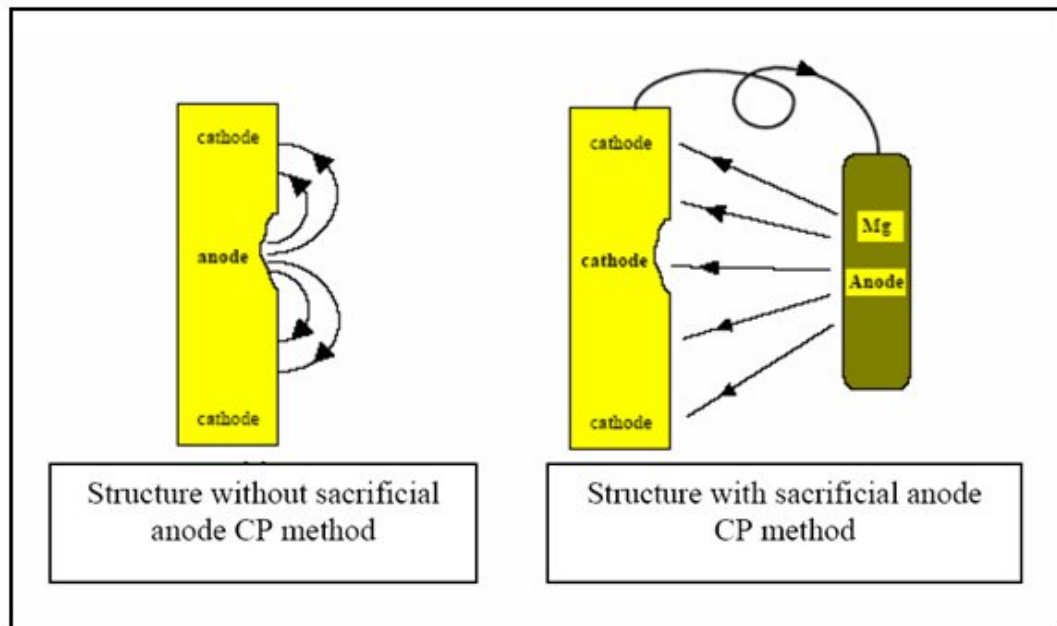
It's reduced by the surplus of electron provided by the sacrificial anode and at the same times, the reduction of dissolved oxygen by reaction



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.



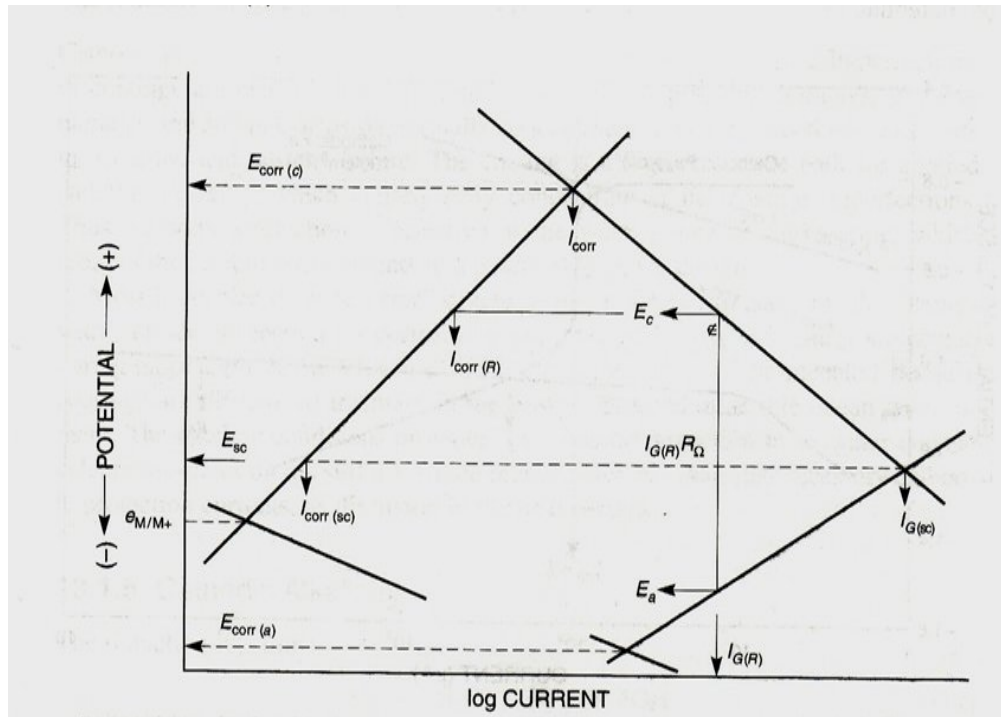
**Figure 2.8** Comparison between Natural Condition Corrosion and with Cathodic Protection Applied.

Source: Jones, D.A .1993

For soil use, aluminum, magnesium and zinc are use 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”

potential,  $E_{sc}$  with the galvanic current  $I_{G(sc)}$  flowing in the couple. The galvanic current provides cathodic protection in the same manner as an impressed current. At  $E_{sc}$  the corrosion rate of the structure has been reduced from  $I_{corr}$  to  $I_{corr(sc)}$  (Denny, A.J, Uhling, H.H, Revie, R.W. 1985).



**Figure 2.9:** Schematic polarization diagram for a sacrificial anode coupled to a cathodically protected metal structure.  $I_{corr}$  reduced to  $I_{corr(sc)}$  by the galvanic current  $I_{G(sc)}$ . Presence of solution resistance  $R_{\Omega}$  reduces galvanic current to  $I_{G(R)}$  separates anode and cathode by a potential  $I_{G(R)}R_{\Omega}$  and reduces  $I_{corr}$  to  $I_{corr(R)}$ .

Source: Pierre R. Roberge 1999

The requirement for a metal to be a practical galvanic or sacrificial anode material is:

- (i) The potential between the anode and corroding structure must be large enough to overcome the anode-cathode cells on the corroding structure.
- (ii) The anode material must have sufficient electrical energy current to permit reasonably long life with a practical amount of anode material.

- (iii) Anodes must have good efficiency or high electrical energy content of the anode should be available for useful cathodic protection current output.

### **2.7.3 Principle of Cathodic Protection Works in Soils**

Pipelines are constructing through different soils on their way across the land. In every case where two different soils are in contact with a single piece of metal, a concentration cell is possible. In most cases occurring in naturally occurring soils, that portion of pipe lying in more conductive soil is the anode and the portion in the less conductive soil is the cathode. Moist soils themselves act as the electrolyte and the pipe provides the connecting circuit (National Association of Corrosion Engineers, Houston 1980).

Corrosion occurs where the current discharge from the metallic structure into the soil at anodic areas. Where current flows from the environment onto the pipe (cathodic areas), there is no corrosion. In applying CP to a structure, then the objective is to force entire structure exposed to the environment to collect current environment. When this condition had been attained, the exposed surface become a cathode and corrosion is the successfully mitigated (Darowicki, K, Bohdanowicz, W. Walaszkowski, J. 2001).

## **2.8 ANODE MATERIAL**

### **2.8.1 Magnesium anodes**

Magnesium is the highest operating voltage of all common Galvanic Anodes but has the lowest efficiency and highest cost per ampere year of current flow. Typically used in soils and waters with resistivity higher than 1500 ohm-cm. (U.S. Army Corps of Engineers, 2004). Table 2.4 show properties of magnesium anode.

**Table 2.4:** Properties of Magnesium Anode

|                            |       |   |
|----------------------------|-------|---|
| Electrochemical Properties | (i)   | Ampere Hour/Pound Consumed Theoretical=1000   |
|                            | (ii)  | Current Efficiency=50%  |
|                            | (iii) | Ampere Hour/Pound Consumed Practical=500  |
|                            | (iv)  | Pounds Consumed per-Year of output=17   |
| Advantages                 | (i)   | Very high efficiency = >90%   |
|                            | (ii)  | Highest Available Driving Potential – This is advantage in higher resistivity soils. Generally this is the only applicable anode material in soils having resistivity of 2000 ohm-cm or higher.           |
|                            | (iii) | Available in the greatest number of sizes and shapes for many applications  |
|                            | (iv)  | No temperature limitations  |
|                            | (v)   | Select Backfill is not required although its use is highly recommended. If not used, lower efficiencies and selective attack of the magnesium metal will occur resulting in shorten anode operating life. |
| limitations                | (i)   | Relative low efficiency = approximately 50% for all alloys.   |
|                            | (ii)  | Most expensive common galvanic anode metal.   |
|                            | (iii) | Typically significantly higher material cost per ampere-year of cathodic protection provide than aluminum anodes.   |
|                            | (iv)  | Due to high driving potential ,should not be used(except under very special)  |

Source: U.S. Army Corps of Engineers, 2004

### 2.8.2 Zinc anodes

Zinc was an ideal material because it has very high operating efficiency and a relatively low driving voltage, which is an advantage in the very conductive (low resistivity) soil. Table 2.5 show properties of zinc anode.

**Table 2.5:** Properties of Zinc Anode

|                            |       |   |
|----------------------------|-------|---|
| Electrochemical Properties | (i)   | Chemical composition  |
|                            | (ii)  | Current capacity – 372-amps-hours/pound Theoretical   |
|                            | (iii) | Current efficiency above 90% efficiency   |
| Advantages                 | (i)   | Very high efficiency=>90%   |
|                            | (ii)  | Low driving potential- This is advantage in low resistivity environments such as soil with resistivity less than 200 ohm-cm   |
|                            | (iii) | Lowest cost compare to magnesium  |
|                            | (iv)  | Available to use both underground and under water.  |
| limitations                | (i)   | Must not be used in applications where temperatures exceed 1200 Fahrenheit because inter-granular corrosion attack of the zinc will cause very premature failure of material. |
|                            | (ii)  | Typically higher cost per ampere-year of cathodic protection provide than aluminum anodes in soil applications, due to low driving potential                                  |
|                            | (iii) | Should not be used (except under very special circumstances)in soil resistivity greater than 2000 ohm-cm  |

Source: U.S. Army Corps of Engineers, 2004

### 2.8.3 Composition

Since only the sacrificial anodes methods will be applied in this project, so it is necessary to consider the material composition of the sacrificial anode used. In order to meet most anode specifications, high grade primary metal must be used. Most primary metals are available to more than one specification, depending on the method of manufacture and the amount and method purification or refining carried out. So, it is to be sure to specify the right basic analysis for the main anode metal. Typical analysis of primary metals used for anodes are as follow Table 2.5.

**Table 2.5.** Composition of anodes

| Type of anodes  | Composition      |
|-----------------|------------------|
| Aluminum anode  | 99.80% Aluminum  |
|                 | Fe 0.006 max.    |
|                 | Si 0.008 max.    |
|                 | Cu 0.004 max     |
|                 | Zn 0.002 max.    |
|                 | Sn 0.001 max.    |
|                 | Others 0.003 max |
| Magnesium anode | 99.80% Magnesium |
|                 | Ni 0.002 max.    |
|                 | Zn 0.002 max.    |
|                 | Ca 0.002 max.    |
|                 | Al 0.008 max.    |
|                 | Pb 0.003 max.    |
|                 | Si 0.072 max.    |
|                 | Sn 0.002 max.    |
|                 | Cu 0.003 max     |
|                 | Mn 0.017 max     |
| Zinc anode      | 99.99% Zinc      |
|                 | Pb 0.003 max     |
|                 | Cu 0.001 max     |
|                 | Cd 0.003 max     |
|                 | Fe 0.002 max     |
|                 | Sn 0.001 max     |

Source: (Bushman, J.B. 1984):

In general, heavy metal impurities that will result in self-corrosion. Thus it must be kept to minimum and this is reflected in the compositions which specify maximum content of copper, lead, Iron, etc or deliberates additions of alloying elements to nullify their effect. The alloying elements can reducing self-corrosion of anodes, make anode's potential more negative, prevent passivation occurs and increasing their efficiency.

## 2.9 COATINGS AND CATHODIC PROTECTION

Cathodic protection provides an ideal supplement for coating systems. Imperfections in coatings are nearly always present in the form of pinholes, holidays, physical damage and so on. It is advantageous to use insulating coatings with sacrificial



anodes system when supplying cathodic protection. These coatings need not be pore free, because the protective current flows preferentially to the exposed metal areas, which require the protection. Coating is useful in distributing the protective current, in reducing total current requirements and in extending the life of the anode (Gibala, R; Tirell, M; and Wert, C. 1993).

The coating is a high resistance path for applied cathodic currents, which consequently concentrate at the coating imperfections. Thus, cathodic protection is effective at the weak points of the coating, which reduces the current requirements to a practical level for design. Most buried steel structure use a combination of organic coating with cathodic protection or corrosion prevention (Denny A. Jones;H.H Uhling ;R W Revie,1985) The corrosion process can be prevented or retarded by suppressing either the cathodic or anodic reaction or by inserting a high resistance in the path of corrosion current flowing in the electrolyte cell. The cathodic reaction can be suppressed by preventing the passage of oxygen and moisture to the steel (Bayliss, D.A, Deacon, D.H. 1982).

### **2.9.1 Types of Coating**

They are several types of coatings such as metallic, non metallic, in- organic and etc: (Roberge P.R, 1999)

- (i) **Metallic coatings:** Metallic coatings provide a layer that changes the surface properties of the work piece to those of the metal being applied. The work piece becomes a composite material exhibiting properties generally not achievable by either material if used alone. The coatings provide a durable, corrosion-resistant layer, and the core material provides the load-bearing capability. Metallic coatings are deposited by electroplating, electro less plating, spraying, hot dipping, chemical vapor deposition, and ion vapor deposition. Some important coatings are cadmium, chromium, nickel, aluminum, and zinc. Copper, gold, and silver are also used in electrical equipment and occasionally for specialty fastener applications.

- (ii) Non-metallic coatings: These coatings consist of either inorganic or organic material.
- (iii) Inorganic coatings: Inorganic coatings can be produced by chemical action, with or without electrical assistance. The treatments change the immediate surface layer of metal into a film of metallic oxide or compound that has better corrosion resistance than the natural oxide film and provides an effective base or key for supplementary protection such as paints. In some instances, these treatments can also be a preparatory step prior to painting.
- (iv) Organic coatings: Paints, coatings, and high-performance organic coatings were developed to protect equipment from environmental damage. Organic coating is probably the most familiar method to protect metal from corrosion. They include material such as pitch, tar, bitumen, oils and greases, all of which are applied to the metal surface and function principally by excluding corrosive media. Many modern synthetic materials such as polyvinyl chloride and epoxy resin can also be used as protective coatings.

Oil paints constitute an important type of surface coatings. Oil paints contain four main constituents, namely pigment, drying oil, drier and thinner. After the paint has been applied to a surface, the thinner evaporates, the drier takes up oxygen from the atmosphere and passes it on to the drying oil; cross linking of the drying oil molecules occurs followed by setting the paint. The protection provided by oil paints to metal is not simply due to barrier action. Paint films are rather porous and it has been demonstrated that oxygen and water diffuse through them at a fairly rapid rate. Hence, under a paint film, the cathodic process of oxygen reduction is possible as there is certainly no dearth of reactants. The cathodic reaction cannot occur at the film or solution boundary since these paint films do not conduct electrons. So, it can be concluded that it is unlikely that cathodic inhibition is responsible for the observed lack of corrosion of metal in this condition (Denny A. Jones, D.A, Uhling H.H, Revie, R W. 1985).

## **CHAPTER 3**

### **METHODOLOGY**

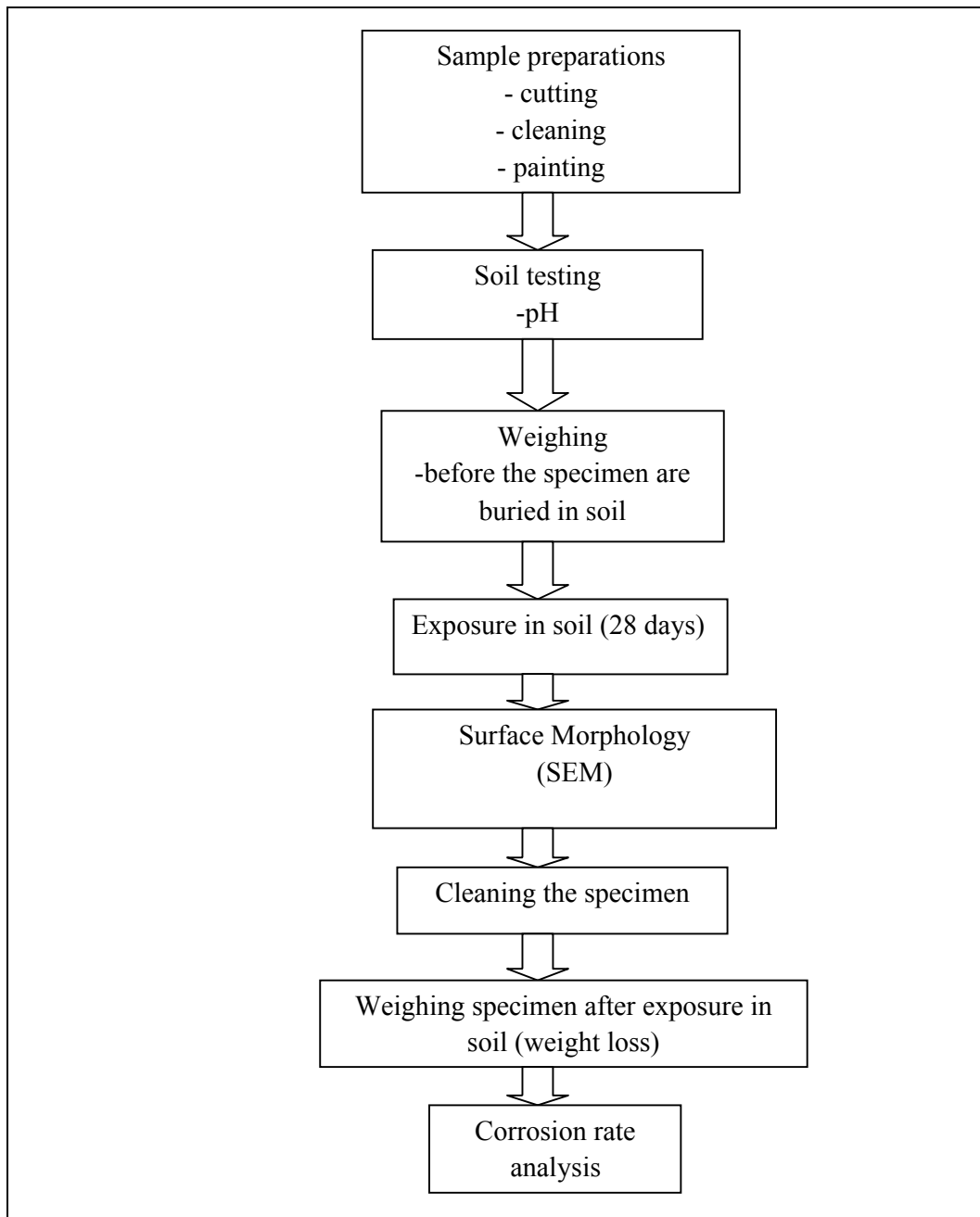
#### **3.1 INTRODUCTION**

In this chapter, the methodology of this study will be carefully discussed. Methodology include in this study specimen preparations, designing of cathodic protection system, exposure in soil, weighing the specimen, surface morphology, cleaning specimen and finally corrosion rate analysis.

The specimen for this project is steel pipe meanwhile type of anodes used were zinc and magnesium. The test carried out was analyzed of soil pH. The steps in this research was referred from the American National Standard (ASTM) depends on the suitability. The surface morphology of the specimen has been examined by using Scanning Electron Microscopy (SEM).

### 3.1.1 General Experiment Procedure for CP by Using Sacrificial Anode

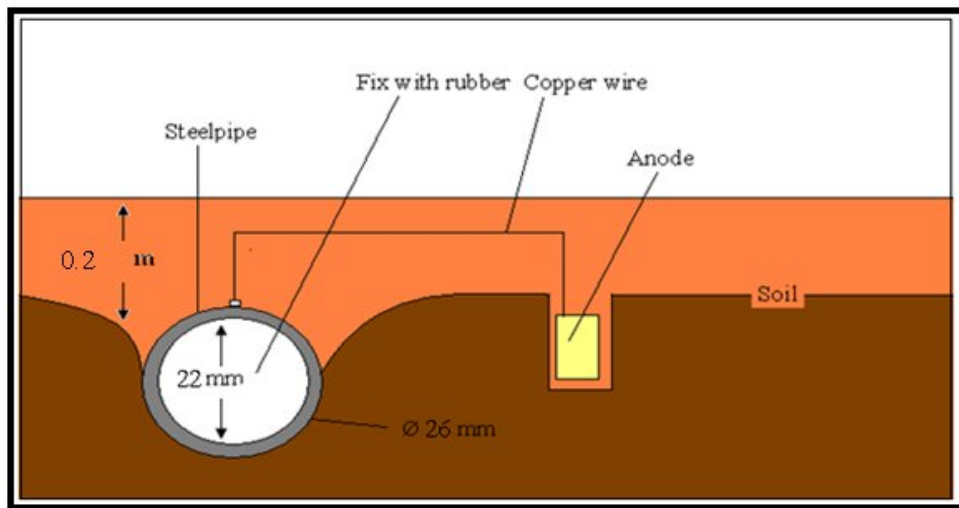
Figure 3.1 shows that experiment procedure for Cathodic Protection by using sacrificial anodes. The sample was cut, cleaned and painted before weighing and exposure.



**Figure 3.1** Experimental Procedure for CP

### 3.2 DESIGNING TEST RIG

The design configuration is represented in Figure 3.2 where four pieces of steel pipe are connected to anode and the others two not connected to any anode. Soil testing was done to determine the pH of the soil and the necessary depth to bury the specimen in order to reduce the effect of soil pH. The weight of steel pipe and anodes was measured for corrosion rate analysis. Then, the specimen was buried in the soil for 28 days.

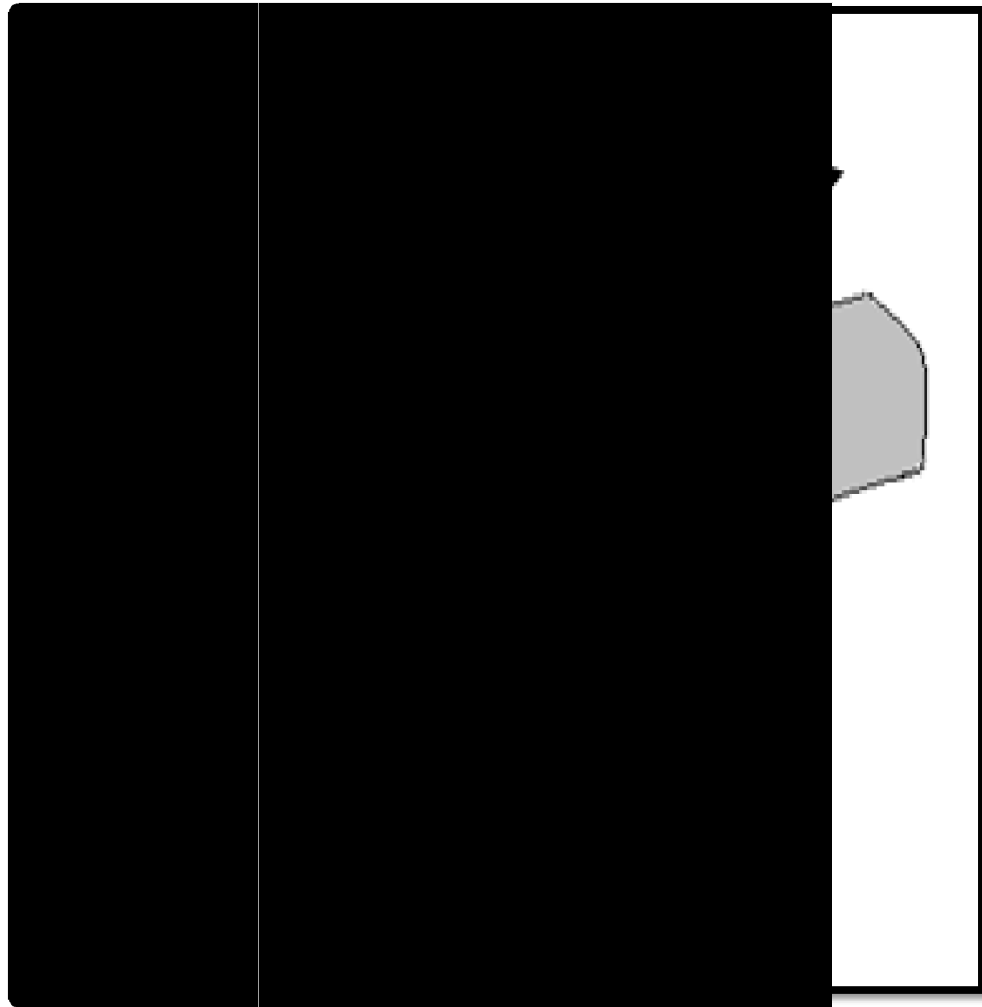


**Figure 3.2** Design Configuration

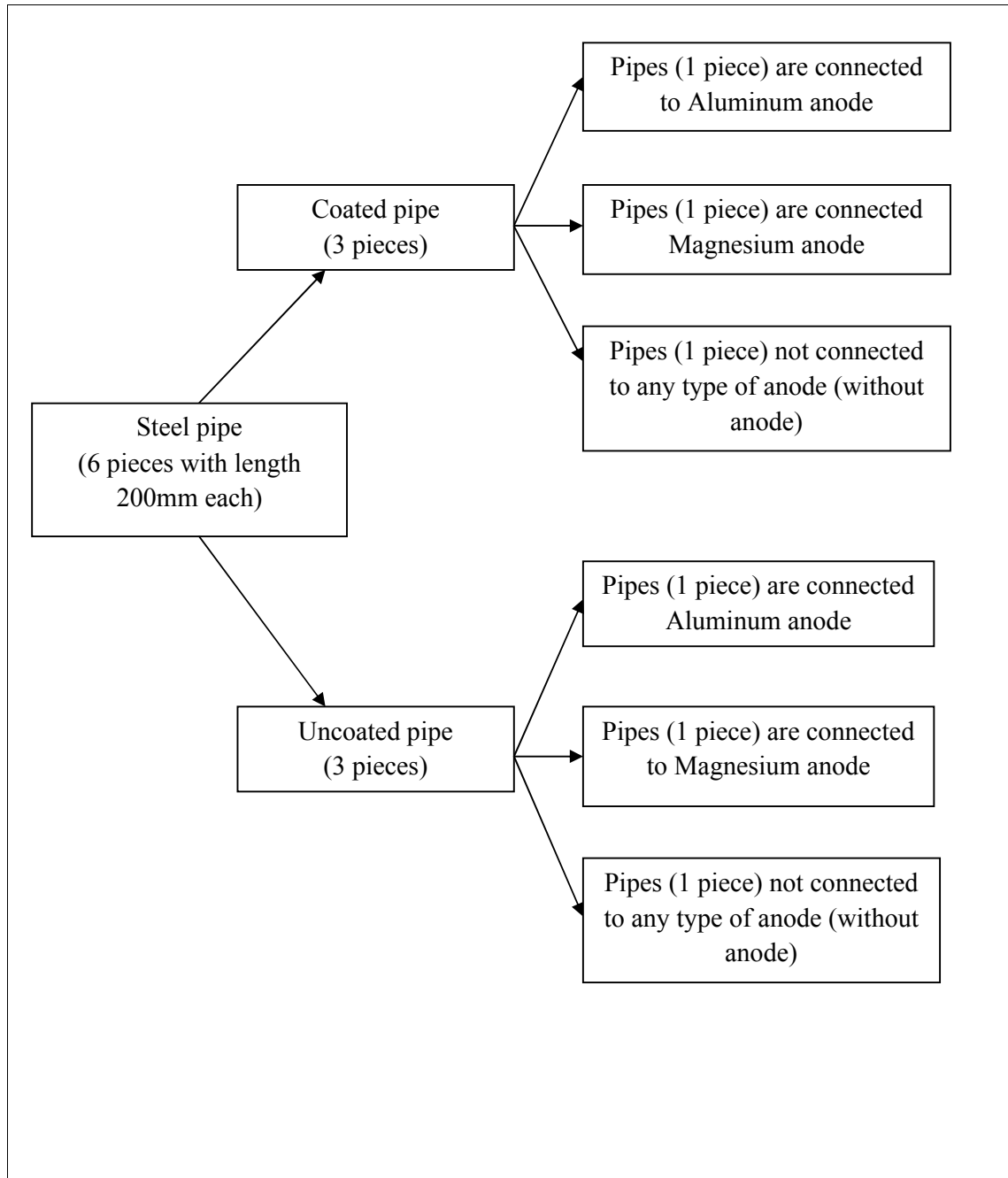
### 3.3 SAMPLES PREPARATIONS

Figure 3.3 shows that specimen used in this study. Steel pipe were cut into six pieces with same length and were divides into two groups which is coated and uncoated. The material used in this project is the steel pipe. There were 6 pieces of steel pipe with the 22 mm inner diameter and 26 mm outer diameter used and was cut in same length (200mm). The surfaces of steel pipe were cleaned from oil, grease and dirt by degreasing with a solvent cleaner or scrubbing or both. Each pieces of steel pipe were weighed to know the initial weight for each specimen. Then weight and dimension of

each specimen were measured. Then three (3) pieces of steel pipe were painted. Type of anode is used was magnesium and zinc with the length of anode was estimated quarter from length of steel pipe. All the steel pipe must be fixed by rubber at it is end before it was buried in soil to prevent soil and water enters the internal side of pipe. The steel pipe is connected to anodes by using the copper wire. Figure 3.4 shows the configuration of specimen testing.



**Figure 3.3** Dimension of Steel pipe



**Figure 3.4** Configuration of Specimen Testing

### 3.4 WEIGHING BEFORE AND AFTER TESTING

Prior to burying in soil, the clean and dry specimens were weighed using micro weighing scale as shown in Figure 3.5 to take the initial weight of the specimens. After the specimen was exposed in soil, the specimen was weighed again to take the final weight of the specimens by using same digital micro weighing scale. The weight different between before and after exposure are representing the corrosion rate of the specimen.



**Figure 3.5** Micro Weighing Scale

### 3.5 SOIL pH TESTING

Soil pH is an important measurement in analysis of corrosion in soil. The more acidic the soil is, the higher 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. Before the specimens were buried, the pH of soil was determined to reduce the effect of pH to corrosion rate. For this experiment, the soil sample was collected at the field of UMP Gambang at the different depth. Then, pH of the soil was determined. Figure 3.6 and Figure 3.7 shows that the pH meter and soil testing method



After the soil sample was prepared, they were analyzed by using a pH meter in. This pH of soil test is referred to American National Standard, ASTM G 51 -95. This test method covers a procedure for determining pH of soil in corrosion testing.



**Figure 3.6** pH meter



**Figure 3.7** Soil Testing Method using pH Meter

### 3.6 INSTALLATION AND EXPOSURE

All steel pipe specimens were buried in a soil at the UMP Gambang field. The experiment was including the coated and uncoated steel pipes that are connected to magnesium and aluminum anodes. The steel pipes were connected to anode by using copper wire. All the steel pipe must be fixed by rubber before it were buried in soil to prevent soil and water enters the internal side of pipe for each experiment. All the specimen with or without anodes, were buried approximately 0.2 meter in depth.

The exposure period was for 28 days before the specimen were taken out for cleaning, weighing and investigation of surface. After each test, the steel pipes were taken out followed by cleaning process. The weight of steel pipe and the anodes were being measured before and after test in order to calculate the corrosion rate by weight loss method. The installations of specimen shown in Figure 3.8- Figure 3.12.



**Figure 3.8** Cathodically Protected Coated Steel Pipe with Mg



**Figure 3.9** Cathodically Protected Coated Steel Pipe with Zn



**Figure 3.10** Unprotected Coated Steel Pipe



**Figure 3.11** Cathodically Protected Uncoated Steel Pipe with Mg



**Figure 3.12** Cathodically Protected Uncoated Steel Pipe with Zn

### **3.7 CLEANING PROCEDURE OF THE SPECIMEN**

The surface of the tested specimens was cleaned from all corrosion products. This cleaning procedure was according to American National Standard, ASTM G 1 -03. This practice covers suggested procedures for preparing bare, solid metal specimens for test, for removing corrosion products after the test has been completed, and for evaluating the corrosion damage that occurred. The cleaning procedure will depend on the base material as well as the nature of the corrosion product. The cleaning procedure can be divided into two processes which are methods for preparing specimen for test and methods for cleaning after testing.

By referring to ASTM Designation G 1 -03, Corrosion product removal procedures can be divided into three general categories which are chemical, mechanical and electrolytic. Chemical procedures involve the immersion test specimen in the specific solution that is designed to remove the corrosion products with minimal dissolution of any base metal. Mechanical procedures are the methods that often utilized to remove heavily encrusted corrosion products which include scraping, scrubbing, brushing, ultrasonic cleaning, mechanical shocking, and impact blasting. In this study, only the chemical procedures will be used to clean the specimens in order to minimal the losses of base metal. The degreasing agents that will use in this process are thinner and kerosene.

For the chemical cleaning procedures for removal corrosion products are referred to ASTM Designation G 1 -03, table A1.1. The specimen were clean using 1000 mL hydrochloric acid (HCL ,sp gr 1.19) solution with temperature 20 to 25 °C. Solution should be vigorously stirred or specimen should be brushed for 1 to 25 minutes.

### **3.8 SURFACE MORPHOLOGY EXAMINATIONS**

Surface visualization was carried out after the time exposure. Observations on the surface structure of the samples for determine the type of corrosion was observed by using Scanning Electron Microscope (SEM) EVO 50 in the UMP Mechanical laboratory. Figure 3.13 shows the type of SEM has used. In this study the Scanning Electron Microscope (SEM) is a microscope that uses electrons rather than light to form an image. The SEM has a large depth of field, which allows a large amount of the sample to be in focus at one time. The SEM also produces images of high resolution, which means that closely spaced features can be examined at a high magnification. Preparation of the samples is relatively easy since SEM only require the sample to be conductive. The combination of higher magnification, larger depth of focus, greater resolution, and ease of sample observation makes the SEM one of the most heavily used instruments in research areas today.

#### **3.8.1 Procedure for Using Scanning Electron Microscope**

The procedures required for SEM are:

- (i) Sample preparation
- (ii) Magnification range expected to be the most effective
- (iii) Depth of focus needed
- (iv) Choose working distance, aperture size, lens current, beam voltage.



**Figure 3.13** Scanning Electron Microscope

### 3.9 CORROSION RATE ANALYSIS

The corrosion rate measurements have been expressed by using weight loss method. The expression mills penetration per year is the most desirable way of expressing corrosion rates. This expression is readily calculated from the weight loss of the metal specimen during the corrosion test by the formula given as below:

$$\text{Corrosion rate} = \frac{\times}{\times \times}$$

Where,

k = a constant ( $3.45 \times 10^6$ ) for corrosion rate unit in mils per year (mpy)

A = area ( $\text{cm}^2$ )

W = mass loss in grams

D = density ( $\text{g}/\text{cm}^3$ )

T = Time of exposure in hours

The corrosion rate may also be expressed such as micro per year ( $\mu\text{m}/\text{y}$ ), inches per year (ipy), milligrams/square decimeter/day (mdd) and others.

## CHAPTER 4

### RESULT AND DISCUSSIONS

#### 4.1 INTRODUCTION

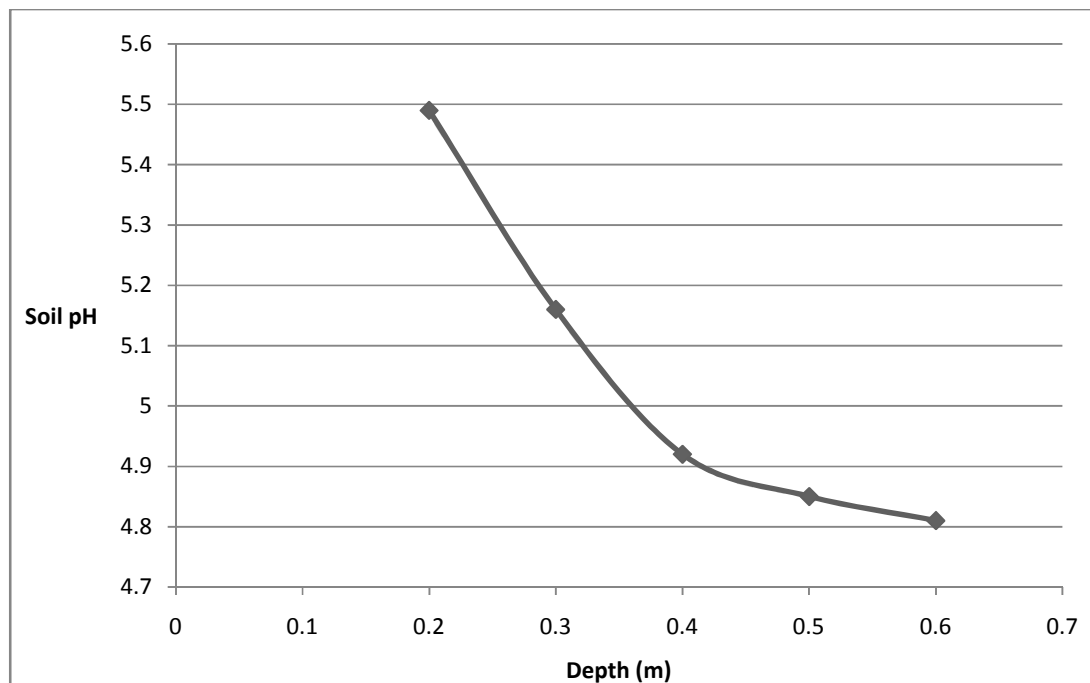
The parameters for the Cathodic Protection design include the pipe parameters, geotechnical information, anodes parameters, and coating parameters related to design. These parameters are very essential to be identified before the design process begins. Besides that, the microstructure of specimens also were examined by using Scanning Electron Microscope (SEM) to identify the type of corrosion occurs affected by underground corrosion. All the specimens are weighing before and after to determine the weight loss of specimens and for measurement of corrosion rate

#### 4.2 SOIL pH TEST

Testing for soil pH had been held for range between 0.2 m to 0.6 m in depth. The results of pH test are shown in Table 4.1. The testing is conduct at the three times and average pH is calculated for each type of sample. From Table 4.1, clearly shown that the pH of the soil is between 5.49 to 4.81 and classified as a medium acidic. The highest value of soil pH is at the depth 0.2 m and the lowest value of pH at the depth 0.6 m. Figure 4.1 shows effect of depth of soil on soil pH. The soil pH decrease when the depths of the soil are increase. The pH at 0.2 m is 5.49 while it is reduced to 4.81 at 0.6 m of depth. It shows that the depth of soil at 0.6 m is more acidic compare to others.

**Table 4.1** pH of soil samples

| Sample | Depth , m | pH   |      |      | Average pH  |
|--------|-----------|------|------|------|-------------|
|        |           | 1    | 2    | 3    |             |
| A      | 0.2       | 5.49 | 5.46 | 5.53 | <b>5.49</b> |
| B      | 0.3       | 5.14 | 5.26 | 5.07 | <b>5.16</b> |
| C      | 0.4       | 4.93 | 4.89 | 4.96 | <b>4.92</b> |
| D      | 0.5       | 4.99 | 4.79 | 4.77 | <b>4.85</b> |
| E      | 0.6       | 4.78 | 4.87 | 4.79 | <b>4.81</b> |

**Figure 4.1** Effect of Depth of Soil on Soil pH

The decreasing pH with soil depth is affected by the activities of microorganism in the soil. To reduce the effect of soil pH, the specimen will bury at 0.2 m. This is because; pH of soil is the main factor that affects underground corrosion. The more acidic the soil is, will affect the corrosion rate will be higher due to deposition of ion hydrogen (Bashi, S.M., Mailah, N.F., Radzi M.A. 2003).



### 4.3 VISUAL INSPECTION AFTER EXPOSURE OF SPECIMENS

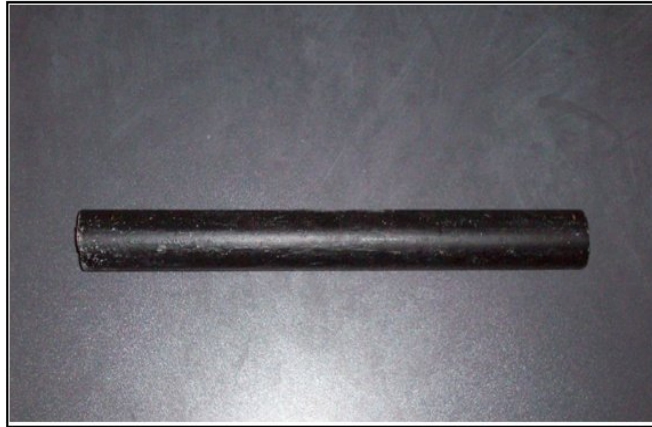
From visual inspection of the specimen were done after the time exposure in a soil. The brown colour was observed which is present for corrosion product or rust. The cathodically protected steel pipe with coating show that the surface is corrode only at the scratched surface which is shown in Figure 4.2-Figure 4.4. The concentration of peeling was at the center of the along the steel pipe.



**Figure 4.2** Cathodically Protected Coated Steel pipes with Magnesium Anode



**Figure 4.3** Cathodically Protected Coated Steel pipe with Zinc Anode



**Figure 4.4** Coated Steel Pipe

For the cathodically protected steel pipe without coating, its surface was severely corroded as shown in Figure 4.5- Figure 4.7. The corroded surface of coated steel pipe has smaller area compared to uncoated steel pipes. Figure 4.2 and Figure 4.5 also shows that the surface of magnesium anode after the exposure in a soil. For the magnesium anode, the brown colour was observed on a surface which is present for corrosion product. The surface of zinc anode was observed a white dissipation which is present for corrosion product as shown in Figure 4.3 and Figure 4.6. By visual inspection, it is also shown that the magnesium anode corroded more compared to zinc anode



**Figure 4.5** Cathodically Protected Uncoated Steel Pipe with Magnesium Anode



**Figure 4.6** cathodically Protected Uncoated Steel pipes with Magnesium Anode



**Figure 4.7** Unprotected Steel Pipes

The corrosion happen on the surface of steel pipes and sacrificial anodes was not uniform. This may be affected by the mixture of soil types along the steel pipe. Besides that, the galvanic corrosion also takes place as results of the different in potential existing between the steel pipes anodes and soil. Galvanic corrosion form when bimetallic couple, and magnesium and zinc become anode because it's less noble

material and steel pipe which is more noble material will act as the cathode in the corrosion cell.

Uniform corrosion occurs when there are local anodic and cathodic sites on the surface of the specimen. Due to polarization effects, these locations shift from time to time and a given area on a metal will be acts as both anode and as a cathode over any extended period of time. The averaging effect of these shifting local action cells results in a rather uniform attack and general loss of material and roughening of the surface.

The peeling of paint occurs due to the rough surface of the steel pipe and coating efficiency differented along the steel pipes. Besides that, mixture of soil along the steel pipe also will affect the pilling of the paint concentrate at the centre of pipe (Jones, D.A., Uhling, H.H. Revie, R W. 1985).

#### **4.4 ELECTRON MICROSCOPY EXAMINATIONS**

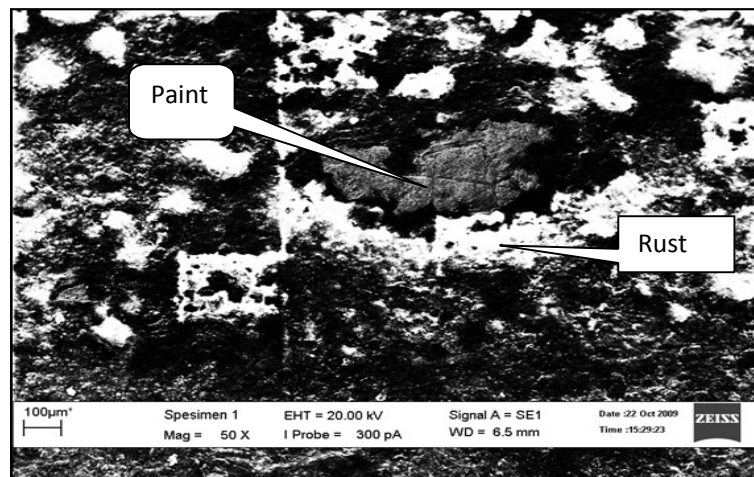
The microstructure of the steel pipe was examined by using SEM with magnification of 50X and for anode examinations, 250X magnifications was used.

##### **4.4.1 Steel pipe Examinations by S.E.M**

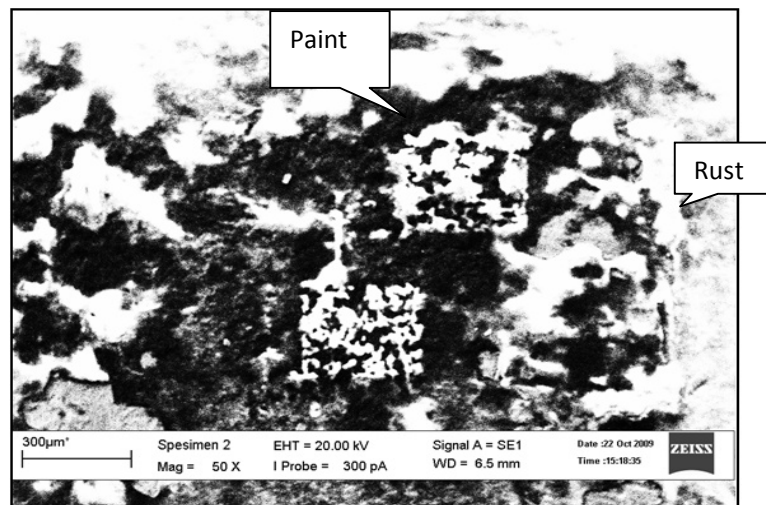
The surface morphology of steel pipe after corrosion was shown in Figure 4.8 – Figure 4.10. Figure 4.8 shows the surface morphology of coated steel pipe that is connected to the magnesium anode. It is shown that the surface of steel pipe appear an oxide film. The dark regions represent coating on a surface of steel pipe. Figure 4.9 shows that the surface morphology of coated steel pipe with using zinc anode. It is also observed oxide film and surface of coated steel pipe.

Figure 4.10 shows that surface morphology of coated steel pipe. The examination shows the surface oxides film and scratched on surface of steel pipe. The scratches were from the original zinc surface which formed during the cleaning process where the initial corrosion product was removed by using abrasive paper. The peeling of

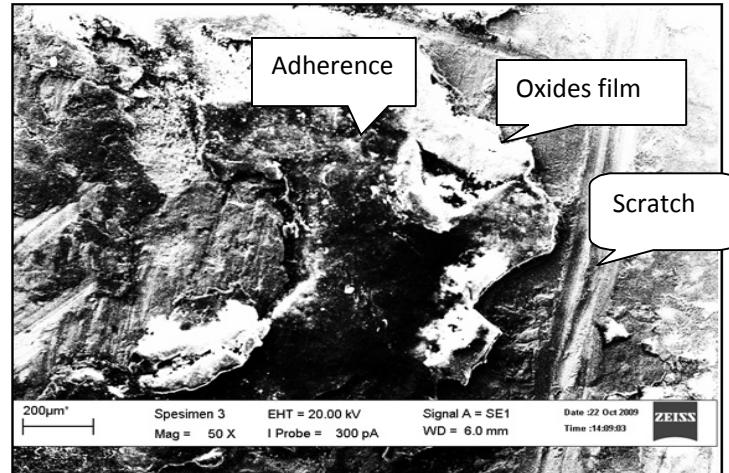
paint formed because the concentration and efficiency of coating. The peeling of paint concentrate at the centre of coated steel pipe due to the position of the anode which is placed at the centre of steel pipe when it buried in soil. This oxide film is called a product of corrosion. The area of oxide film or corrosion product on an uncathodically protected steel pipe with coating is larger compare to the cathodically protected steel pipe with coating.



**Figure 4.8** Surface Morphology of Coated Steel Pipe with Magnesium Anode  
Magnification 50 X

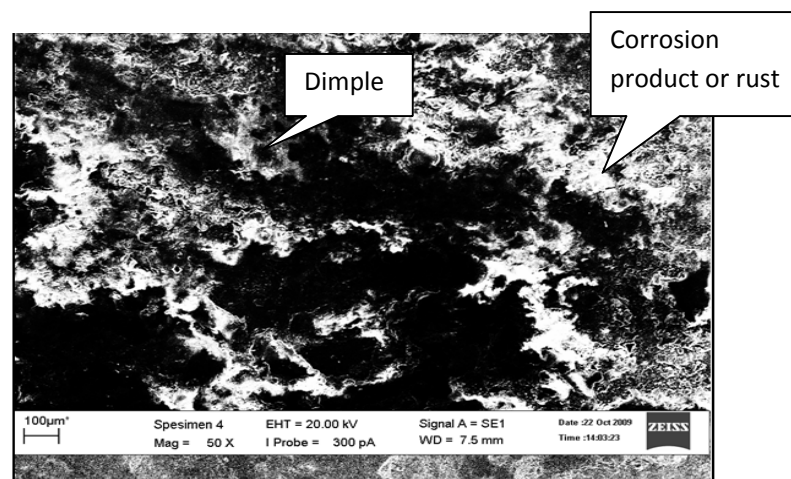


**Figure 4.9** Surface Morphology of Coated Steel Pipe with Zinc Anode  
Magnification 50X

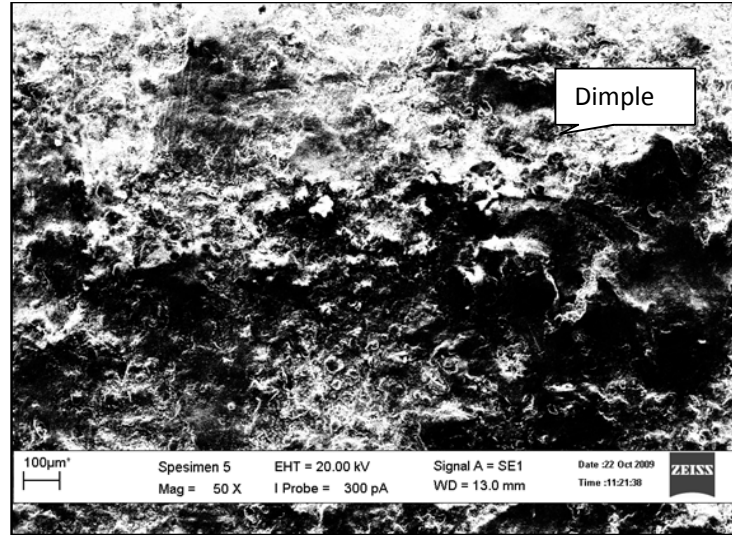


**Figure 4.10** Surface Morphology of Coated Steel pipe  
Magnification 50X

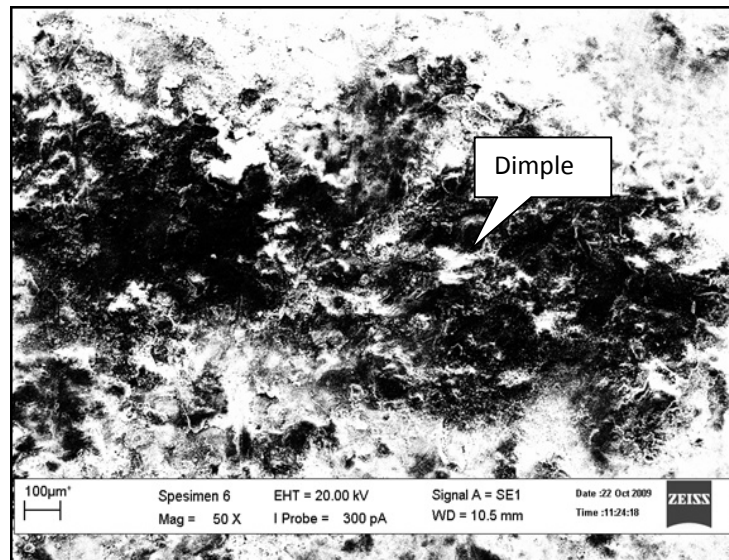
Figure 4.11-Figure 4.13 shows the surface morphology of uncoated steel pipe that connected to the magnesium anode and zinc anode. An oxide film region was also observed on the surface of coated steel pipe. The dark region present for coating of surface steel pipe. Besides that, the dimple also forms on a steel pipe without coating. The region of oxide film is larger in uncoated steel pipe compare to coated steel pipe.



**Figure 4.11** Surface Morphology of Uncoated Steel pipes with Magnesium  
Anode  
Magnification 50X



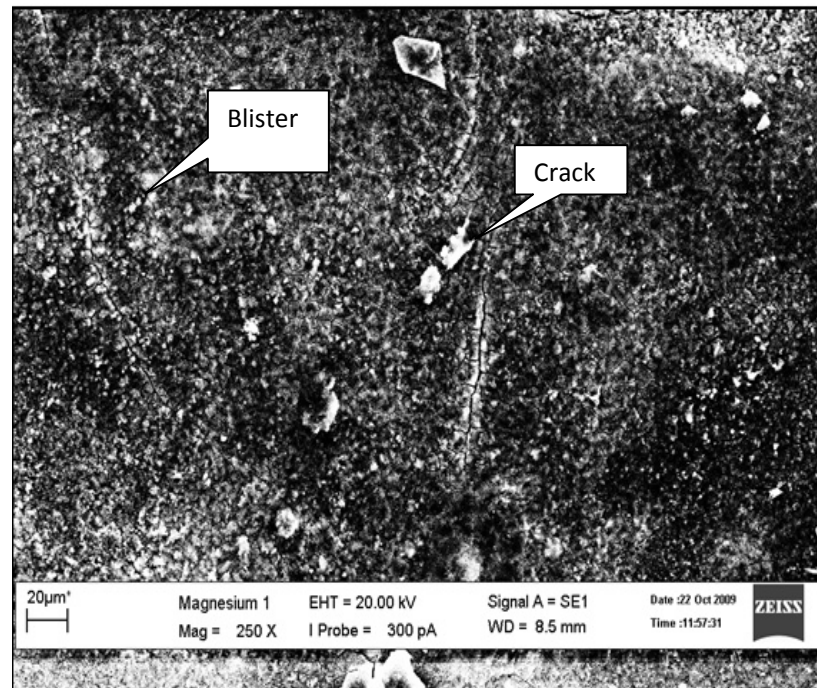
**Figure 4.12** Surface Morphology of Uncoated Steel pipe With Zinc Anode  
Magnification 50X



**Figure 4.13** Surface Morphology of Unprotected Steel pipe  
Magnification 50X

#### 4.4.2 Anodes examination By S.E.M

Figure 4.14 shows the surface morphology of the magnesium anode and zinc anode. It appears a white region which is called oxide film for magnesium and zinc anodes. The crack corrosion also was observed on surface of magnesium. Besides that it's also occurs a blister on magnesium surface.



**Figure 4.14** Surface Morphology of Magnesium Anode

Magnification 250 X

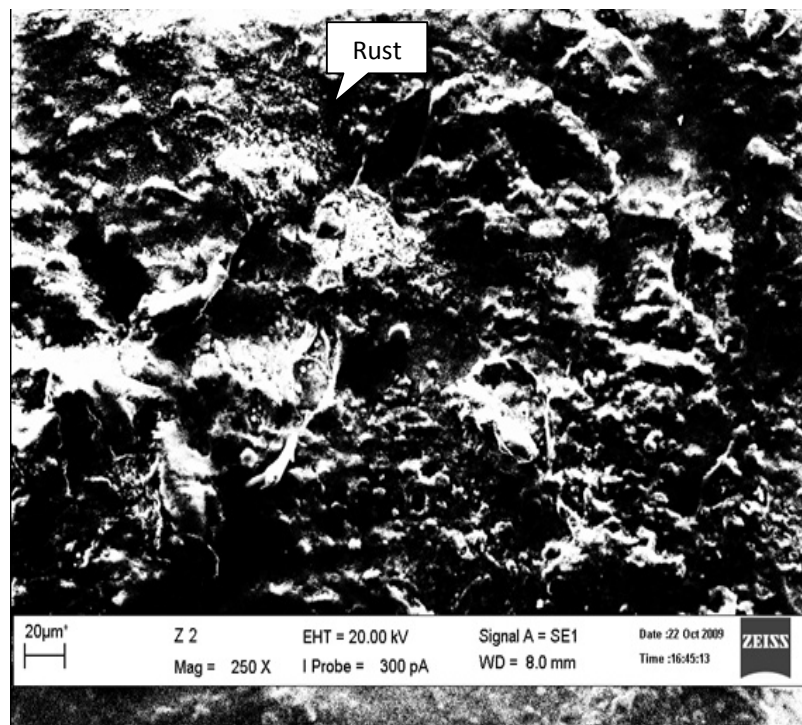
Figure 4.15 shows that the surface morphology of the magnesium anode and zinc anode. For the surface morphology of zinc anodes the oxides film is form on a surface.

The blister formation is slow corrosion process where the oxygen in air attacks the magnesium base material underneath the protective plated surface, dissipating through tiny little cracks in the surface. The uniform corrosion also occurs at the



magnesium surface. Since the effect of uniform corrosion unclearly seen, weight loss is the most commonly used method of measuring corrosion rate of uniform corrosion.

Uniform corrosion occurs when there are local anodic and cathodic sites on the surface of the specimen. Due to polarization effects, these locations shift from time to time and a given area on a metal will be acts as both anode and as a cathode over any extended period of time. The averaging effect of these shifting local action cells results in a rather uniform attack and general loss of material and roughening of the surface. (Money, K.L 1987).



**Figure 4.15** Surface Morphology of Zinc Anode  
Magnification 250 X

#### 4.5 Corrosion Rate Determination

The weight loss method was used to determine the corrosion rate of the steel pipe and the sacrificial anodes have been discussed in section 3.9. The corrosion rates were determined in unit of mpy (mils per year). By using equation of weight loss method, the corrosion rate was obtained and the results were represented in Table 4.1 and Table 4.2.

**Table 4.2** Corrosion Rate Results of Galvanic Steel pipe

| <b>Specimen</b> | <b>Coating</b> | <b>Surface Area (cm<sup>2</sup>)</b> | <b>Weight Before, (g)</b> | <b>Weight After, (g)</b> | <b>Weight Loss, (g)</b> | <b>Time exposure (hours)</b> | <b>Corrosion rate, (mpy)</b> |
|-----------------|----------------|--------------------------------------|---------------------------|--------------------------|-------------------------|------------------------------|------------------------------|
| with Mg Anode   | Coated         | 328.23                               | 461.78                    | 461.29                   | 0.49                    | 672                          | 0.80                         |
| With Zn Anode   | Coated         | 328.23                               | 461.34                    | 459.92                   | 1.42                    | 672                          | 2.32                         |
| Without anode   | Coated         | 328.23                               | 458.97                    | 457.31                   | 1.66                    | 672                          | 2.71                         |
| With Mg Anode   | Uncoated       | 328.23                               | 458.63                    | 452.60                   | 6.03                    | 672                          | 9.86                         |
| With Zn Anode   | Uncoated       | 328.23                               | 458.46                    | 452.04                   | 6.42                    | 672                          | 10.49                        |
| Without anode   | Uncoated       | 328.23                               | 460.48                    | 450.89                   | 9.59                    | 672                          | 15.68                        |

**Table 4.3** Corrosion Rate of Sacrificial Anode

| <b>Specimen</b>     | <b>Type of Anode</b> | <b>Surface Area, (cm<sup>2</sup>)</b> | <b>Weight Before, (g)</b> | <b>Weight After, (g)</b> | <b>Weight Loss, (g)</b> | <b>Time exposure, (hours)</b> | <b>Corrosion rate, (mpy)</b> |
|---------------------|----------------------|---------------------------------------|---------------------------|--------------------------|-------------------------|-------------------------------|------------------------------|
| Coated Steel pipe   | Magnesium            | 38.34                                 | 22.91                     | 22.64                    | 0.27                    | 672                           | 16.19                        |
|                     | Zinc                 | 15.02                                 | 56.79                     | 56.72                    | 0.07                    | 672                           | 4.84                         |
| Uncoated steel pipe | Magnesium            | 38.34                                 | 24.08                     | 22.57                    | 1.51                    | 672                           | 90.58                        |
|                     | Zinc                 | 15.02                                 | 56.85                     | 56.54                    | 0.31                    | 672                           | 21.42                        |

Note: Density of steel pipe = 9.565 g/cm<sup>3</sup>

Density of Magnesium Anode = 2.23 g/cm<sup>3</sup>

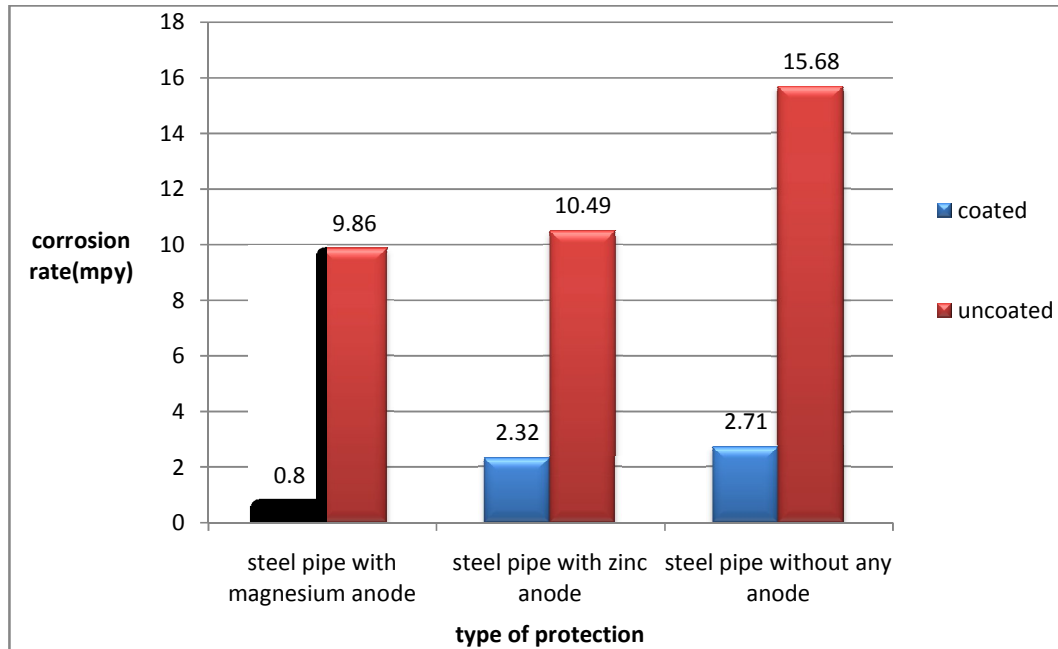
Density of zinc Anode = 4.947 g/cm<sup>3</sup>

The measurement of corrosion rate was divided into two, corrosion rate analysis for steel pipe and corrosion rate analysis for sacrificial anode. From Table 4.1, it is shown that, the corrosion rate for coated steel pipe by using magnesium anode was lowest which 0.80 mpy is. When the coated steel pipe cathodically protected with sacrificial zinc anode, the corrosion rate was 2.32 mpy which is slightly higher compare to the corrosion rate of coated steel pipe cathodically protected with sacrificial magnesium anode. However the corrosion rate is lower compare to the coated steel pipe

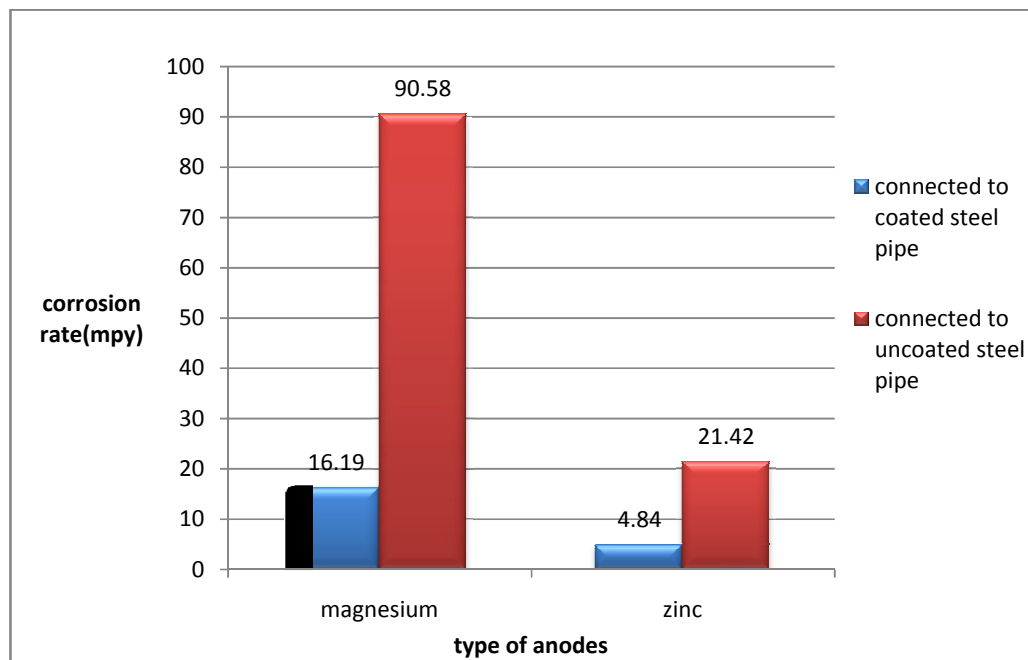
without using any sacrificial anode. The corrosion rate for coated steel pipe without using any anode is 2.71 mpy.

When the uncoated steel pipe cathodically protected with magnesium sacrificial anode, the corrosion rate is lowest compare to the uncoated steel pipe with using sacrificial zinc anode and uncoated steel pipe without using any sacrificial anode. The results corrosion rate for uncoated steel pipe with using sacrificial magnesium anode and zinc anode is 9.86 mpy and 10.49 mpy respectively. The corrosion rate of the unprotected steel pipe was the highest at 15.68 mpy. The corrosion rate for coated steel pipe is around 0.80 mpy to 2.71 mpy which is lowest compare to corrosion rate for uncoated steel pipe is around 9.86 mpy to 15.68 mpy.

Referring to the Table 4.2, the result of corrosion rate for both the sacrificial magnesium anode which is connected to the coated and uncoated steel pipe was highest about 16.19 mpy to 96.58 mpy. The corrosion rate for both of sacrificial zinc anode that connected to the coated and uncoated is lower compare to corrosion rate for sacrificial magnesium anode, about 4.84 mpy and 21.42 mpy. The corrosion rate for sacrificial anode that connected to coat steel pipe was lower compare to the anode that connected to uncoated steel pipe. The result of corrosion rate for magnesium anode was 16.19 mpy when connected to coat steel pipe and 90.58 mpy when it's connected to uncoated steel pipe. The result for both zinc anode connected to coat steel pipe is 4.84 mpy and 21.42 mpy for zinc anode that connected to uncoated steel pipe.



**Figure 4.16** Effect of Protection on Corrosion Rate



**Figure 4.17** Corrosion Rate of Sacrificial Anode

Figure 4.16 shows that effect of protection on corrosion rate. The corrosion rate for cathodically protected of uncoated steel pipe is higher comparing to cathodically protected coat steel pipe. Besides that, the corrosion rate for coated steel pipe without using any anode is highest compare to coated steel pipe that connected to sacrificial anodes. For the uncoated steel pipe, the corrosion rate also is lower for the cathodically protection using magnesium anode compare to the protection using zinc anodes. Coated steel pipe has lower corrosion rate compare to uncoated steel pipe. The corrosion rate for steel pipe without any anode has highest corrosion rate compare to uncathodically protection steel pipe. It's clearly shows, that the sacrificial magnesium anode gives better performance to reduce corrosion rate of steel pipe as its potential is higher compare to the zinc anode.

Galvanic corrosion takes place as the result in potential existing between the materials and the electrolyte present. The electrochemical reaction occurs on the steel pipe when the corrosion take places are as follow (Bayliss, D.A and Deacon, D.H. 1982):

Anodic reactions:



Cathodic reaction



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



The ferrous and hydroxyl ions react together to form ferrous hydroxide called rust in Eq (4.4):



When the active metal are present or connected to the steel pipe the oxidation reaction took place as follow Eq.(4.5):

For magnesium anodes:



Thus the final overall reaction with magnesium anode present is Eq.(4.6)



For zinc anodes:



Thus the final overall reaction with aluminum anode present is Eq 4.8)



Each half-cell reaction has an electrical potential, known as the half-cell electrode potential. The anodic reaction potential,  $E_a$ , plus the cathodic reaction potential,  $E_c$ , adds up to  $E$ , the cell potential. If the overall cell potential is positive, the reaction will proceed spontaneously.

The Figure 4.17 shows that corrosion rate for sacrificial anodes. Corrosion rate of magnesium anodes is higher compare to zinc anode. The corrosion rate will increase when uncoated steel pipe is connected to sacrificial anode compare to sacrificial anode that connected to coat steel pipe. The result also shows that, the corrosion rate of anodes

that connected to the coated steel pipe is lower compare to the anode connected to uncoated steel pipe.

From the results, it shows that the magnesium is very strong anodic metal when it's connected to the pipeline compare to zinc .This because magnesium is more electronegative compare to zinc or its potential energy is lower. Magnesium and zinc shows that, it's more electronegative compare to steel pipe.

As magnesium and zinc anode is more electronegative than steel pipe, magnesium and zinc will corrode and in so will discharge current and protect the pipeline. Corrosion is an electrochemical reaction composed of two half cell reactions, an anodic reaction and a cathodic reaction. The anodic reaction releases electrons, while the cathodic reaction consumes electrons.

Corrosion cells are created on metal surfaces in contact with an electrolyte because of energy differences between the metal and the electrolyte. Different area on the metal surface could also have different potentials with respect to the electrolyte. Without cathodic protection, one area of the steel pipe structure exists at a more negative potential than another and will produce corrosion results. However, when a much less inert object such as magnesium anode is placed adjacent to the structure of steel pipe to be protected; and a metallic connection (insulated copper 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, magnesium and zinc corrodes sacrificially to protect the structure (Darowicki, K. Bohdanowicz, W. Walaszkowski, J. 2001)

Thus, since zinc and magnesium are more electronegative than steel they are increasingly able to supply electrons to the more electropositive steel when in electrical contact in soil, and will effect cathodic protection of the steel surface. Some anode material is lost by self-corrosion, and the anodes are not converted to electrical energy with 100% efficiency.

The effectiveness of Cathodic Protection is depends on the performance on sacrificial anode that will be used. When the strong anodic metal for example



magnesium is used to protect the steel pipe, the effectiveness of cathodic protection is higher compare to the zinc anode or the other metal such as aluminum that located at above in galvanic series. This because magnesium is more electronegative compare to the zinc anode and aluminum. The standard emf series is very useful to rank general resistance of metals to corrosion.

The coated steel pipe has lower corrosion rate compare to uncoated steel pipe. This is because the cathodic protection is effective at the weak points of the coating. The coating will acts as resistance in metallic path between the anode and cathode. Cathodic protection provides an ideal supplement for coating systems. The coating is a high resistance path for applied cathodic currents, which consequently concentrate at the coating imperfections. The corrosion rate can be reducing by suppressing either the cathodic or anodic reaction or by inserting a high resistance in the path of corrosion current flowing in the electrolyte cell (Roberge, P.R 1999).

The conjoint use of coatings and cathodic protection takes advantage of the most attractive features of each method of corrosion control. Thus, the bulk of the protection is provided by the coating and cathodic protection provides protection to flaws in the coating. As the coating degrades with time, the activity of the cathodic protection system develops to protect the deficiencies in the coating. A combination of coating and cathodic protection will normally result in the most economic protection system (Jones, D.A. Uhling, H.H. Revie, R W. 1985).

#### **4.6 CONCLUSION**

Table 4.4 summarizes the overall results of the study including surface morphology, visual inspection and corrosion rates for steel pipe after Cathodic Protection had been applied and exposed in soil for 28 days.

**Table 4.4** Summary of the Overall Results

|          | Specimen        | Corrosion rate             | Surface morphology                   | Visual inspection   |
|----------|-----------------|----------------------------|--------------------------------------|---------------------|
| Coated   | With Mg Anode   | Corrosion rate = 0.80 mpy  | -Oxide film occur<br>- Dimple        | -uniform corrosion  |
|          | With Zinc Anode | Corrosion rate = 2.32 mpy  | -Adherence<br>-Scratch               | -galvanic corrosion |
|          | Without Anode   | Corrosion rate = 2.71 mpy  |                                      |                     |
| Uncoated | With Mg Anode   | Corrosion rate = 9.86 mpy  | - Dimple occur<br>- peeling of paint | -galvanic corrosion |
|          | With Zinc Anode | Corrosion rate = 10.49 mpy |                                      | -uniform corrosion  |
|          | Without Anode   | Corrosion rate = 15.68 mpy |                                      |                     |

## CHAPTER 5

### CONCLUSION AND RECOMMENDATION

#### 5.0 INTRODUCTION

This chapter will conclude the research and briefly discussed about the recommendation that can applied for the future work. The conclusion were done according to the result obtain in Chapter 4. In order to study the performance of sacrificial anode as a method on underground steel pipeline, other aspects of future work also will be discussed.

#### 5.1 CONCLUSION

There are several parameters that affecting the design known as sensitivity parameters. These parameters are soil pH, type of anodes, driving potential, design life, and coating. But, major effecting parameters are; soil pH, coating efficiencies and type of anodes because the current output of anodes and the interaction between anodes and structure will be depending on these parameters.

Several conclusions could be drawn from the study are:

- (i) Coated steel pipe has lower corrosion rate compare to uncoated steel pipe.
- (ii) Cathodic protection with magnesium anode give a better protection compare to the zinc anode
- (iii) Combination of cathodic protection and coating give highest protection to the steel pipe compare with coating only
- (iv) Combination of cathodic protection and coating give highest protection to the steel pipe compare to cathodic protection only.

## 5.2 RECOMMENDATIONS

For the future work in order to study the performance of sacrificial anode as a method of cathodic protection on underground steel pipeline, the following aspect could be taken into consideration:

- (i) Comparing the results with other type of anodes such as aluminum anode.
- (ii) Use different method of cathodic protection which is impressed current to compare with sacrificial anode method.
- (iii) Longer exposure period of specimen in order to get clearer forms of corrosion that occurs.
- (iv) Determine the soil salinity and soil resistivity of soil before buried the specimen.
- (v) Comparing the results among different type of coating to the steel pipe and effect to the Cathodic protection system
- (vi) Use the different types of composition of anodes and comparing the composition of anodes before and after exposure in soil.

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**APPENDIX A****Figure 6.1** Soil Samples**Figure 6.2** Specimens Before Buried



**Figure 6.3** Paint used as coating



**Figure 6.4** Copper wire tot connected Specimen



## APPENDIX B

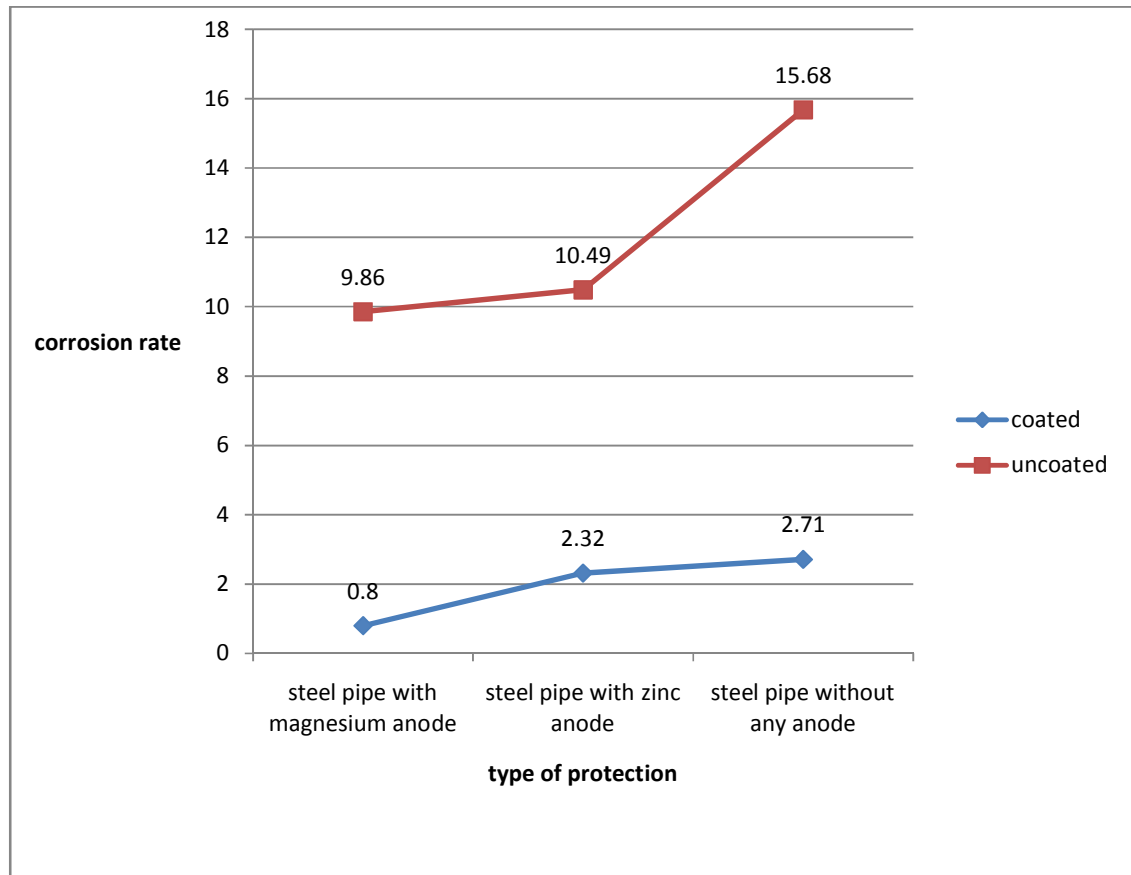
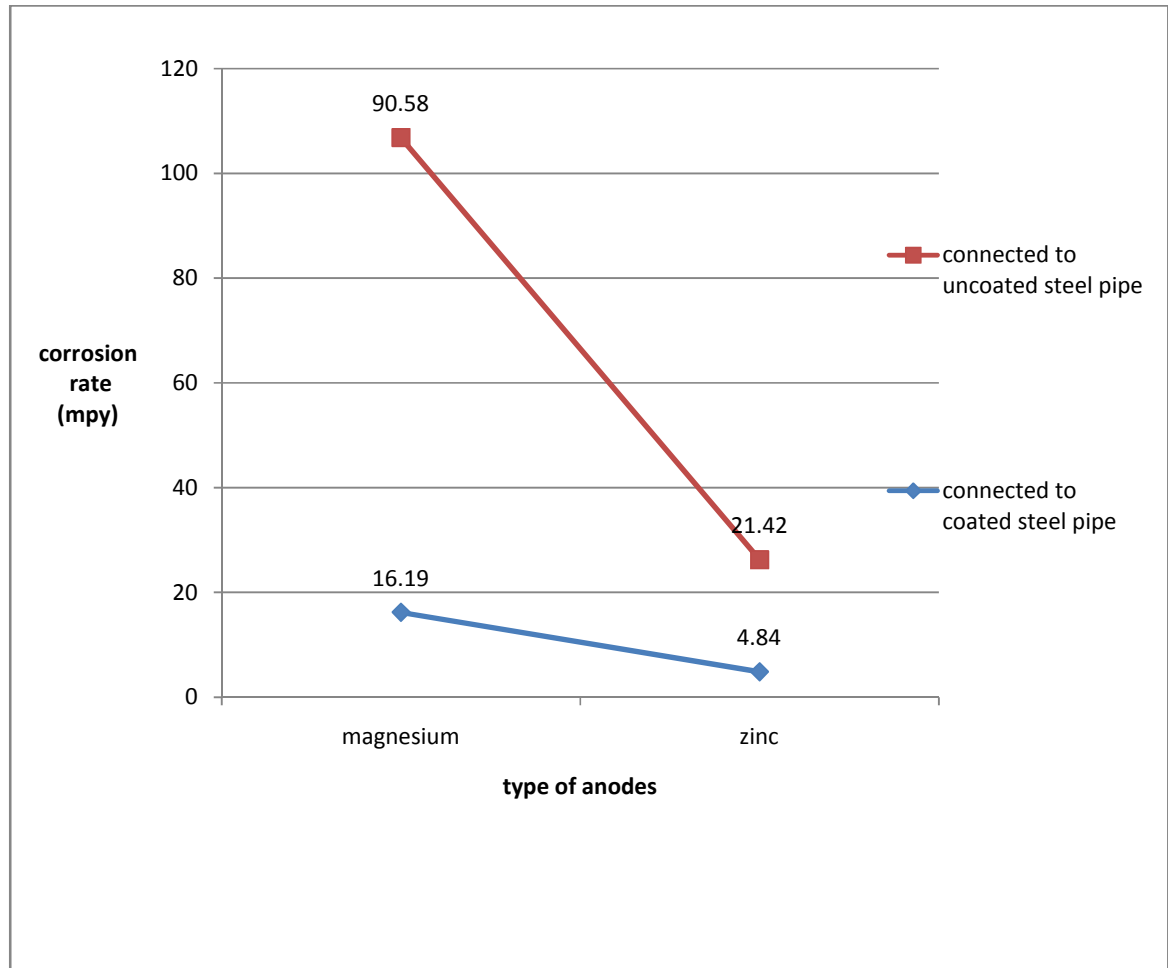


Figure 6.5 Graph Corrosion Rate Vs Type of Protection



**Figure 6.6** Graph Corrosion Rate Vs Type of Anodes

## APPENDIX C

### Design of Anode or Anode calculation

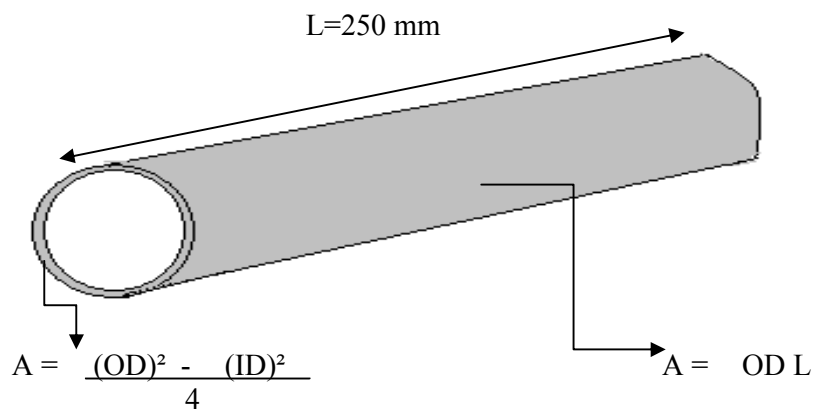
#### Anode calculation

Calculations for a buried 27 mm (0.027 m) diameter steel pipeline

The pipeline length = 250 mm (0.25 m)

Outer diameter (OD) = 27 mm (0.027m)

Inner diameter (ID) = 22 mm (0.022m)



The area to be protected is the outside area of the pipe

$$A_s = \left\{ \frac{(0.027 \text{ m})^2 - (0.022 \text{ m})^2}{4} \right\} 2 + (0.027 \text{ m})(0.25 \text{ m}) = 0.0216 \text{ m}^2$$

- 1) Current density requirement,  $J = 40 \text{ mA/m}^2$ .
- 2) Calculate current demand or current required,  $I(\text{A})$

$$I = J \times A$$

Where,  $J$  = current density

$A$  = Area to be protected ( $\text{m}^2$ )

$$\begin{aligned}
 I &= (40 \text{ mA/m}^2)(0.0216 \text{ m}^2) \\
 &= 0.8636 \text{ mA or } 0.8636 \times 10^{-3} \text{ A}
 \end{aligned}$$

A) For Magnesium anodes

Theoretical current capacity = 2200 Ah /kg

Efficiency = 50%

$$\begin{aligned} \text{The useful output of magnesium} &= (2200 \text{ Ah/kg}) \times (50\%) \\ &= 1100 \text{ Ah/kg} \end{aligned}$$

$$\begin{aligned} \text{The consumption rate} &= \text{Current capacity of anode} / \text{current demand} \\ &= \frac{1100 \text{ Ah/kg}}{0.8636 \times 10^{-3} \text{ A}} \\ &= 1273.7 \times 10^3 \text{ h / kg} \end{aligned}$$

Since, there is 8760 h/yr .So the weight of magnesium per year is:

$$\begin{aligned} &= \frac{8760 \text{ h/yr}}{1273.7 \times 10^3 \text{ h / kg}} \\ &= 6.8776 \times 10^{-3} \text{ kg / yr} \end{aligned}$$

The anodes would need to be distributed equally to distribute the current along the pipeline as evenly as possible. For a system life of 0.0767 years (28 days) the magnesium required is

$$\begin{aligned} \text{Weight of anode} &= (6.8776 \times 10^{-3} \text{ kg / yr}) (0.0767 \text{ yr}) = 0.5275 \times 10^{-3} \text{ kg} \\ &= 0.5275 \text{ g} \end{aligned}$$

B) For zinc anode  
For zinc anodes

Theoretical current capacity = 810 Ah /kg

Efficiency = 90%

$$\begin{aligned} \text{The useful output of zinc} &= (810 \text{ Ah/kg}) \times (90\%) \\ &= 729 \text{ Ah/kg} \end{aligned}$$

$$\begin{aligned} \text{The consumption rate} &= \text{Current capacity of anode} / \text{current demand} \\ &= \frac{729 \text{ Ah/kg}}{0.8636 \times 10^{-3} \text{ A}} \\ &= 844.14 \times 10^3 \text{ h / kg} \end{aligned}$$

Since, there are 8760 h/yr .So the weight of magnesium per year is:

$$= \frac{8760 \text{ h/yr}}{844.14 \times 10^3 \text{ h / kg}} = 10.3774 \times 10^{-3} \text{ kg / yr}$$

The anodes would need to be distributed equally to distribute the current along the pipeline as evenly as possible. For a system life of 0.0767 years (28 days) the magnesium required is

$$\text{Weight of anode} = (10.3774 \times 10^{-3} \text{ kg / yr}) (0.0767 \text{ yr}) = 7.959 \times 10^{-4} \text{ kg}$$

$$\text{Or } 0.7959 \text{ g}$$

## APPENDIX D

GANTT CHART / PROJECT SCHEDULE FOR FYP 1

| PROJECT ACTIVITIES   | W 1 | W 2 | W 3 | W 4 | W 5 | W 6 | W 7 | W 8 | W 9 | W 10 | W 11 | W 12 | W 13 | W 14 |
|--|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|
| 1) Got the project title and arrange discussion time with supervisor | █   |     |     |     |     |     |     |     |     |      |      |      |      |      |
| 2) Meeting with supervisor   |     | █   | █   | █   | █   | █   | █   | █   | █   | █    | █    | █    | █    | █    |
| 3) The rough idea about the project                                  |     | █   | █   | █   |     |     |     |     |     |      |      |      |      |      |
| 4) Learning the theory   |     | █   | █   | █   | █   | █   | █   | █   | █   | █    | █    | █    |      |      |
| 5) Do research and collect the information                           |     |     | █   | █   | █   | █   | █   | █   | █   | █    | █    | █    | █    | █    |
| 6) Prepare for chapter 1 (Introduction)                              |     |     |     |     | █   | █   | █   | █   |     |      |      |      |      |      |
| 7) Prepare for chapter 2 (Literature)                                |     |     |     |     |     | █   | █   | █   | █   |      |      |      |      |      |
| 8) Prepare for chapter 3 (Methodology)                               |     |     |     |     |     |     | █   | █   | █   | █    | █    | █    |      |      |
| 9) Prepare for presentation  |     |     |     |     |     |     |     |     |     |      |      |      | █    | █    |
| 11) Project presentation   |     |     |     |     |     |     |     |     |     |      |      |      |      | █    |

Figure 6.7 Gantt Chart FYP 1

## GANTT CHART / PROJECT SCHEDULE FOR FYP 1

| PROJECT ACTIVITIES          | W 1 | W 2 | W 3 | W 4 | W 5 | W 6 | W 7 | W 8 | W 9 | W 10 | W 11 | W 12 | W 13 | W 14 | W 15 | W 16 |
|-----------------------------|-----|-----|-----|-----|-----|-----|-----|-----|-----|------|------|------|------|------|------|------|
| 1) Experiment setup         | █   | █   |     |     |     |     |     |     |     |      |      |      |      |      |      |      |
| 2) Exposure the specimen    |     |     |     |     |     |     | █   | █   | █   | █    | █    | █    | █    |      |      |      |
| 3) Cleaning specimen        |     |     |     |     | █   | █   |     |     |     |      |      |      |      |      |      |      |
| 4) Corrosion rate analysis  |     |     |     |     | █   | █   | █   |     |     |      |      |      |      |      |      |      |
| 5) Macroscopic examination  |     |     |     |     |     |     |     |     |     |      |      |      | █    | █    | █    |      |
| 6) Result analysis          |     |     |     |     |     |     |     |     |     |      |      |      | █    | █    | █    |      |
| 7) Report writing           |     |     | █   | █   | █   | █   | █   | █   | █   | █    | █    | █    | █    | █    | █    | █    |
| 8) Prepare for presentation |     |     |     |     |     |     |     |     |     |      |      |      | █    | █    | █    | █    |
| 9) Project presentation     |     |     |     |     |     |     |     |     |     |      |      |      |      |      |      | █    |

Figure 6.7 Gantt Chart FYP 2

## **APPENDIX A**



## **APPENDIX B**

## **APPENDIX C**

## **APPENDIX D**