

**DESIGN A NOVEL INHIBITOR FOR CORROSION
PROTECTION IN OIL AND GAS ENVIRONMENTS**

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I hereby declare that the work in this project is my own except for quotations and summaries which have been duly acknowledge. This project has not been accepted for any degree and it is not concurrently submitted for award of other degree.

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**I specially dedicate this to my parents and those who have guided and motivated
me
for this project.**

ABSTRACT

This is a study on the designing and performance of corrosion inhibitor in oil and gas environments. The objective of this project is to determine the right composition of a corrosion inhibitor that can be used as corrosion protection in oil and gas environments. A suitable parameter to imitate the oil and gas environment used as guideline in this project which is a solution of 30% NaCl, room temperature, carbon steel as the experiment specimen. The data analyzed by using LPR (Linear Polarization Resistance) to determine the corrosion rate. the composition selected for the corrosion inhibitor is palm oil and amine. The minimum corrosion rate obtained from the experiment is 1.345 mmPY which is the combination of 2.0 ml palm oil and 3.0 ml of amine. Finally, by considering the result of each experiment that had been conducted, the composition of palm oil and amine can be used as a corrosion inhibitor.

ABSTRAK

Ini adalah satu kajian terhadap penciptaan dan prestasi inhibitor untuk menghalang proses pengaratan di dalam persekitaran industri minyak dan gas. Objektif projek ini adalah untuk menentukan komposisi yg paling sesuai yang boleh dijadikan inhibitor untuk mencegah dan melindungi daripada terjadinya proses pengaratan di dalam persekitaran industri minyak dan gas. Parameter yang sesuai berdasarkan persekitaran di dalam industry minyak dan gas dijadikan petunjuk utama dalam menjalankan eksperiment untuk kajian ini iaitu dengan menggunakan 30% kandungan NaCl, suhu bilik dan besi karbon sebagai spesimen untuk eksperimen. Data yang diproses dan dikaji adalah menggunakan LPR (Linear Polarization Resistance) untuk menentukan kadar pengaratan yang terjadi. Komposisi yang dipilih untuk dijadikan inhibitor bagi menghalang proses pengaratan ialah minyak kelapa sawit dan amine. Nilai kadar pengaratan yang paling minimum diperolehi daripada eksperimen yang dijalankan adalah 1.345 mmPY iaitu gabungan daripada komposisi 2.0 ml minyak kelapa sawit dan juga 3.0 ml amine. akhirnya, setelah mengambil kira dan mempertimbangkan keputusan bagi setiap eksperimen yang dijalankan, komposisi minyak kelapa sawit dan juga amine boleh digunakan sebagai inhibitor untuk mengelak daripada terjadinya proses pengaratan.

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LIST OF SYMBOLS

R_p	Polarization Resistance
CR	Corrosion Rate
LPR	Linear Polarization Resistance
I_{corr}	Corrosion Current
K	A constant that defines the units for the corrosion rate
EW	Equivalent Weight
ρ	Density
A	Sample area
β_a	Anodic Beta Coefficient
β_c	Cathodic Beta Coefficient

LIST OF ABBREVIATIONS

NaCl	Sodium Chloride
CO ₂	Carbon Dioxide
Fe	Ferum
H	Hydrogen
H ₂ O	Hydrogen Oxide

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

This chapter explains about the background of study, problem statement, objectives and the scopes of this study. The main purpose for this study can be identified by referring at the problem statement of this study. Furthermore, the details of this study and outcome can be achieved on the objectives and its scopes.

1.2 BACKGROUND OF STUDY

Corrosion is a crucial and important problem faced in many sectors of industry. In oil and gas production, severe corrosion problems can arise when CO₂ is produced along with production fluids. One method to control significant metal losses occurring due to corrosion in the oil and gas industry is to use corrosion inhibitors.

Inhibitors are chemicals composition that will react with a metallic surface, and the environment this surface is exposed to, will give the surface a certain level of protection. Inhibitors usually work by adsorbing themselves on the metallic surface, and then will protect the metallic surface by forming such a film on it. Normally, inhibitors are distributed from dispersion or a solution. Some of it is included in a protective coating formulation. Inhibitors can help to slow down the corrosion processes by either:

- Increasing the anodic or cathodic polarization behaviour which can be seen from a Tafel slopes;
- Reducing the diffusion or the movement of ions to the metallic surface;
- Increasing the electrical resistance on the metallic surface.

1.3 PROBLEM STATEMENT

Corrosion can be easily interpreted as a deterioration of a metal or its own properties that will attacked every component in the life of every oil and gas field in every stage of it. Every stage of the oil and gas field means from the casing strings to production platforms, from drilling through to abandonment and so on. Basically, corrosion is totally an adversary worthy of all the high technology and research we can throw at it.

Because it is almost impossible to prevent corrosion, it is becoming more apparent that controlling the corrosion rate may be the most economical solution. Therefore, designing a novel inhibitor for corrosion protection in oil and gas environments is highly beneficial for the future of oil and gas industry.

1.4 OBJECTIVES

The main objective of this study is to design a novel inhibitor that can be used as a corrosion protection in oil and gas environments.

1.5 SCOPE

This project is based on experimental used test bench that available in the laboratory of University Malaysia Pahang as the main equipment. The Linear Polarization Resistance (LPR) technique will be used to measure the polarization resistance R_p and thus the corrosion rate could be determined. LPR measurements were conducted by plotting a curve of anodic and cathodic currents. Then to measure

corrosion rate, it can use polarization resistance (R_p). Carbon steel will be used as the material in this project.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter will discuss about the previous related study and researches on fin. The source of the review is extracted from journals, articles, reference books and internet. The purpose of this section is to provide additional information and relevant facts based on past researches which related to this project. This chapter will cover the corresponding terms such as the fundamental of corrosion, its effect in oil and the efficiency of using inhibitor as corrosion protection in oil and gas industry.

2.2 CORROSION

As had been stated, corrosion can be seen as the deterioration of materials which is done by chemical interaction with the environment. The term corrosion itself sometimes can also be applied to the degradation of other materials such as plastics, concrete and wood, but generally we refer it to metals. The most widely used metal in the industry is iron which is usually referred as steel and the following discussion is mainly related to the corrosion process that happened on it.

As we all know, corrosion involves in the deterioration of a material when it reacts with the environment of the steel. Corrosion is the primary means which we can say that the metals deteriorate. Literally, corrosion consumes the material to reduce its load carrying capability and will cause stress concentrations to it. Moreover, corrosion is also often a major part of maintenance cost and the corrosion prevention is very vital in many designs that include steel as the material. Corrosion

is not expressed in the terms of a design property value which is like any other properties. But it is rather in the more qualitative terms such as the material can be in an immune, resistant, susceptible or very susceptible condition to the corrosion process.

Corrosion process also involves in two chemical processes which is oxidation and also reduction. Basically, oxidation is the process of stripping electrons from an atom and the reduction process will occurs when an electron is added to an atom. These oxidation processes will take place at an area which is known as the anode. At the anode, the positively charged atoms will leave the solid surface and then will enter into an electrolyte as ions. The ions will then leave their corresponding negative charge in the form of electrons in the metal through a conductive path to travel to the location of the cathode.

Finally, at the cathode, the corresponding reduction reaction will then takes its place and consumes the free electrons. The electrical balance of the circuit can be restored at the cathode when the electrons react with neutralizing positive ions, such as the hydrogen ions in the electrolyte.

From this description, it can be clearly seen that there are basically four essential components that are needed for a corrosion reaction to proceed. These components are an anode, a cathode, an electrolyte with oxidizing species, and also some direct electrical connection which is between the anode and cathode.

The most common and also an important electrochemical reactions in the corrosion of iron are:

Anodic reaction (corrosion)



Cathodic reactions (simplified)



or



The equation in reaction 2a is the most common reaction in acids and in the pH range 6.5 – 8.5. The most important reaction with oxygen can also be seen in the reduction equation in 2b. In this corrosion latter case, it is usually accompanied by the formation of solid corrosion debris from the reaction between the anodic and also cathodic products.

Although the atmospheric air is the most common environmental electrolyte, natural waters, such as seawater, as well as man-made solutions, the environments can also frequently associated with the corrosion problems.

2.2.1 Corrosion in Oil and Gas Industry

Corrosion problems have always presented such a severe challenge to the oil and gas producing operations. For that matter, operators need to plan for long periods of continuous production with the maintenance scheduled for the prescribed shutdown periods. Unfortunately, corrosion does not always respect these schedules that they made, which resulting in the severe economic penalties due to loss of product.

In addition to that, the risk of pollution and hazards to safety are other important reasons for adequate corrosion engineering. Governmental legislation concerning oil and gas extraction also had becoming more stringent in order to minimize these risks that we had been stated. Furthermore, corrosion hazards have also intensified with the extraction in deeper waters and in more hostile environments. The innovations aimed at reducing the offshore field development costs which involve the reductions in platform weight, increase the use of satellite wells and subsea manifolds require specific attention to corrosion prevention.

2.3 CORROSION INHIBITOR

It is well known that corrosion is a natural process and it is almost impossible to prevent it completely. Thus we can only try to control the corrosion process. Even though coatings and cathodic protection are often said as the most

effective, chemical inhibitors are also widely used to reduce corrosion particularly in gas wells producing CO₂, H₂S and also water. But, the effectiveness of the inhibitor and compatibility with produced fluids must be first tested in the laboratory. The inhibitor film efficiency depends on the inhibitor concentration and its contact time with the metal surface.

One of the major ways in protecting the internal production pipelines in the field of operations against corrosion process is by applying corrosion inhibitors to it. The corrosion inhibitors are evaluated in order to make sure if the corrosion preventive measures applied are necessary and also to know if the required life-time can be achieved with the corrosion inhibitor as effective life of corrosion inhibitors varies with the quantity of water intrusion.

By definition, a corrosion inhibitor is a chemical compound or substance that, when we added it in such a small concentration to an environment, it will effectively decrease the corrosion rate. The efficiency of an inhibitor can be simply expressed by the measure of this improvement below:

$$\text{Inhibitor efficiency (\%)} = 100 \frac{(\text{CR uninhibited} - \text{CR inhibited})}{\text{CR uninhibited}}$$

Where;

CR uninhibited = Corrosion rate of uninhibited

CR inhibited = Corrosion rate of inhibited

Generally, the efficiency of an inhibitor will increase together with an increase in inhibitors concentration. For example a typically good inhibitor would give 95% inhibition at a concentration of 0.008% and 90% at a concentration of 0.004%). More than that, the reliability of assessment of the effectiveness of gas flow lines protection by inhibition depends on the method employed on it. Assessment based on results received by several methods shows that it is possible to find a set of inhibitors that rate the most effective for each specific field and to develop the most optimal technology for their application. As a matter of fact, the effectiveness or the corrosion inhibitor efficiency, of a corrosion inhibitor is a

function of many factors such as the fluid composition, flow regime condition, environment temperature, partial pressure of CO₂ and H₂S.

Gopal and Jepson (1995), defined that inhibitor react as a substance, that when it is added in a small concentrations, it will decrease the effect of corrosion rate. Corrosion inhibitors can fall into four general categories based on its mechanism and composition, these categories are;

- i. Barrier Inhibitors
- ii. Neutralizing Inhibitors
- iii. Scavenging Inhibitors

2.4 COMPOSITION OF INHIBITOR

2.4.1 Palm Oil

They are many active green inhibitor intermediates present in the market that are using palm oil as one of their composition. Palm oil are widely used in the industry as corrosion inhibitor, however their properties and behaviour in such complex environment is far from being well known from scientific point of view.

The layer form on the metal surfaces will displace any water and form a monomolecular hydrophobic layer on the surface. The most effective system for this type of application would be a good solution for a metal. The protective coating is resistant to aqueous and acid corrosion.

Palm oil may be incorporated into lubricants for metal working, where it will function as an emulsifier and corrosion inhibitor. .

2.4.2 Amines

Amines contain nitrogen that are considered to be hard bases and so adsorb best to metal surfaces that are considered to be hard acids. Iron and steel are particularly well suited to being protected with amine-based corrosion inhibitors in acidic media. Generally amines with higher electron densities on their nitrogen atoms bind more strongly to metal surfaces and are more effective corrosion inhibitors. Cyclic amines are often better corrosion inhibitor than acyclic amines as ring strain eases the nitrogen lone pair more exposed for donation. Also the presence of electron-donating groups on substituent aromatic rings helps to increase the electron density at the nitrogen bond angles that often perform best of all at corrosion inhibition.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

Several methods are selected to get the project done smoothly. The project must be done according to the objective and run effectively. The Gantt chart and flow chart are must have item in my methodology. The fuel cell needed to be sketched and the dimension are need to be precise so that right dimension can be selected for the bicycle and the design must be suitable for the bicycle so that it is not that over-estimate.

The study will be focused on designing a novel inhibitor for corrosion protection in oil and gas environments by using carbon steel as the material for experiments. The study also intends to determine the best inhibitor composition that can be used to decrease the corrosion rate of the carbon steel. In order to study the corrosion rate, LPR (Linear Polarization Resistance) are used. A detail of flow chart used to study in this work is shown in Figure 3.1.

3.2 FLOW CHART

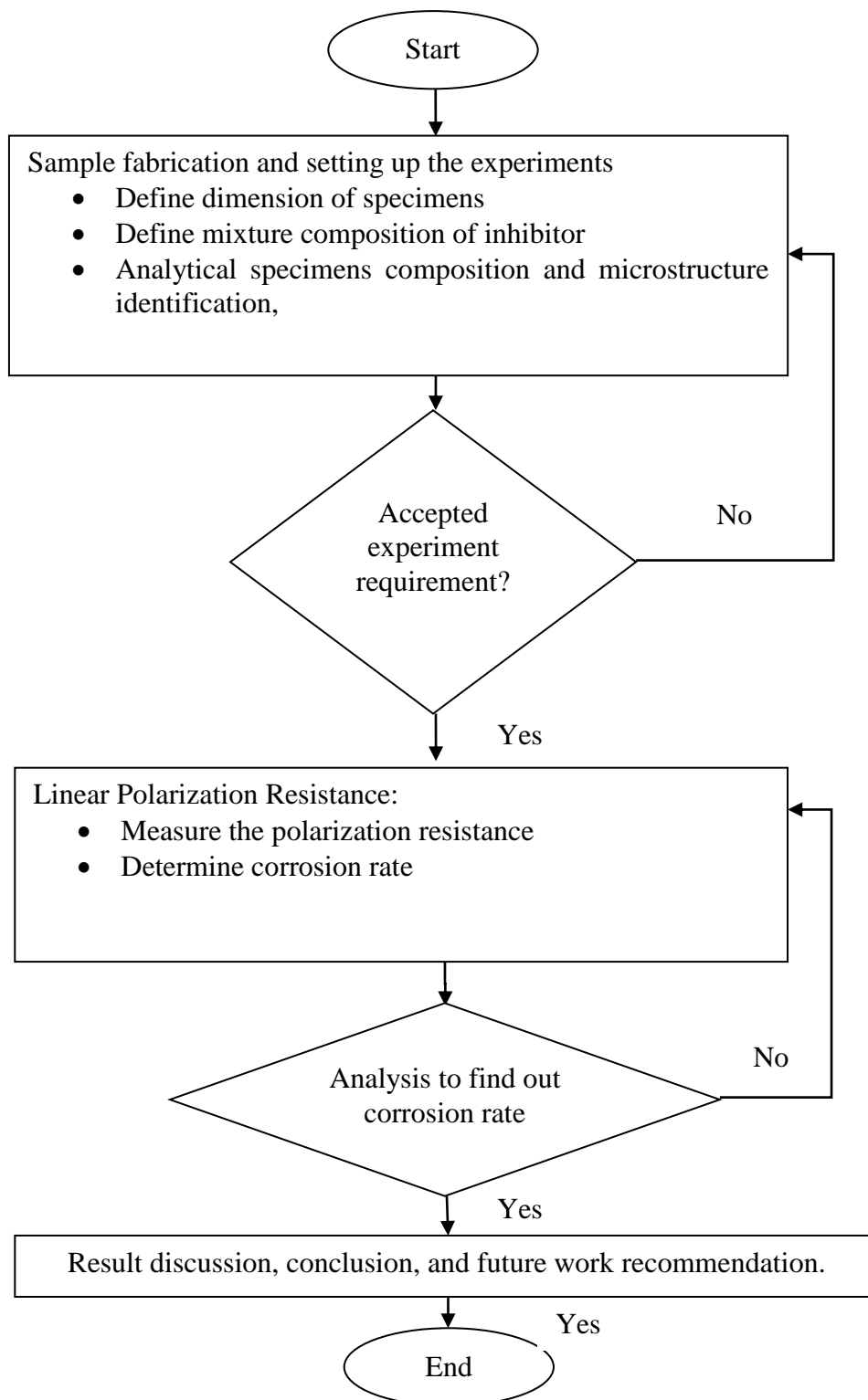


Figure 3.1: Experiment Flow Chart

3.4 EXPERIMENTAL PROCEDURE

3.4.1 Electrode

A three-electrode set-up was used in all electrochemical experiments. Carbon steel cylindrical was employed as the working electrode. Glass cell was fitted with graphite electrodes as an auxiliary electrode and a Ag/AgCl as a reference electrode.

3.4.2 Specimen Preparation

The working electrodes were carbon steels which have chemical compositions as can be seen in Table 1. It was a cylinder rod of 1.2 cm² in diameter and 1 cm thickness. Before immersion, the specimen surfaces were polished successively with 240, 400 and 600, 1200 grit SiC paper, rinsed with alcohol, and degreased using acetone.

Table 3.1: Steel 080A15 (BS 970) properties

Properties	Percentage (%)
C	0.148
Si	0.175
Mn	0.799
P	0.010
S	0.032
Cr	0.069
Mo	0.014
Ni	0.065

3.4.3 Cell Solutions

The schematic of the experimental setup are shown in Figure 1. The experiments were performed in static solutions condition. The total pressure is 1 bar, the temperature was 22°C (room). Initially, glass cell was filled with 1 liter of distilled water and 3% wt NaCl was stirred with magnetic stirrer. Then, CO₂ gas was bubbled through the cell (at least one hour prior to experiments) in order to saturate and de-aerates the solution. After the solution was prepared, the pH was measured to reach the pH setting (3.8).

Monitoring of pH was used to determine whether the solution is in equilibrium. During the experiment, constant concentration of CO₂ gas was continuously bubbled through the electrolyte in order to maintain consistent water chemistry.

3.5 CORROSION RATE MEASUREMENTS

3.5.1 Linear Polarization Resistance

The Linear Polarization Resistance (LPR) technique is used in order to measure the polarization resistance, R_p and thus the corrosion rate can be determined. LPR measurements were conducted by plotting a curve of anodic and cathodic currents. The curve is the total current of the anodic and cathodic reactions. Then to measure corrosion rate, it can use polarization resistance (R_p). Polarization resistance is resistance at the location very near to E_{corr} . On this point the current versus voltage curve approximates a straight line. By simplifying equation, it can be obtained the Stern-Geary equation to calculate corrosion rate. The data from the LPR test, then, is used to measure corrosion rate using following equations:

$$I_{corr} = \frac{b_a b_c}{R_p 2.303(b_a b_c)}$$

$$R_p = \frac{B}{i_{corr}} = \frac{(\Delta E)}{(\Delta i)_{\Delta E \rightarrow 0}}$$

$$B = \frac{b_a \cdot b_c}{2.3(b_a + b_c)}$$

$$\text{Corrosion rate} = I_{\text{corr}} \cdot 3272 \text{ EW} / \rho A$$

Where:

CR : Corrosion rate (mm/y)

I_{corr} : Corrosion current (amps)

K : A constant that defines the units for the corrosion rate

EW : The equivalent weight in grams/equivalent

ρ : Metal density (grams/cm³)

A : Sample area (cm²)

β_a - anodic Beta coefficient in volts/decade

β_c - cathodic Beta coefficient in volts/decade

3.5.2 Test Procedure

During the experiment, the corrosion potential and LPR of the cylindrical rod were measured every 15 minutes during 10 hours. The reading of the corrosion rate was determined using potentiostat (ACM 1350 Gill) using scan rate of 20 mV/mnt. The procedure is similar to that described in ASTM G 5-94 - standard reference test method for making the potentiostatic and potentiodynamic polarization measurements and also ASTM G 102 – to practice the calculation of corrosion rates and the related information from electrochemical measurements.

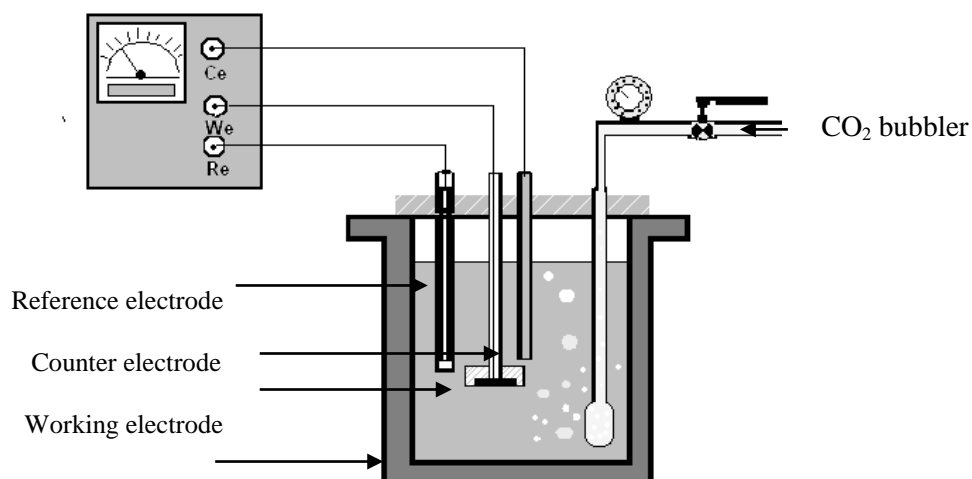


Figure 3.2: Schematic of the experimental test cell and the electrodes configurations

Figure 3.2 above shows the typical experimental arrangement for the static test in LPR experiment. The working electrode will be used in this project is carbon steel.

The analysis using potentiostat has a certain inherent assumptions that need to be considered which is the reaction rate or also known as corrosion current can be expressed as being proportional to the exponential of the voltage offset. Which it is from the corrosion potential for one oxidation (anodic) and one reduction (cathodic) reaction.

Furthermore, uncompensated resistance in the electrolyte and leads can either be absent or is much smaller than the polarization resistance value. The polarization resistance value that is measured by this technique is equal to the sum of all resistances value of which the actual polarization resistance is one of it contributor.

Mass transfer also cannot be the controlling or the rate limiting step and both of the anodic and the cathodic reactions must be under activation control. Otherwise, the Tafel slope that is corresponding to the mass transfer controlled process will show an infinite result and the above equations have to be modified accordingly.

The corrosion potential also does not lie close to the reversible potentials for the reduction and oxidation reactions process. Being a value of 25 mV or so from the reversible potential is often a sufficient value.

In order to estimate the rate of uniform corrosion from the polarization resistance, each one of the reacting site across the entire electrode surface is assumed to function simultaneously as a cathode and also an anode. The anodic and cathodic sub-reactions do not occur on different sites of it.

Moreover, no additional electrochemical reactions will occur to interfere with the current density versus voltage curve. Experimentally, the induced artifacts can sometimes cause a significant error during an experiment. These errors can occur even if the assumptions that had been stated above are fulfilled. Some of these sources of these error are because of an inappropriately large voltage scan rate, large uncompensated or solution resistance, non-linearity in vicinity of corrosion potential when using a limited number of points or assuming a linear regression, errors in Tafel slopes, varying corrosion potential (steady state not achieved) and also might cause by the non-uniform current and potential distributions.

3.6 SPECIMENT PREPARATION

In order to do research on this project, the specimen need to be prepare first. Carbon steel has been used for this project due to the one of the project's scope. After cutting the carbon steel material into the desired size, it was then being coated with epoxy resin to make sure only one of its surfaces will be exposed. It was done this way so that we will only focus the corrosion on the exposed region. The exposed region will then being grinded and polished until it reached the acceptable condition to be experimented.

3.6.1 Polishing and Grinding

Grinding process will removes saw marks, levels and also can clean the specimen surface. Polishing process at the other hand will removes the artifacts of

grinding but very little stock. Usually, grinding process uses a fixed abrasive and these abrasive particles are bonded to the paper or platen for its fast stock removal. Polishing uses free abrasives on a cloth which have the abrasive particles that are suspended in a lubricant and can roll or slide across the cloth and also the specimen.

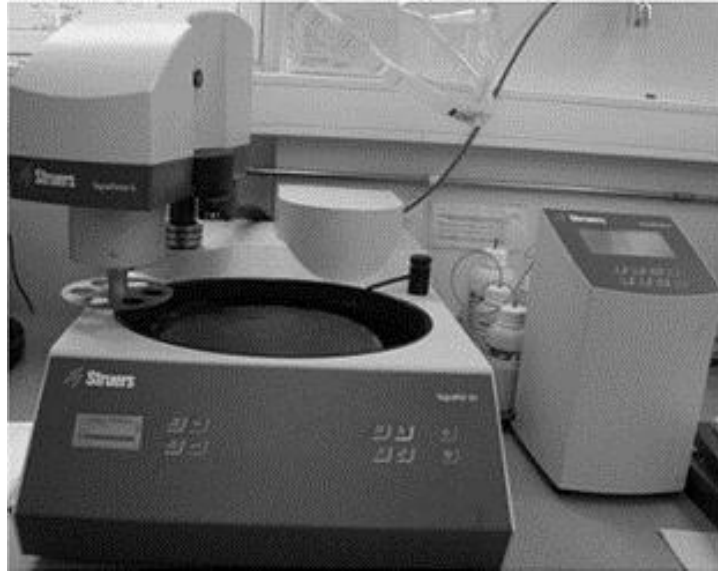


Figure 3.3: Grinding and polishing machine

Figure 3.3 above is an example of grinding and polishing machine that had been use widely for specimen such carbon steel. Grinding is a metal-working machining process that is used to utilize the abrasive wheels as the cutting tool. Technically, grinding can be seen as a sub-process of cutting. Each abrasive grain on the wheel will act as a single-point cutting edge and it will remove a tiny chip from the work piece. Grinding is an effective process to hog out large amounts of material rapidly, but the grinding process still can be used to produce very fine finishes and a very accurate dimension of a specimen.

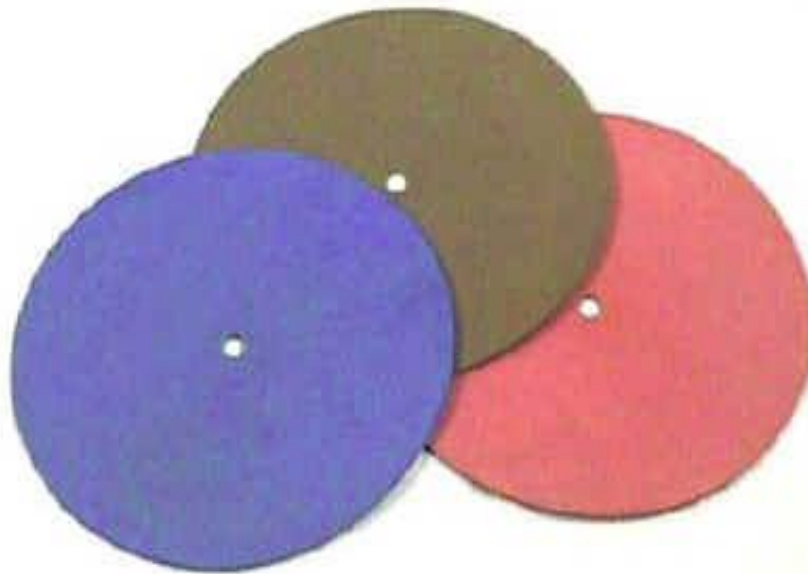


Figure 3.4: Resin bond diamond discs

As in Figure 3.4, the resin bond diamond discs have the diamonds locked into its multi-level resin material. These resin bond diamond discs are designed for smoothing and pre-polishing of the material samples and to remove chips and scratches of a material. It is almost perfect for improved processes such as lapping, grinding, and pre-polish finishing of materials which is above 60 on the Rockwell C scale.

Generally, grinding, polishing and also lapping process is primarily considered to be a three-body abrasive mechanism. It is due to the fact that it uses free abrasive grains that can roll or slide between the work piece surface and the lapping plate even though some grains become embedded in the lap leading to two-body abrasion. A loose abrasive machining process that combines the abrasive particles within oil or aqueous medium will depend on the material being finished. It is a must that the fine abrasive is applied to the material, continuously or at specific intervals, to a work surface so that it will form an abrasive film between the grinding, polishing, & lapping plate and the parts that needs to be polished.



Figure 3.5: Specimen

The unpolished and grind specimen can be seen from figure 3.5 above. From the figure we can see that the surface of the specimen are corrode and it can affect the result of the experiment if the corrode region did not being polish away.

3.7 EXPERIMENT SETUP

The experiment setup of the potentiostat is not as hard as it seems. When the specimen and also the solution of the experiment had been ready, the experiment can be started.

Basically, a potentiostat is an electronic device that its function is to controls the voltage difference between a working electrode and a reference electrode. Both of the electrodes are contained in an electrochemical cell. The potentiostat implements this controlling process by injecting current into the cell through an auxiliary electrode. Basically, in almost all applications, the potentiostat will measure the current flow between the working and the auxiliary electrodes. The controlled variable in potentiostat equipment is the cell potential and its measured variable is the cell current. A potentiostat typically will function with the present of

electrochemical cell that contained three electrodes and that is true for both field probes and lab cells.



Figure 3.6: Potentiostat connected to the computer

As in Figure 3.6, we can see the experiment setup for potentiostat which already being connected to the computer. The corrosion rate will then can be determine from the IV Man software.

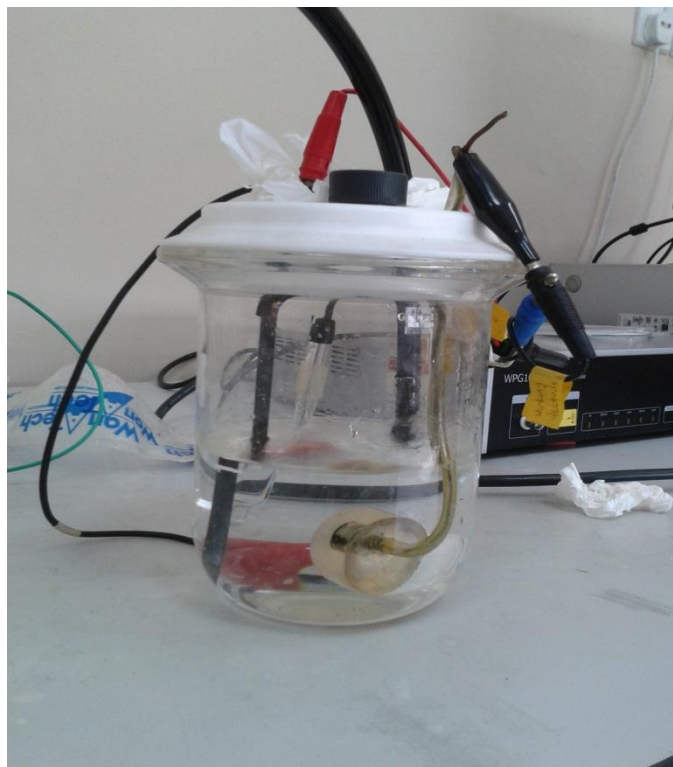


Figure 3.6: Potentiostat

The setup for potentiostat can be seen from figure 3.6 and each one of the equipment used in this experiment setup has their own.

Working electrode work as an electrochemical that the reactions that need to be studied will occur at the working electrode. In corrosion testing, the working electrode will be acted as a sample of the corroding metal. Generally, the working electrode is not the actual metal structure that needs to be studied. A much smaller sample is used to represent the structure of the material that we want to study. This kind of experiment is analogous to testing using weight loss coupons and the working electrode can either be bare metal or coated with resin.

Reference electrode is a reference electrode that is in the potentiostat equipment used in measuring the working electrode potential. A better reference electrode should have a constant electrochemical potential as long as there is no current flows through it.

Moreover, the auxiliary electrode in the other hand acts as a conductor that completes the cell circuit. The auxiliary or the counter electrode in lab cells is generally an inert conductor that looks like a platinum or graphite. In field probes it is generally another piece of the working electrode material.

The electrometer circuit in the potentiostat equipment used to measures the voltage difference between the reference and the working electrodes. Its output basically has two major functions which is the feedback signal in the potentiostat circuit and also the signal that will be measured whenever the cell voltage is needed. An ideal electrometer will have zero input current and infinite input impedance.

The current to voltage (I/E) converter in the simplified schematic used to measure the cell current in the experiment. It will force the cell current to flow through a current measurement resistor. The voltage drop across that resistor is a measure of the cell current.

The control amplifier by the way will act as a servo amplifier. It will compare the measured cell voltage with the desired voltage and then will drive the current into the cell to force the voltages so that the voltage will be the same. Under a normal condition, the cell voltage will be controlled so it will be identical to the signal source voltage.

Moreover, the signal circuit is a computer controlled voltage source. It is generally the output of a digital to analog (D/A) converter that are used to convert computer generated numbers into voltages. More than that, galvanostats and a Zero Resistance Amplifiers (ZRAs) are used in most laboratory grade so that the potentiostat can also be operated as galvanostats or ZRAs.

CHAPTER 4

RESULT AND DISCUSSION

4.1 RESULTS

From the experiment that conducted, the result that obtained is analysed by using LPR technique.

4.1.1 Amine as an Inhibitor

The experiment starts by just using amine on certain amount to determine its efficiency as a corrosion inhibitor. The experiment conditions are as follow:

1. Saturated CO₂
2. 30% NaCl
3. pH 3.8
4. Room temperature

The condition of the experiment is put that way so that it can imitate the condition of the corrosion that happened on the carbon steel pipeline under the sea.

On the first experiment, 1.0 ml of amine had been injected with amine and after an immersion for 30 minutes, the corrosion rate of the carbon steel can be determine right from the IVMan software. It is also can be calculated by using following formula which is:

$$\text{Corrosion rate} = I_{\text{corr}} 3272 \text{ EW}/\square\text{A}$$

Where:

CR : Corrosion rate (mm/y)

I_{corr} : Corrosion current (amps)

K : A constant that defines the units for the corrosion rate

EW : The equivalent weight in grams/equivalent

ρ : Metal density (grams/cm³)

A : Sample area (cm²)

β_a - anodic Beta coefficient in volts/decade

β_c - cathodic Beta coefficient in volts/decade

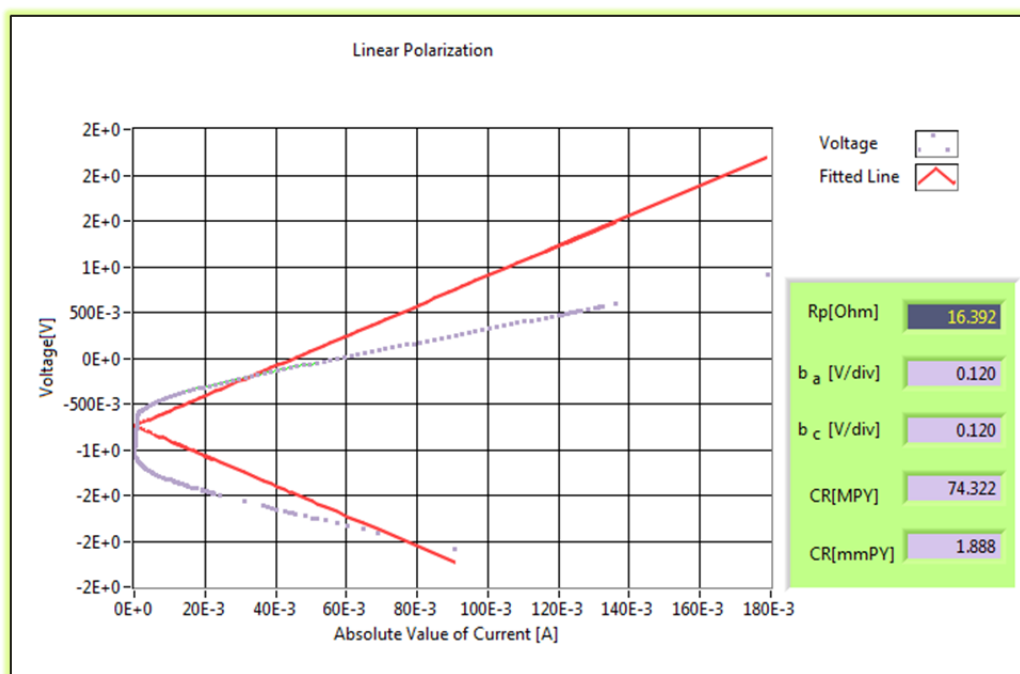


Figure 4.1: Graph absolute value of current vs voltage for 1.0 ml amine

Based on the Figure 4.1 the result shows that the corrosion rate for the carbon steel specimen in the potentiostat experiment when injected with 1.0 ml of amine is 1.888 mmPY or 74.322 MPY.

Basically, mmPY stand for milimeter per year and mPY stands for miles per year which the equation to get this is:

$$1 \text{ mpy} = 0.0254 \text{ mm/y} = 25.4 \text{ microm/y}$$

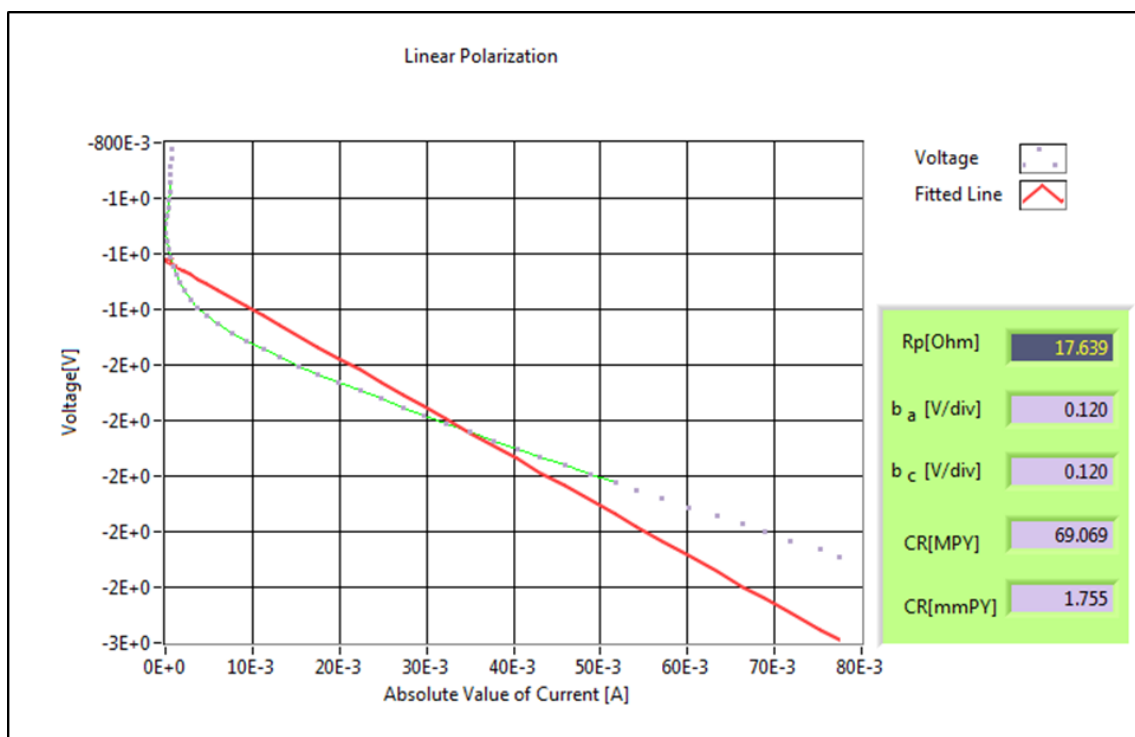


Figure 4.2: Graph absolute value of current vs voltage for 2.0 ml amine

Figure 4.2 above shows the result for the experiment when the experiment solution was injected with 2.0 ml of amine. The result for the corrosion rate for this added amount of amine is 1.755 mmPY.

The result have slight different between 1.0 ml amine injected and 2.0 ml amine injected. We can see that the corrosion rate of the carbon steel had decrease when we added the amount of amine into the 30% NaCl and saturated CO₂ solution.

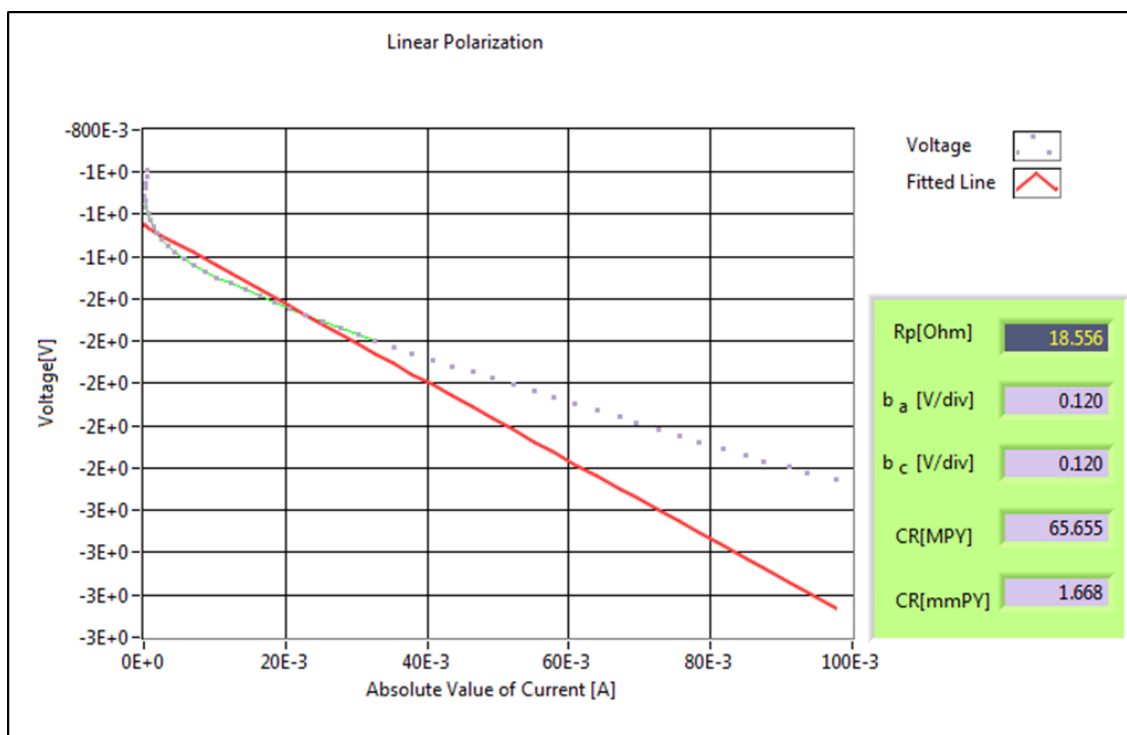


Figure 4.3: Graph absolute value of current vs voltage for 3.0 ml amine

Based on the Figure 4.3 above, 3.0 ml of amine had been injected and the result is we got 1.668 mmPY as for the corrosion rate. The result had also decrease compare to the result of corrosion rate for 1.0 ml and 2.0 ml of amine injected.

From the experiment, we can conclude that the higher amount of amine injected, the lower the corrosion rate of the carbon steel. These results are due to the ability of amine to absorb CO₂ help to reduce the corrosion rate. Amine had been a good solution to absorb CO₂ gas that had been one of the factors that lead into corrosion on a metal.

4.1.2 Amine and Oil as an Inhibitor

Amine and oil can be a great composition of corrosion inhibitor because the ability of amine to absorb CO₂ and also the ability of oil to protect the surface of the metal to avoid or decrease the potential of corrosion process from happening.

To design such a new or novel inhibitor, I had combine the solution of amine and palm oil in order to decrease the corrosion rate of the specimen that I am using in the experiment which is carbon steel.

Palm oil can also be classified into a green inhibitor which is an environmentally friendly corrosion inhibitor that can avoid pollution in the environment such in a sea. To determine whether it can be a good inhibitor, different amount of palm oil had been injected in a solution of 30% NaCl and saturated CO₂ together with 3.0 ml of amine.

In the first experiment, 1.0 ml of oil palm was injected together with 3.0 ml of amine and the result of the experiment was determined then from the LPR.

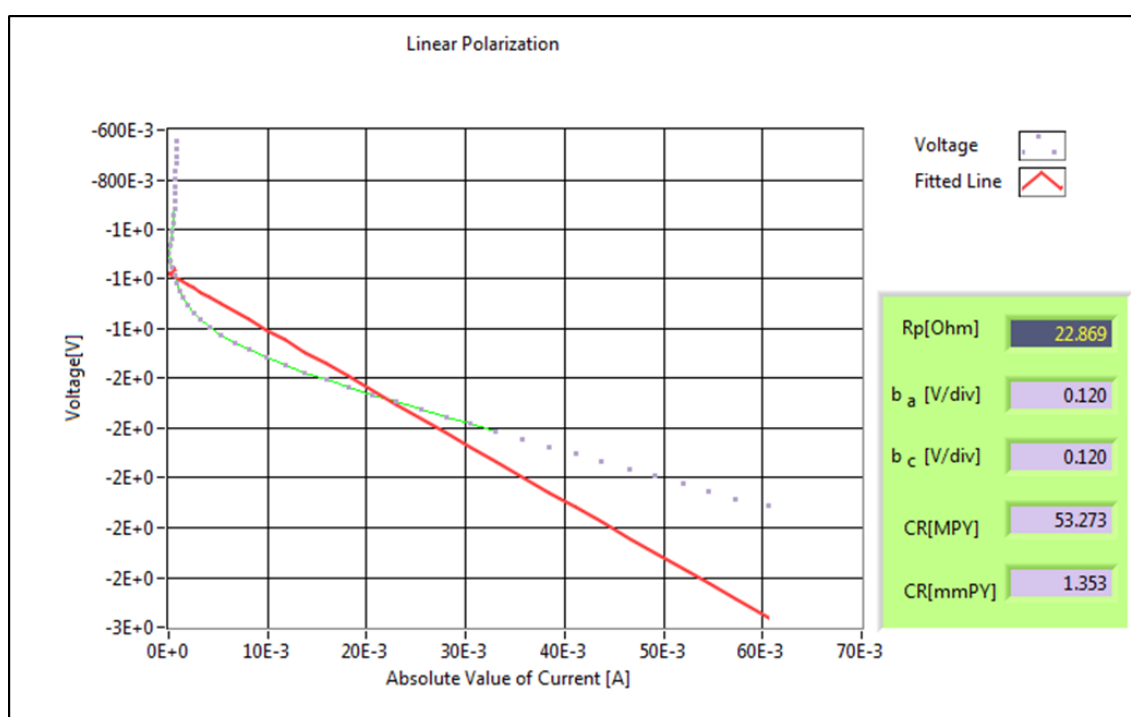


Figure 4.4: Graph absolute value of current vs voltage for 3.0 ml amine and 1.0 ml palm oil

The result of the experiment for 3.0 ml amine and 1.0 ml of palm oil that being injected into the solution of 30% NaCl and saturated CO₂ can be seen from the Figure 4.4 above.

From the data we can see that the amount of corrosion rate had been decrease by 1.353 mmPY compared to the result for the corrosion rate for only 3.0 ml amine injected without palm oil, the result is 1.668 mmPY. The result have slight different with 0.315 mmPY but it can make a big difference in the oil and gas environment.

A small amount of corrosion rate decrease can save a big amount on money invested for the corrosion protection in the industry. As we know, corrosion attack almost all parts of oil and gas industry. So by that, corrosion is an adversary worthy of all the high technology and research we can throw.

Because it is almost impossible to prevent corrosion, it is becoming more apparent that controlling the corrosion rate may be the most economical solution. In a solution for that, designing a novel inhibitor for corrosion protection in oil and gas environments is highly beneficial for the future of oil and gas industry.

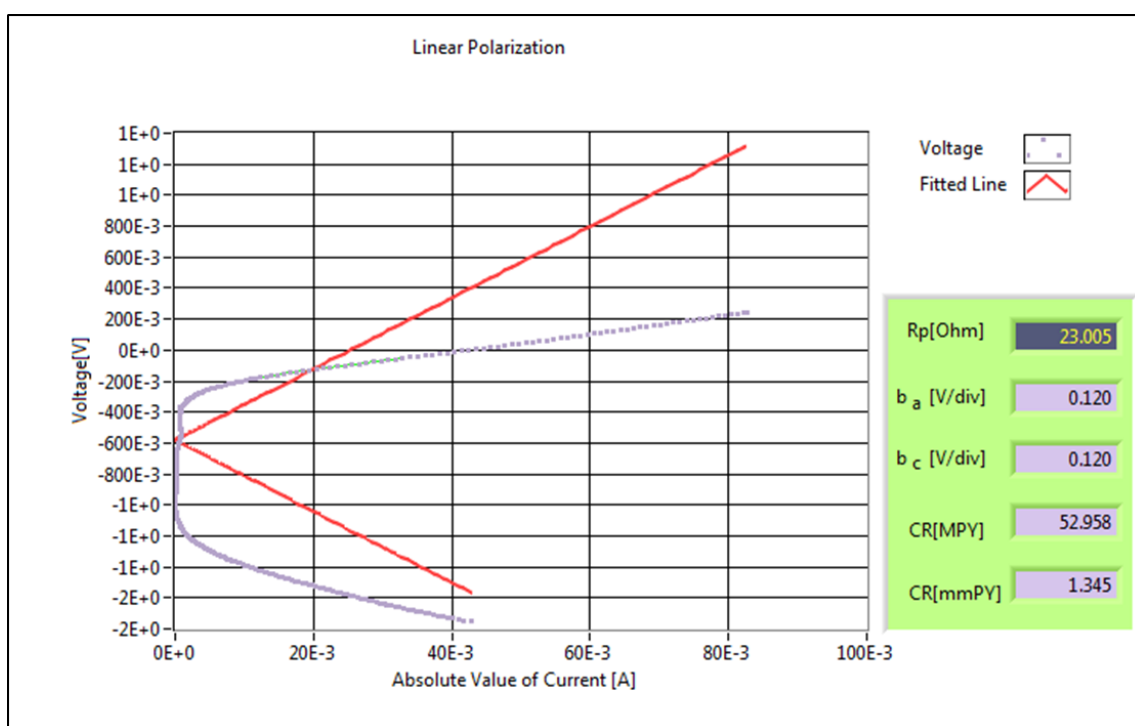


Figure 4.5: Graph absolute value of current vs voltage for 3.0 ml amine and 2.0 ml palm oil

According to the Figure 4.5 above, the corrosion rate that had been gain when the solution had been injected with an added amount of 2.0 ml oil is 1.345 mmPY. The value of corrosion rate is once again decrease when the amount of palm oil had been added with an addition of 1.0 ml.

Table 4.1: The corrosion rate for amine injected obtained from potentiostat experiment.

Amount of amine injected (ml)	Corrosion rate (mmPY)
1.0	1.888
2.0	1.755
3.0	1.688

The result from the different amount of amine injected can be seen clearly from Table 4.3 above. The decrease value of corrosion rate are continuously happened when the amount of the amine injected were added.

Table 4.2: The corrosion rate for palm oil injected with 3.0 ml amine obtained from potentiostat experiment.

Amount of palm oil injected (ml)	Corrosion rate (mmPY)
1.0	1.353
2.0	1.345

Based on the Table 4.2 above, the corrosion rate for the carbon steel specimen had been decrease when added amount of palm oil had been injected together with 3.0 ml of amine

4.2 DISCUSSION

From the evaluation of the results, we can assume that the composition of amine and palm oil together will be such a great corrosion inhibitor that can be used in the oil and gas environment.

The decrease result of the corrosion rate for the carbon steel specimen can be seen clearly from the LPR experiment that had been conduct with added amount of amine and palm oil. With 2.0 ml of palm oil and 3.0 ml of amine, the corrosion rate of 1.345 mmPY being obtained. It means that the corrosion that happened on the surface of the carbon steel pipeline for example is only 1.345 milimeter per year which is such a big achievement if we apply this inhibitor.

Without using a corrosion inhibitor, the corrosion rate can be higher due to the inability of the metal surface to protect itself from the attack of the environments that can lead it to corrode easily. This will then bring such a big loss to the industry and can destroy the composition of the metal itself.

Basically, corrosion happens because the presence of moisture. The oxidation reaction will take its place on the energized area of the metal surface to elute metal as an ion (anode). A reduction process will take place on the low energy area which is in cathode. On the metal surface, oxidation process on anode and the reduction process on cathode will proceed in equal rates and the metal corrosion will take place. Normally, corrosion of metal will occur on anode.

Moreover, the main factor that causes the corrosion on steel in water is the existence of dissolved salt like sodium chloride (NaCl) that make the solution (distilled water) more active to rust.

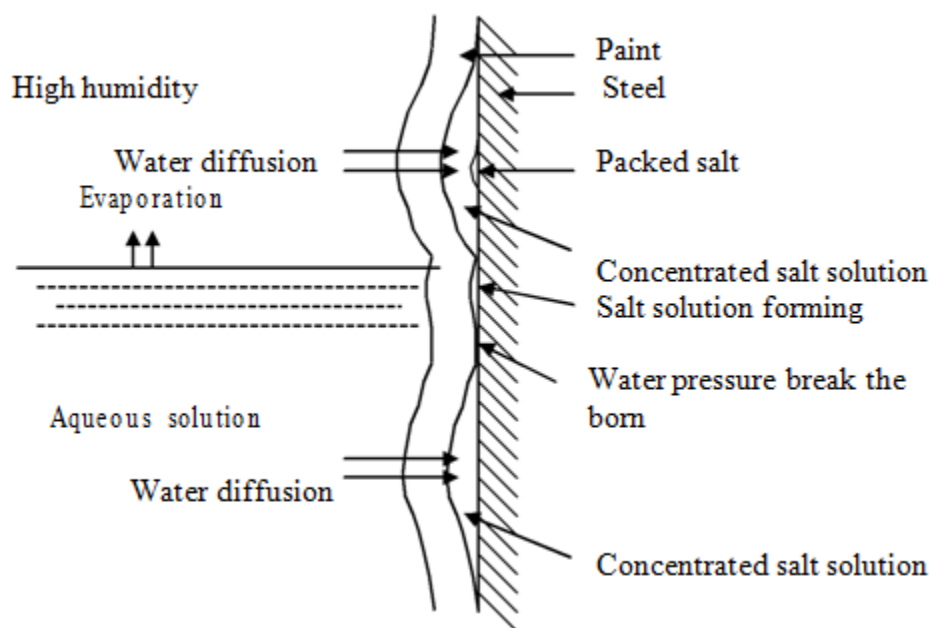


Figure 4.6: The development of peeling on the paint layer caused by osmotic pressure.

Source: (Sponas and Fonda, 1998).

Based on the Figure 4.6 above, the bond between the paint layer and steel that protected (coated) must be strong and covered to whole surface to protect from damage caused by osmosis process. The common paint (no addition of epoxy), bond between the paint and surface of steel not too strong compared to the paint that contain the epoxy that causes the water easy to diffuse to the paint. Then, this will affect to the paint that is it easy to exfoliation (peeling) and fade in colour

By that, painting the metal surface with paint will not be such a great idea because the paint and surface of steel is not strong enough to protect the surface of the steel. Injecting a corrosion inhibitor will be the more preferable solution to protect the metal from corrodes.

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

5.1 CONCLUSION

From the research that have been done, we can see that corrosion inhibitors are substances that when being added in such a small concentrations to particular environments with the aim of slowing down the rate of corrosion at sites such in an oil and gas environment can slow down or decrease the value of corrosion rate happened on the surface of metal.

Basically, corrosion inhibitors will help to slow down the corrosion processes on a metal by increasing the anodic or cathodic polarization behaviour, which will then help to reduce the movement or diffusion process of ions to the metallic surface. It will then help to increase the electrical resistances of the metallic surface.

Based on the research that I have been done, the combination of amine and palm oil can be a great inhibitor since both of it have its own advantage and ability to protect corrosion from happened. Amine itself have an ability to absorb the CO₂ gas and palm oil itself can form a film layer to protect the surface area of the metal from corrode.

5.2 RECOMMENDATION

As for the recommendation, it is recommended to use another parameter in this research experiment such as change the temperature or the pH for the experiment. In this experiment, the parameter that had been used is a condition where 3.8 pH, room temperature, 30% of NaCl and a specimen of carbon steel are used. So, for the next study, the solution, and the specimen can be changed so a different result can be obtained

Furthermore, the composition and the properties of the inhibitor can be added with other suitable chemical composition so the efficiency of it can be higher.

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