EVALUATION OF THE IMPACT OF OPERATING TEMPERATURE TO CORROSION RATE FOR (CUI)

By

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14901

Dissertation submitted in partial fulfilment of the requirements for the

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CERTIFICATION OF APPROVAL

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A project dissertation submitted to the Mechanical Engineering Programme
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In partial fulfilment of the requirement for the
BACHELOR OF ENGINEERING (Hons.)
(MECHANICAL)

Approved by,

…………………………….
(Dr. Masdi Bin Muhammad)

UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK

January 2015

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

…………………………………..

(MUHAMMAD HAZIQ BIN ZAINAL)

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ABSTRACT

CUI can be classified as severe form of localized corrosion that has been plaguing chemical process industries since the energy crisis of the 1970s forced plant designers to include much more insulation in their designs. Flow of water is the key problem in CUI. Moisture may be external or may be present in the insulation material itself. Corrosion may attack the jacketing, the insulation hardware, or the base of equipment. For high temperature equipment, water entering an insulation material and diffusing inward will eventually reach a region of dry out at the hot pipe or equipment wall. Then, to this dry out region is a zone in which the pores of the insulation are filled with a saturated salt solution. When a shutdown or process change occurs and the metal-wall temperature falls, the zone of saturated salt solution moves into the metal surface.

After the reheating process, the wall will temporarily be in contact with the saturated solution, and stress-corrosion cracking may begin. The cycles in CUI associated problems are a strong accelerator of corrosion damage since they provoke the formation of an increasingly aggressive chemistry that can lead to the worst corrosion problems possible, for instance stress corrosion cracking, and premature catastrophic equipment failures.

The majority of CUI occurrences reported are between the -4°C and 175°C (25°F and (347°F). This research is done to study the relationship between operating temperature and corrosion rate due to CUI. For this experiment, a laboratory cell was setup according to ASTM G189-07 for the simulation of CUI. The CUI cell consisted of six carbon steel ring specimens separated by insulated spacers and held together by blind flanged pipe sections on both ends. Thermal insulation which was placed around the testing section provided the annular space to retain the solution which represents the test environment. For this experiment, rock wool and perlite insulator have been used to study the behaviour of corrosion rate. The ring specimens were used to test electrodes in two separate electrochemical cells. Therefore, corrosion measurements were made using both electrochemical polarization resistances (for 65ºC and 121ºC) and mass loss data under isothermal test conditions.

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CHAPTER ONE: INTRODUCTION

1.1 Background

Corrosion is one of the major problems that can affect the production in industry. As for example, corrosion under insulation (CUI) problem facing by the petrochemical industry. Problems such as major equipment outages and unexpected maintenance costs stemming from CUI, account for more unplanned downtime than all other problems. [2] Corrosion under insulation (CUI) is a corrosion failures that happened and observed between the metal surface and the insulation on that surface as a result of water penetration. The sources of the moisture may come from rain water, leakage, deluge system water, wash water, or sweating from temperature cycling or low temperature operation.

CUI problem is difficult to discover until the insulation is removed for inspection. It is because of the corrosion is hidden under the insulation throughout the process. To avoid CUI, it is very important to always inspect for or repair by any technical methods such as radiography, ultrasonic or other forms of inspections which usually involves high cost and most cases requires the removal of the insulation for inspection. [4] There are very limited studies on effective method of inspection without removal of insulation such as the application of optical fibre –Doppler sensors which already have the explosion-proof characteristics. [5]

1.2 Problem Statement

Corrosion under insulation (CUI) can be classified as major problem. It is typically difficult to identify as lies hidden under insulation material. This can be a huge complication especially in plants that have to operate for a long period of time. This failure can be catastrophic in nature and can cause adverse economic effect in terms of downtime and repairs cost. One of the problem is the types of insulator. Different insulator can lead to a different results of CUI. It is depending on the type of material that been used as the insulator for pipe. Hence, the best way to handle this situation is to prevent this kind of problem from occur as well as affected the industry in future.

From that particular statement and studies, this project is very important to know in details the relationship between operating temperature and the corrosion rate, which the corrosion rate due to CUI can be predicted and precautions can be made before the occurrence of CUI in pipeline.

1.3 Objectives of the Project and Scope of Study

The main objective of this project is to establish the relationship between operating temperature and the corrosion rate. In order to achieve the objective, all of main scope of activities are depending on ASTM G189-07. This standard, also known as (Standard Guide for Laboratory Simulation of CUI) is an important reference for the project to determine the corrosion rate happened inside insulation. Other than that, from this experiment we can obtain and compare the results from data that divided into two types of insulator, which have been used in industries for a long time.

Moreover, there are certain parts of scopes of studies that plays an important role to achieve the objective. The scopes of studies are:

1. To perform experimental work to gain corrosion rate based on ASTM G189-07.
2. To analyse the result and establish the relationship between operating temperature and the corrosion rate based on the data obtained.

CHAPTER TWO: LITERATURE REVIEW AND THEORY

2.1 Corrosion

Corrosion can be defined as degradation, deterioration or destruction of materials that occurs when it reacts with its environment. [6] Corrosion can be classified into several types such as uniform corrosion, galvanic corrosion, concentration cell corrosion, pitting, crevice, inter-granular corrosion, de-alloying, erosion, microbial corrosion and others. Early detection of corrosion is very crucial in order to maintain the condition of a component or system from desired certain level. With early detection, precaution measures can be applied so that huge damage can be prevent from occurs.

2.2 Insulation

Insulation is used to minimize heat loss, reduce costs of maintenance and improve efficiency. It may also be employed to minimize heat gain or to protect personnel from the risk of injury from hot or cold pipe surfaces. Traditional insulation systems typically consist of insulating material such as mineral wool or calcium silicate, which is then protected by an outer layer of cladding in oil and gas industries. In addition, thin metal sheet or composite wraps are the most common cladding materials. To help coop the risk of CUI, insulation systems are designed and installed with great care given; in order to sealing joints, terminations as well as protrusions. Despite these efforts, chances for corrosion to happen be still exist. Mechanical damage, degradation of sealants, rainwater, deluge systems and atmospheric moisture will all contribute to water ingress through into the insulation system, resulting in a warm, damp corrosive environment against the steelwork.

For this phenomena of CUI, once water penetrates an insulation material, a highly corrosive environment can be created at the interface between insulation and pipe. Moisture is often unable to escape and vaporize, leading to prolonged periods of moisture contact and further build –up of corrosive contaminants. This raises the boiling point of the water, would lead the further risk of corrosion to higher temperatures as well as increasing the corrosion rate.

2.3 Corrosion under Insulation

Corrosion under insulation (CUI) is a serious issue faced by most of industries due to the moisture penetrates through the insulation, caused by ineffective barrier system. The moisture will accumulate between the material and insulation, resulting in deteriorates that leads to early corrosion damages. When water breaches the external cladding used to protect the insulation, it starts to corrode the external surface of the pipe. [3]

CUI can occur under any type of insulation depending on the type of metal. All of these corroded metals are usually insulated, and depending on other related factors. Insulation in piping mostly applied due to heat conservation, process control, personnel protection, fire protection or any other reasons. [1]

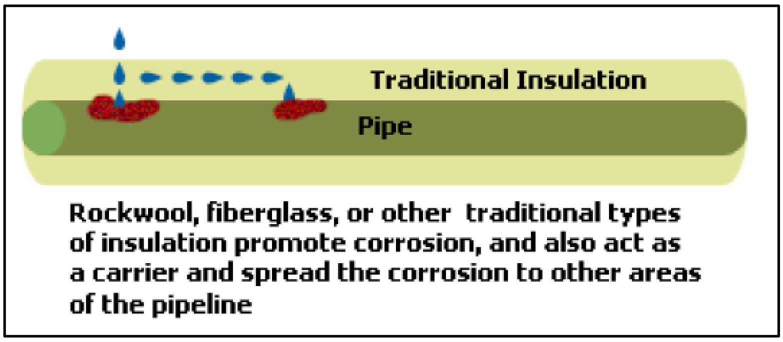


Figure 1: Corrosion under Insulation *[7]*

Several conditions must be fulfil for existence of corrosion. The initiation of corrosion of steel or other materials under insulation are due to the presence of water, oxygen and other corroded substances. The presence of water and oxygen on the metal surface will cause electrochemical reaction that consists of an oxidation, which via metal dissolution and also "reduction reaction" which is reduction of oxygen, at the surface of the material that corrodes. In oxidation reaction, metal ions and electrons are generated while at reduction reaction, the electrons from oxidation reaction are consumed. The illustration of the reaction is as shown in Figure 2 below.

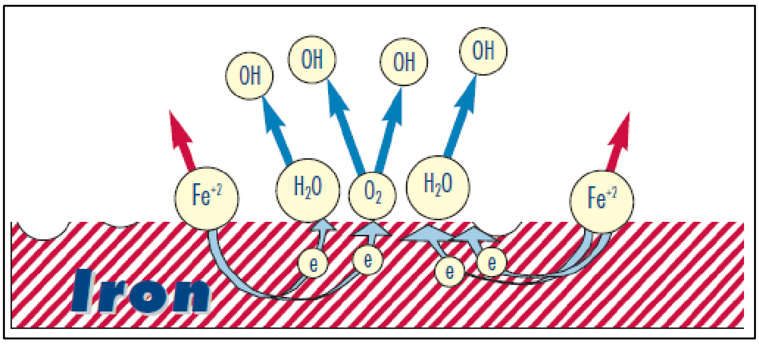


***Figure 2: Corrosion Mechanism** [9]*

Oxygen and water are converted into hydroxide ions when the present of electrons in environments with water or moisture occur. These hydroxide ions then will combine with iron ions to form hydrated oxide (Fe (OH) 2). Subsequent reactions form a mix of magnetite (Fe_3O_4) and hematite (Fe_2O_3). This red-brown mixture of iron oxides is rust or known as corrosion. [7]

Anodic reaction	**:**	$Fe \rightarrow Fe^{2+} + 2e^-$
Cathode reaction	**:**	$O_2 + 4e^- + 2H_2O \rightarrow 4OH^-$
Overall reaction	**:**	$Fe^2 + 2OH^- \rightarrow Fe\,(OH)_2$

In order to discuss the effect of operating temperature in industries to the corrosion rate obtain, the author had listed the rate of corrosion rate with comparing to the function of the driver tables below. In summary, table shows in details the corrosion rate obtain from temperature in the range of -12°C up until 176 °C.

Table 1: Corrosion Rate (mpy) for Calculation of the Damage Factor [8]

Operating Temperature (°F)	Corrosion Rate as a Function of Driver (1) (mpy)			
	Marine / Cooling Tower Drift Area	Temperate	Arid / Dry	Severe
10	0	0	0	0
18	1	0	0	3
43	5	3	1	10
90	5	3	1	10
160	10	5	2	20
225	5	1	1	10
275	2	1	0	10
325	1	0	0	5
350	0	0	0	0

Note:
1. Driver is defined as the atmospheric condition causing the corrosion rate.
2. Interpolation may be used for intermediate values of temperature.

Table 2: Corrosion Rate (mmpy) for Calculation of the Damage Factor [8]

Operating Temperature (°C)	Corrosion Rate as a Function of Driver (1) (mm/y)			
	Marine / Cooling Tower Drift Area	Temperate	Arid / Dry	Severe
-12	0	0	0	0
-8	0.025	0	0	0.076
6	0.127	0.076	0.025	0.254
32	0.127	0.076	0.025	0.254
71	0.254	0.127	0.051	0.508
107	0.127	0.025	0.025	0.254
135	0.051	0.025	0	0.254
162	0.025	0	0	0.127
176	0	0	0	0

Note:
1. Driver is defined as the atmospheric condition causing the corrosion rate.
2. Interpolation may be used for intermediate values of temperature.

2.4 Causes of Corrosion under Insulation

Two basic ingredients are needed for corrosion under insulation (CUI) to form which are water and warm temperature. For iron products like carbon steel piping and any other equipment, oxygen is needed for the corrosion process, while for chloride stress corrosion cracking (SCC) of 300 series stainless steel, chloride ions presence is needed. Corrosion can also occur at the presence other corrodants such as acids, acid gases, strong bases and salts.

Table 3: Likely Risk of CUI for Carbon Steel Pipework, Without Trace Heating, Under Various Operating Regimes [8]

Operating Temperature	Risk Of CUI		
	Painted Pipework <10 Years Old	Painted Pipework <10 Years Old	Painted/Unpainted Pipework >10 Years Old
	Intermittent Operation	Continuous Operation	Intermittent or Continuous Operation
< -30 0C	Low - Medium	Low	Medium
-30 0C to 30 0C	Medium	Low - Medium	High
30 0C to 120 0C	High	High	High
>120 0C	Medium	Low	Medium

Oxygen is abundant, freely and readily available in environment. Environments that provide through air contaminants such as marine environments and cooling tower drift for chloride and stack emission for sulphur dioxide, SO_2, can accelerate corrosion. Chloride ions can also be found in a various types of places such as seawater, drinking and process water, and chloride chemical compounds to roadway de-icing salts. The chloride may also be found as the contaminants that may be leached out of the insulation.

Moisture can come from many sources where rainwater is the most common source of moisture to cause CUI. Next source of moisture is water vapour penetrating and soaking down the insulation systems operating at or below ambient temperatures. Besides that, one of the sourced of moisture is ice, normally cold service insulation systems operating below the freezing point. The insulated piping and equipment at cold temperature do not corrode significantly since the available heat and oxygen is limited due to temperature limits. However, it provides near ideal corrosion state where the ice is continually freezing and thawing. Moisture can also come from sources such as water leaks, condensation, leaking process fluids, mist spray from cooling tower and deluge system.

One of the causes for corrosion under insulation (CUI) is operating temperature. Abavarathna [8] stated that the temperature of the metal surface plays an important role with regard to CUI in general. Increasing temperature will increase the rate where electrochemical reactions take place thus increasing the corrosion rate. Further increase in temperature will reduce the corrosion rate due to the lack of a corrosive environment as water evaporates. However, as water evaporates, the concentration of corrosive species on the metal surface increases. Furthermore, high temperature reduces the service life of protective coatings and sealants.

For operating temperature above 150°C, most of the moisture that penetrate through insulation system will evaporates before it can get in contact with the metal surface to start the corrosion process. For operating temperature below 0°C, the water that able to penetrate the insulation system will freeze and transform into ice due to relatively low energy levels. This will case the corrosion rates decreased. The optimum temperature range for corrosion under insulation to happen is between 93°C and 115°C, where there is plenty of heat energy but does not enough to evaporate the moisture before it contacts the pipeline surface [3].

According to API Recommended Practice 571, the rate of corrosion increases with increasing metal temperature up to the point where water evaporates quickly. The corrosion becomes more severe at metal temperatures between each boiling point, 100°C and 121°C, where the water is less likely to vaporize and insulation stays wet longer. The upper temperature range where corrosion under insulation may occur can be extended significantly above 121°C in the marine environments or areas where significant amounts of moisture maybe present.

Equipment that operates below the water dew point tends to condensate water on the surface of the metal. This will increase the risk of corrosion as it provides a wet environment. Equipment that operates on cyclic thermal operation or intermittent service can also increase the corrosion.

The effect of operating temperature on corrosion of steel in water is shown in Figure 3 below.

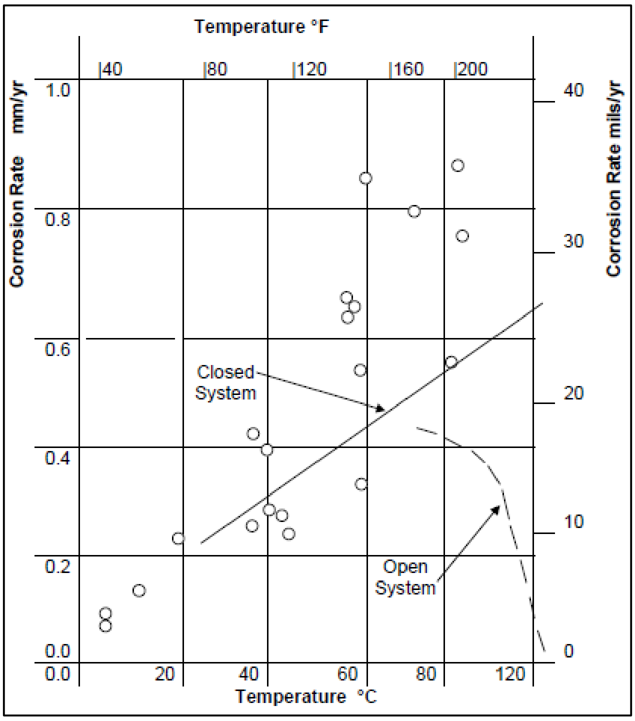


***Figure 3: Comparison of Actual Plant CUI Corrosion Rates Measurements with Laboratory Corrosion Data Obtained in Open and Closed Systems** [8]*

The effect of temperature on corrosion of steel in water is shown above. In an open system, the oxygen concentration in water decreases with increasing temperature, thus decreasing the corrosion rate. In contrast, the corrosion rate in a closed system increases with increasing temperature. The field measurements on CUI for this project represents somewhat similar corrosion behaviour as in a closed system.

2.5 Prevention of Corrosion under Insulation

There are five factors in preventing CUI: insulation selection, equipment design, protective paints and coatings, weather barriers, and maintenance practices. [3] Mitigation is best achieved by using appropriate paints or coatings and maintaining the insulation or vapour barrier to prevent moisture ingress since the majority of construction materials used in plants are susceptible to corrosion under insulation degradation. Thus, high quality coatings and the application of the coating must be properly applied to ensure the insulation can provide protection for a long period of time. The coating system must protect for long periods against water or corrosives. [3] The selection of insulation materials is also very important aspect for prevention of corrosion under insulation. For example, closed-cell foam glass materials will hold less water against the pipe wall compared to mineral wool thus, closed-cell materials potentially be less corrosive. For 300 series stainless steel, low chloride insulation should be used to minimize the potential for pitting and chloride stress corrosion cracking. [7]

CHAPTER THREE: METHODOLOGY AND PROJECT WORK

3.1 Project Activities and Gantt chart

All of the project activity and Gantt chart have been attached in Appendices.

3.2 Research Methodology Flow Chart

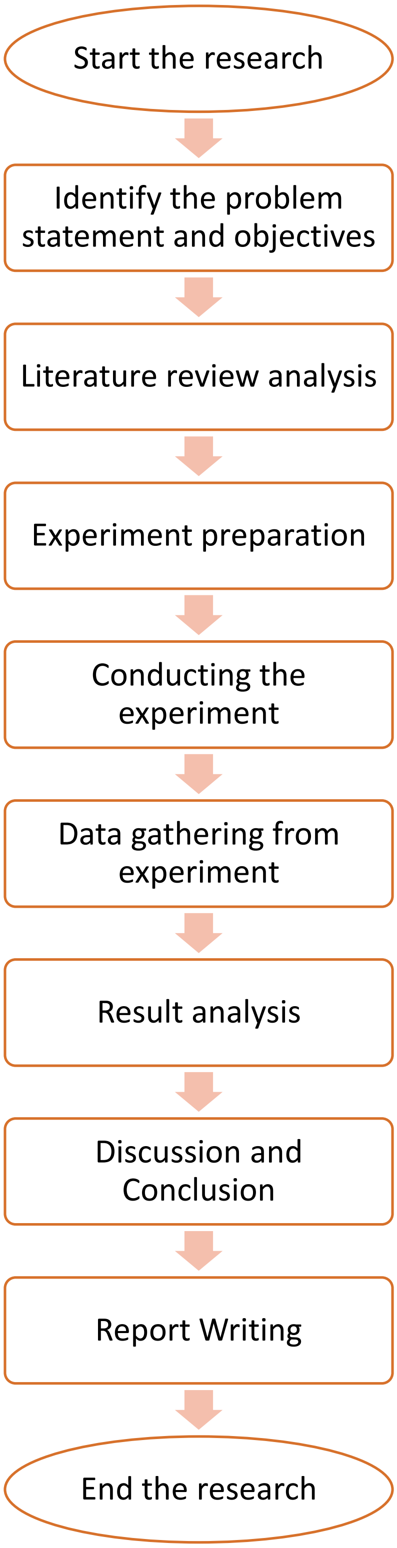


Figure 4: Flowchart for Research Methodology

3.3 Experimental Methodology Flow Chart

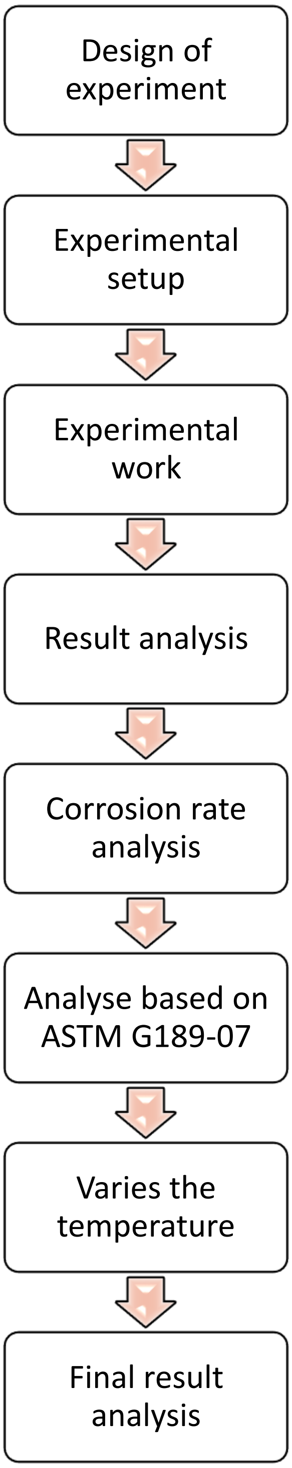


Figure 5: Flowchart for Experimental Methodology

3.4 Experimental Work

Table 4: Apparatus Needed for CUI Experiment

No	Item	Detail
1	Carbon Steel Piping	Big Bore (OD 2in, thickness 0.187in) A106 Grade B
2	Blind Flange Sections	Includes a bolted flange pair consist of weldneck, threded or lap joint flange and attached pipe section
3	Ring specimens	2in OD, 0.187in thickness, 0.25in width, A106 B (minimum of 6)
4	Non –conductive spacers	Material used: polytetrafluoroethylene resin.
5	Internal heater	400W, 0.625in nominal diameter heater, heat transfer oil of at least 100ml capacity (thermal conductive silicone oil)
6	Temperature Controller	Control the temperature through out the experiment
7	Potentiostat	Can determine at least ±20mV of OCP
8	Micrometering Pump	Pump rate from 0.5 to 5mL/min
9	Tubing for Solution	0.125in made from corrosion resistant material + valves with on/off regulation
10	Solution Reservoir	Reservoir made from High density polyethylene (HDPE) or glass.
11	Solution:represent environment/Wether chamber	0.5g of NaCl + 5L of reagent water + 1M of H_2SO_4 to pH 6 (±0.1)
12	Insulation	Water resistant molded perlite with low concentration of chloride (35-40ppm) Rockwool insulator (NACE paper 08036) Cellular Glass N31A, N34A.

3.4.1 Preparation of the rings specimens

Ring specimens consist from the grade of A106B, was used for the construction of the CUI cell experiment. The test specimens, rings of thickness 0.187 inches were machined from the same grade of A106B pipe that have been used in the setup. In addition, for this project six ring specimens were needed to run both Linear Polarization Resistance (LPR) procedure and mass loss test.

Figure 6: Grinding machine for ring specimens

Figure 6 shows that the grinding machine that have been used to resurface the ring specimens. Grinding paper that used are from the range of grit 120, 240/P280, 320/P400, and 600 grade.

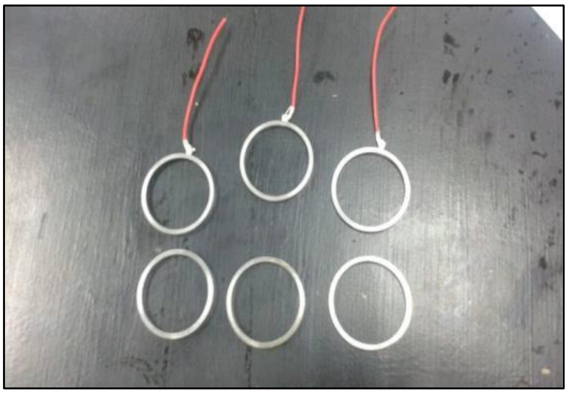


Figure 7: Ring specimens

Figure 7 shows the ring specimens that have been completely grinded. Three of the rings will be used for LPR Experiment, and the remaining will be used for mass loss test.

3.4.2 Measurement of the initial weight for the rings

The initial weight of all ring specimens have been measured. It is an important procedure to know the initial as well as final weight, for mass loss test.

3.4.3 CUI –Cell Setup

This cell consisted of six ring specimens which were separated by non -conductive spacers. The insulation material as shown in the figure 8 used for the spacers was a polytetrafluoroethylene resin.

Figure 8: Non-conductive spacers

The testing section which included alternate rings of insulation and pipe material was held together by two blind flanged pipe sections on both ends of the CUI setup as shown in figure 10. Three pipe clamps were used to hold the cell set-up together. The test temperature at the ring surfaces were achieved via an immersion heater incorporated to the inside of the pipe section which was filled with a thermal conductive silicone oil, in order to be the liquid medium inside the carbon steel pipe.

Figure 9: Ring specimens' setup at CUI -cell

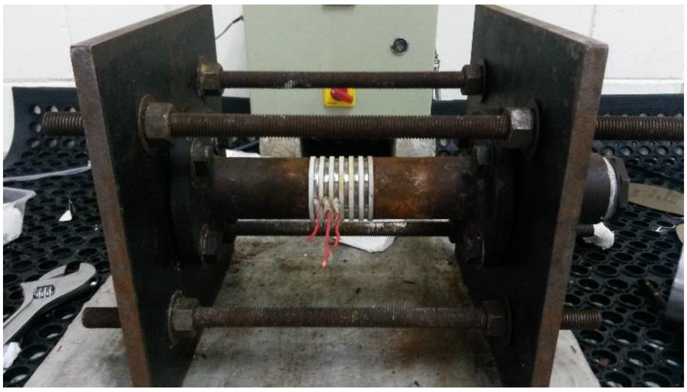


Figure 10: Complete setup for ring specimens

Figure 11: Silicon oil injection process

Figure 11 shows the procedure to put an amount of silicon oil inside the carbon steel pipe. The function for that particular oil is to become a medium inside the pipe, as well as to transfer the heat inside, similar to the actual oil transported pipeline in industries.

Figure 12: Immersion heater

Figure 12 and figure 13 shows the immersion heater procedure in order to setting up the CUI –Cell. This heater is important to set the desired operating temperature at the ring surfaces.

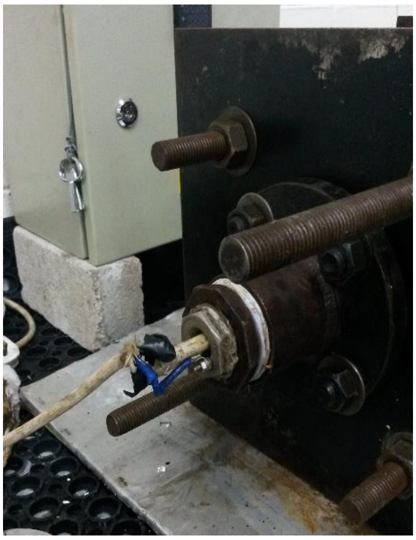


Figure 13: Complete setup for immersion heater

3.4.4 Insulation Setup

A block of thermal insulation placed above the testing section provided the annular space to retain test environment. The insulation used was a water resistant moulded perlite type with a low concentration of chloride (35-40 ppm), and also rockwool insulation as shown in figure 14 and figure 15. The test environment selected was an aqueous solution containing 0.5g (NaCl), 5L of reagent water with pH adjusted to 6 (with H2SO4) in order to simulate atmospheric condensate as shown in figure 16. One half of the outer surfaces of the ring specimens were exposed to the test environment during the testing. Other than that, figure 17 shows test solution was pumped into the annular space between the thermal insulation and the outer surfaces of the ring specimens through two ports. The ring specimens were used as test electrodes in three separates electrode cells. The centre ring was used for the working electrode (WE) while the other two rings were used as the auxiliary electrode (AE) and the reference electrode (RE), related to figure 18.

Figure 15: Perlite Insulation

Figure 14: Rockwool Insulation

Figure 16: Deionized Solution

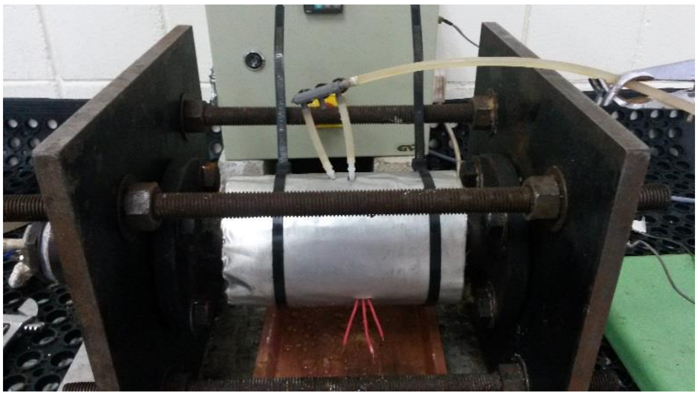


Figure 17: Test solution pump into annular space

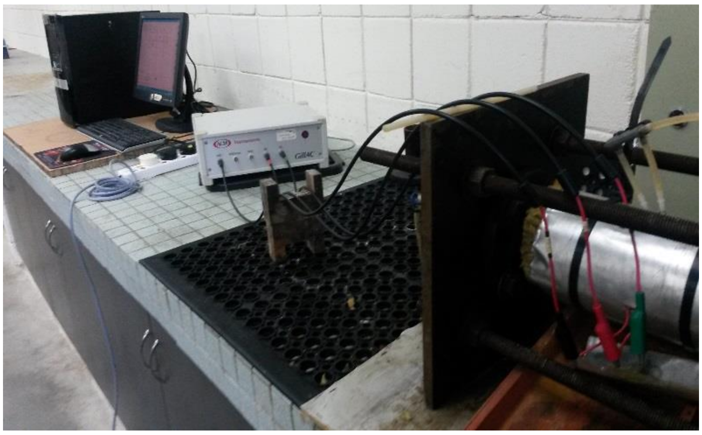


Figure 18: Complete CUI –Cell setup

3.4.5 Simulation of experiment

Test condition selected for these test were isothermal test, which consist of temperature for 65°C and also 121 °C. Moreover, simulation for the experiment was conducted every 72 hours for each temperature.

3.4.6 Mass Loss experiment

The corrosion rates calculated based on mass loss data over the three day exposure period are provided in the results chapter.

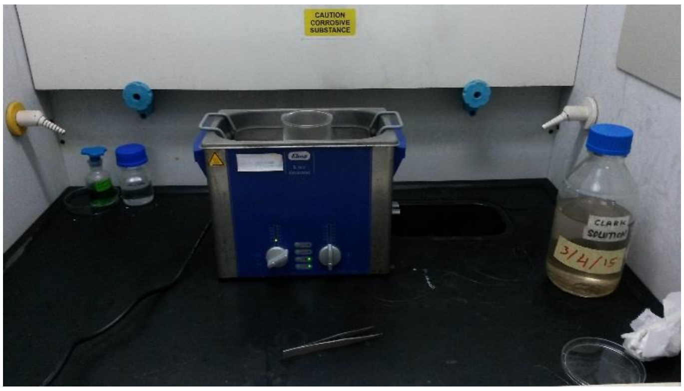


Figure 19: Ultrasonic Bath for Mass Loss Test

Figure 20: Mass Loss procedure

3.4.7 Overall Setup of CUI –Cell Experiment

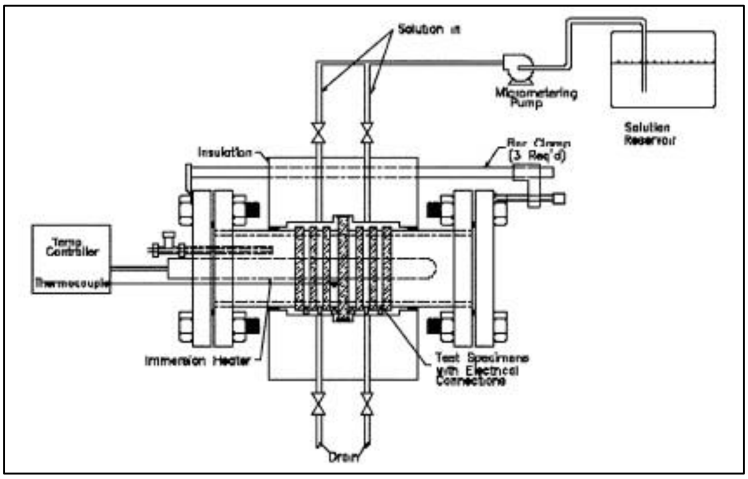


Figure 21: Setup of CUI -Cell Experiment *[8]*

Figure 19 shows the setup of CUI –cell for the whole experiment that need to be taken.

3.5 Phase 1

In Phase I, the experimental work will be done by CUI simulation based on the ASTM G189-07 standard. The result obtained from the simulation is calculated for the corrosion rate. The corrosion rate calculated will be checked and compare with the ASTM G189-07 standard for validation.

Based on ASTM G189-07, specific test environment is required in order to produce an accelerated exposure environment. The solution used consist of 100 ppm NaCl dissolved in reagent water, acidified with addition of H_2SO_4 to pH 6 (±0.1 pH unit) at 24ºC.

3.6 Phase 2

In Phase II, the experimental work will be done by CUI simulation based on the ASTM G189-07 standard, with a few modifications made. The modifications made by using different level of operating temperatures. In this phase, the experimental work is done to check the effect of the operating temperature on the corrosion rate.

In this phase, particular type of insulation which are perlite and rockwool will be test to study the effect on the corrosion rate. Besides, the operating temperatures to be tested to study their effect on the corrosion rate are at 65°C and 121°C.

The test environment used for this phase is similar to ASTM G189-07 which is the solution used consist of 100 ppm NaCl dissolved in reagent water, acidified with addition of H_2SO_4 to pH 6 (±0.1 pH unit) at 24°C. This solution is designed to represent an atmospheric condensate with impurities of chlorides and acids found in industrial and coastal environments.

Finally, based on ASTM G189-07, the corrosion rate will be study and calculated by two techniques, which are linear polarization resistance and mass loss.

3.6.1 Linear Polarization Resistance

The potentiostat will be used in accordance with ASTM Practices G59 [10] and G102 [11] to determine the open circuit potential (OCP) and to make polarization resistance measurements of current versus electrode potential over a range up to at least ±20 mV of the OCP.

The instantaneous corrosion rates of the two working electrodes were obtained using the polarization resistance technique given in ASTM Practice G59. [10] The measurements were repeated at intervals of 30 minutes for the period of exposure.

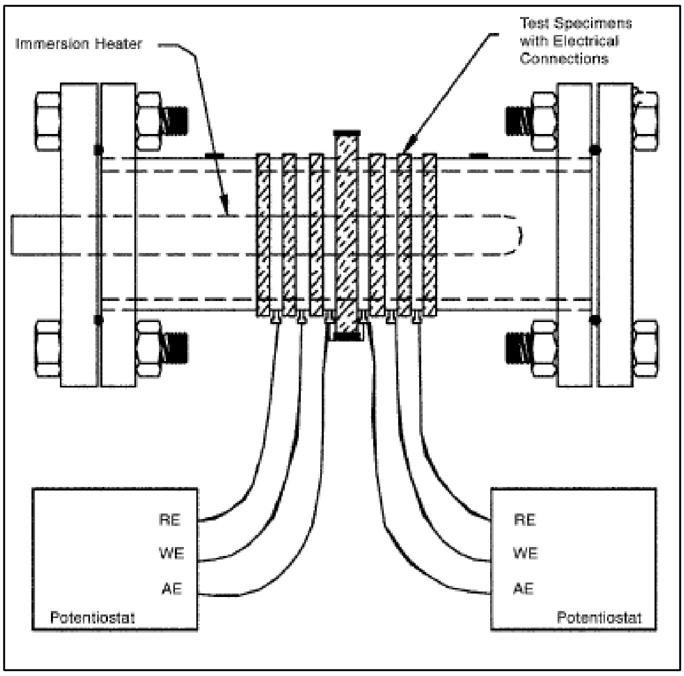


***Figure 22: Schematic of wiring of potentiostat to CUI-Cell Ring Specimens** [14]*

3.6.2 Mass Loss Test

The ring specimens will be rinsed in distilled water or deionized water to remove loose material and accumulated salts, and then dried with a non-chlorinated solvent. The post-specimen mass (M_f) was measured first before cleaning. Clark solution, consisting of 1000mL of hydrochloric acid, 20 g of antimony trioxide (Sb_2O_3), and 50 g of stannous chloride ($SnCl_2$), will be prepared according to ASTM Practice G1. [12]

The specimens will be immersed in this solution for 40 seconds, rinsed with water, cleaned with ethanol in ultrasonic bath for 10 minutes, dried in hot air, and finally, weighed. Finally, the corrosion rate can be calculated by following the equation in ASTM Practice G31. [13]

The difference in initial pre-exposure mass (M_i) and the post-exposure (after cleaning) mass (M_{f1}) for the ring specimens have to be calculated to obtain mass loss corrosion rate using the following equation from ASTM Practice G31[13]:

Corrosion Rate = **(K × M) / (A × T × D)**

where:

K	= constant (mpy: 3.45×10^6; mmpy:8.76×10^4),
M	= mass loss (g) given by (M_i - M_{f1}),
A	= exposed area in (cm^2),
T	= time of exposure (h), and
D	= density (g/cm^3)

CHAPTER FOUR: RESULTS AND DISCUSSION

4.1 Phase 1

In the period of FYP 1, the author had managed to conduct the first phase of this CUI experimentation. The experiment was conducted in Centre of Corrosion Research (CCR) Building.

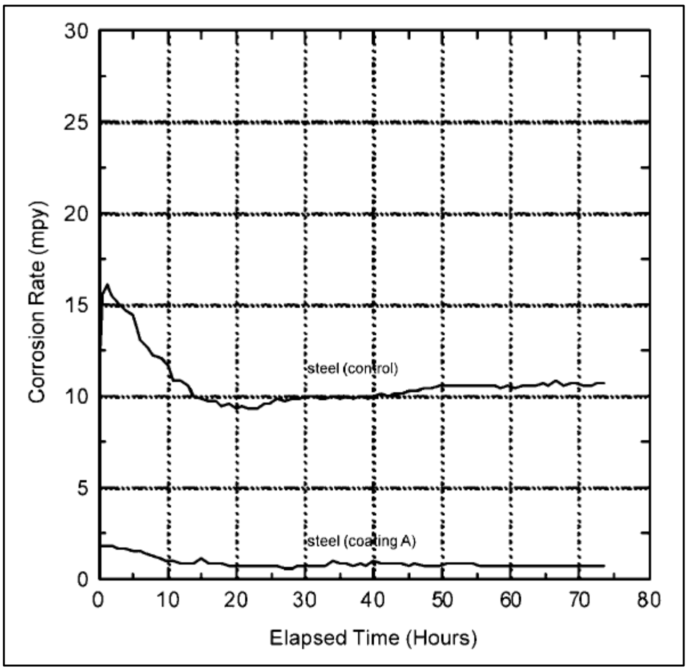


Figure 23: Electrochemical Corrosion Rate Data versus Time for an Isothermal CUI Simulation at 65°C *[14]*

The graph stated is the standard graph by referring to the ASTM G189 -07. On the other hand, this graph is the actual graph that the author can get when running the experiment. Phase 1 is important for the whole execution of this experiment as to refer whether the set-up of CUI –Cell to run this experiment is correct or not.

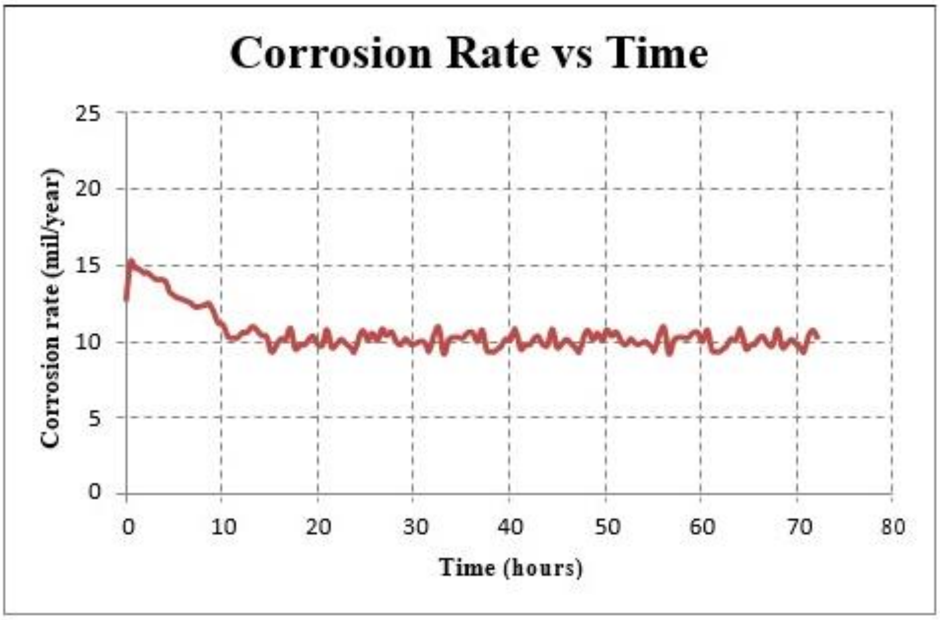


Figure 24: Electrochemical Corrosion Rate Data versus Time for an Isothermal CUI Simulation at 65°C (Result)

Based on **Figure 24**, the result shows that at one hour after the experiment started has the highest reading of corrosion rate. The corrosion rate decrease until after 10 hours and shows a constant corrosion rate in range of 9-11 mil per year. Even though the result shows that the value had some difference compared to the value in graph **Figure 23**, the trend of the graph obtained was similar to the graph in **Figure 23**. Thus, the author can conclude that the experimental setup used and the procedures done for the experiment was valid and as per ASTM Practice G189-07.

4.2 Phase 2

4.2.1 Linear Polarization Resistance (Perlite Insulation)

4.2.1.1 Temperature of 65°C

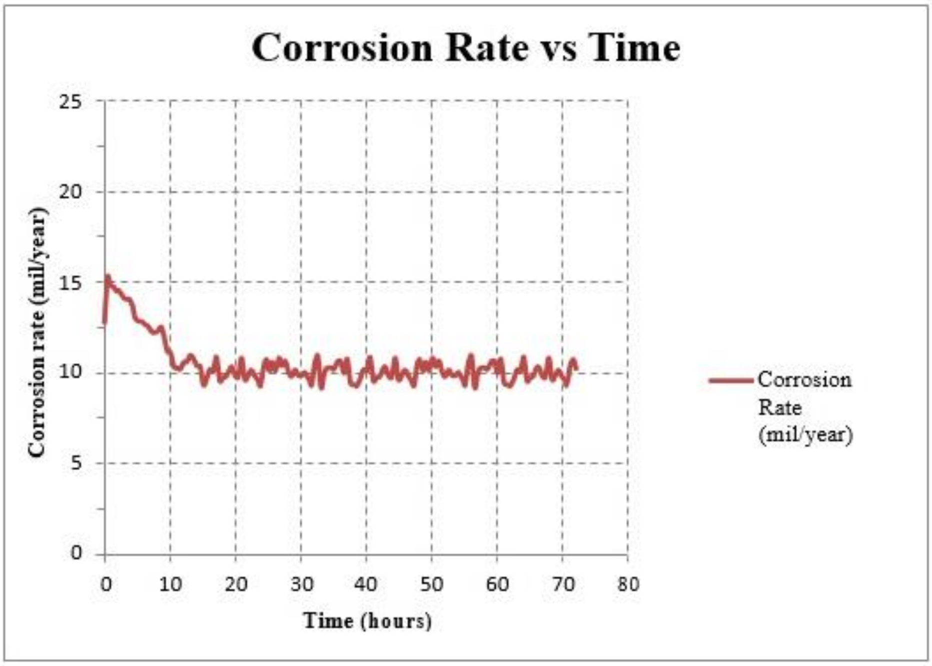


Figure 25: Corrosion Rate versus Time at temperature 65°C (perlite)

Based on **Figure 25**, the highest corrosion rate observed was at about the first hour which was about 15 mil/year. The corrosion rate then decrease until about tenth hour and the corrosion rate is constant at range about 10 mil/year. Hence, the corrosion rate obtained from potential dynamic polarization resistance test is 10 mil/year.

The same result was obtained by Abvarathna et al. in their experiment which was 10 mil/year. [10]

4.2.1.2 Temperature of 121°C

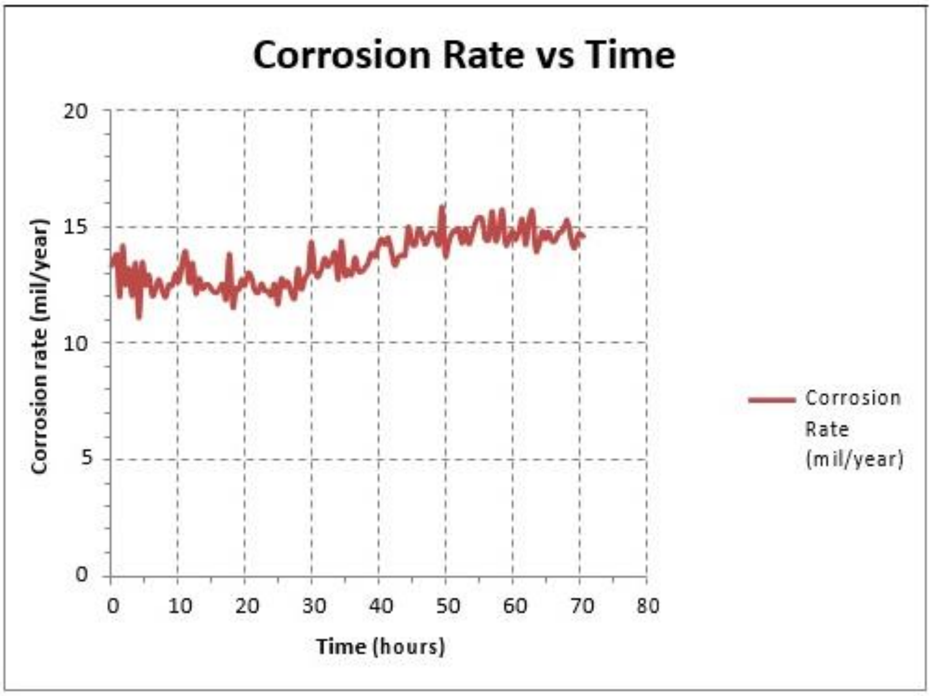


Figure 26: Corrosion Rate versus Time at temperature 121°C (perlite)

Based on **Figure 26**, the trend for the corrosion observed was in the range between 13 to 15 mil/year. Thus, the average value of corrosion rate observed at 121°C was about 13.5 mil/year.

4.2.2 Linear Polarization Resistance (Rock wool Insulation)

4.2.2.1 Temperature of 65°C

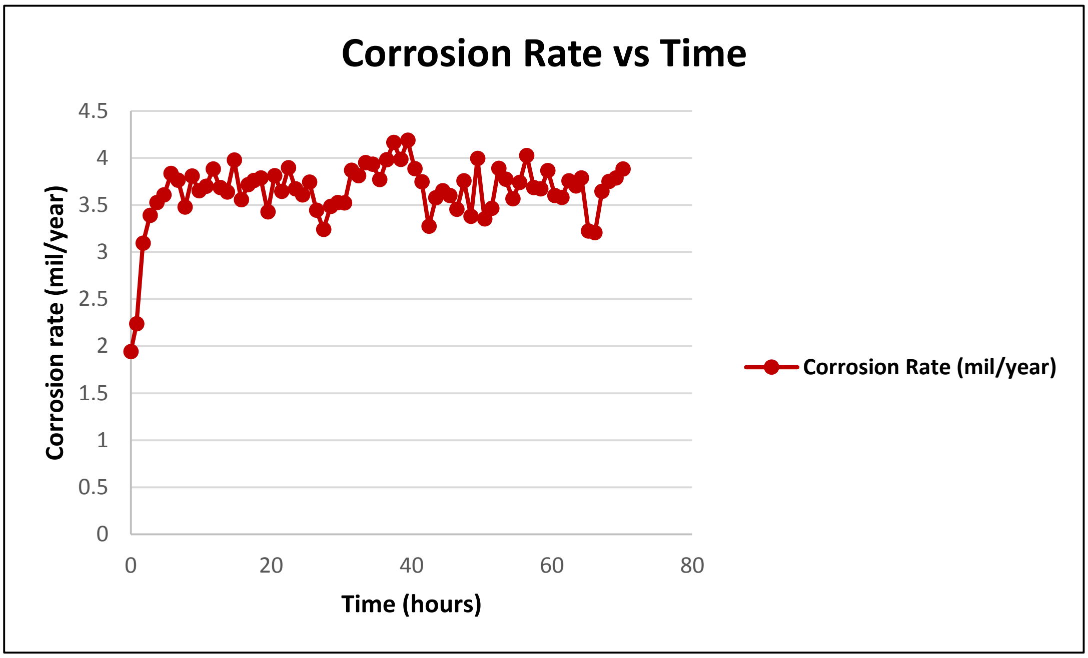


Figure 27: Corrosion Rate versus Time at Temperature of 65°C (rock wool)

Based on **Figure 27**, the corrosion rate observed for the first hour up until fifth hours was from the range of 2 mil/year until 3.9 mil/year. The corrosion rate then decrease and gave consistent reading on the range of 3.5 mil/year up until 4 mil/year. The highest reading of corrosion rate obtained was 4.3 mil/year. Hence, the corrosion rate obtained from potential dynamic polarization resistance test is 3.7 mil/year.

4.2.2.2 Temperature of 90°C

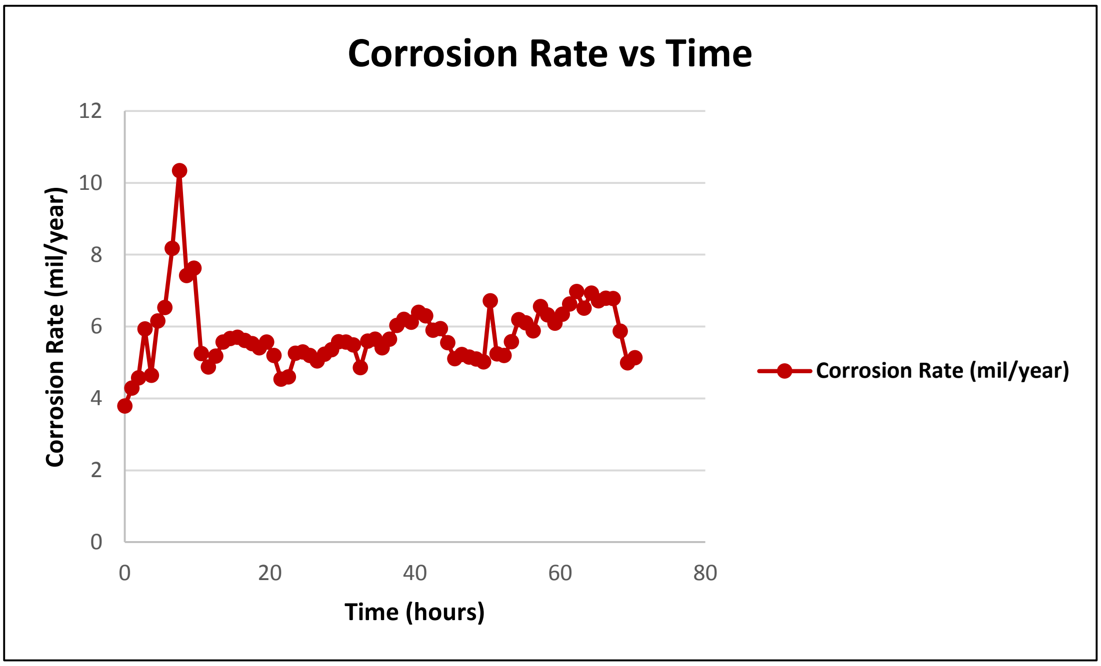


Figure 28: Corrosion Rate versus Time at Temperature of 90°C (rock wool)

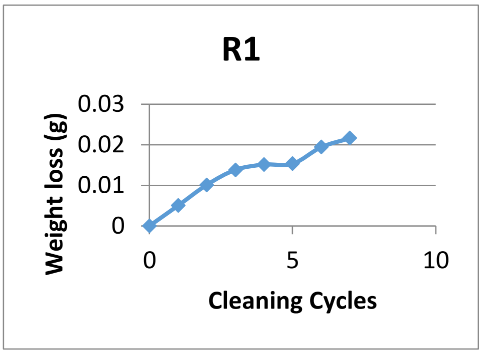
Based on **Figure 28**, the corrosion rate observed for the first hour was 3.8 mil/year. Then, the data showed the highest reading at seventh hour, which was 10.3 mil/year. The corrosion rate then decrease until 4.9 mil/year, at 11th hour, and gave consistent readings on the range of 5.0 mil/year up until 7.0 mil/year. Hence, the average corrosion rate obtained from potential dynamic polarization resistance test is 5.9 mil/year.

4.3 Mass Loss Result

4.3.1 Perlite 65°C

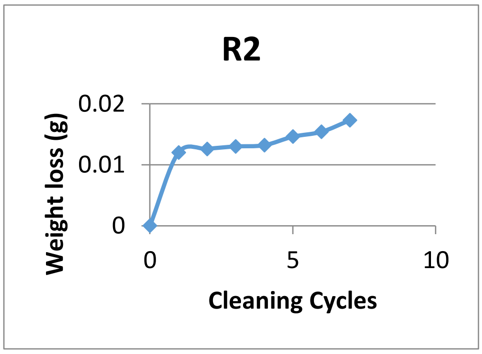
Ring 1

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	23.5681	-	0
1	23.5681	23.5631	0.0050
2	23.5681	23.5580	0.0101
3	23.5681	23.5543	0.0138
4	23.5681	23.5530	0.0151
5	23.5681	23.5528	0.0153
6	23.5681	23.5487	0.0194
7	23.5681	23.5465	0.0216
		In milligram	21.6



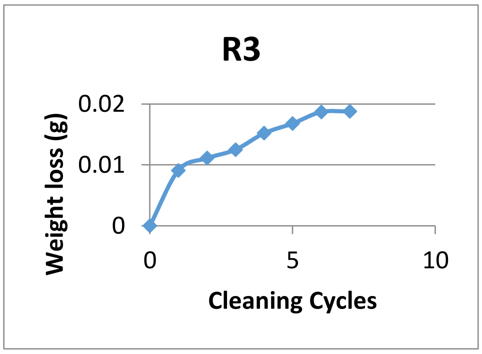
Ring 2

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	23.6768	-	0
1	23.6768	23.6648	0.0120
2	23.6768	23.6642	0.0126
3	23.6768	23.6638	0.0130
4	23.6768	23.6636	0.0132
5	23.6768	23.6622	0.0146
6	23.6768	23.6614	0.0154
7	23.6768	23.6595	0.0173
		In milligram	17.3



Ring 3

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	23.4678	-	0
1	23.4678	23.4587	0.0091
2	23.4678	23.4567	0.0111
3	23.4678	23.4553	0.0125
4	23.4678	23.4526	0.0152
5	23.4678	23.4510	0.0168
6	23.4678	23.4491	0.0187
7	23.4678	23.4490	0.0188
		In milligram	18.8



Corrosion Rate (CR) = $Corrosion\,rate\,mm/y = \frac{mass\ loss\ x\ 87.6}{(area)(time)(metal\ density)}$

Average weight loss (mg) = 19.23 mg

$$= \frac{19.23x87.6}{(9.58)x(72)x(7.86)} = 0.3107\,\frac{mm}{year}$$

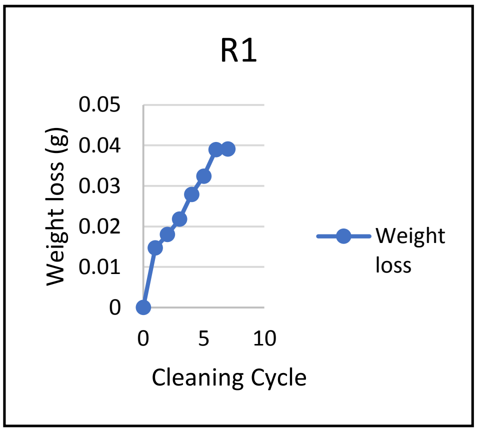
$$Corrosion\ Rate\ (CR) \ = \ {}^{0.3107}/_{0.025}$$

$$= \mathbf{12.428}\ \boldsymbol{mil/year}$$

4.3.2 Perlite 121°C

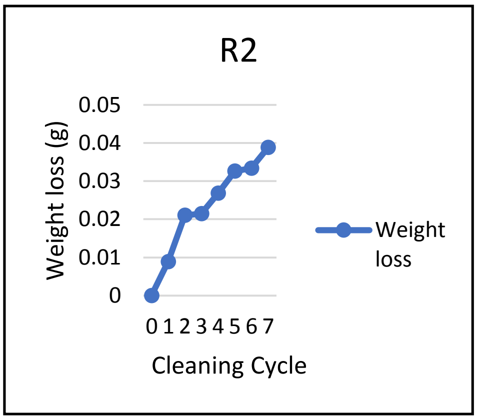
Ring 1

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	23.4560	-	0
1	23.4560	23.4413	0.0147
2	23.4560	23.4380	0.0180
3	23.4560	23.4342	0.0218
4	23.4560	23.4281	0.0279
5	23.4560	23.4236	0.0324
6	23.4560	23.4171	0.0389
7	23.4560	23.4169	0.0391
		In milligram	39.1



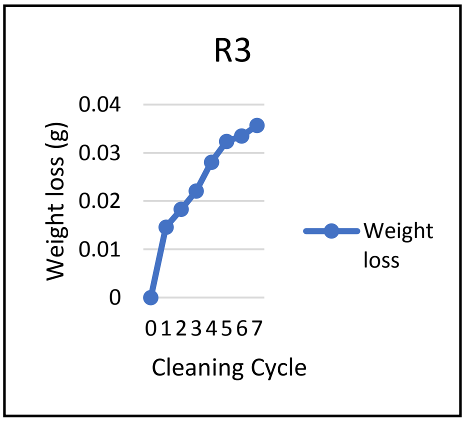
Ring 2

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	23.7224	-	0
1	23.7224	23.7135	0.0089
2	23.7224	23.7014	0.0210
3	23.7224	23.7009	0.0215
4	23.7224	23.6956	0.0268
5	23.7224	23.6898	0.0326
6	23.7224	23.6890	0.0334
7	23.7224	23.6836	0.0388
		In milligram	38.8



Ring 3

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	23.5028	-	0
1	23.5028	23.4882	0.0146
2	23.5028	23.4845	0.0183
3	23.5028	23.4807	0.0221
4	23.5028	23.4747	0.0281
5	23.5028	23.4704	0.0324
6	23.5028	23.4693	0.0335
7	23.5028	23.4671	0.0357
		In milligram	35.7



Corrosion Rate (CR) = $$Corrosion\ rate\ mm/y = \frac{mass\ loss\ x\ 87.6}{(area)(time)(metal\ density)}$$

Average weight loss (mg) = 37.867 mg

$$= \frac{37.867x87.6}{(9.58)x(72)x(7.86)} = 0.6118\,\frac{mm}{year}$$

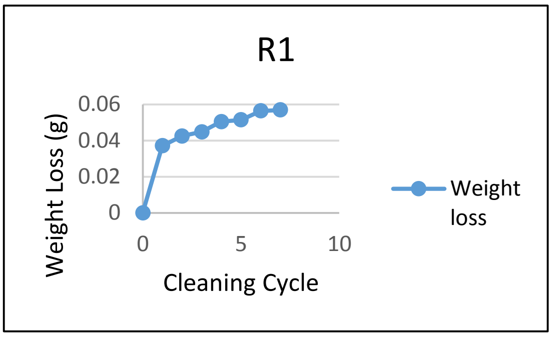
$$Corrosion\ Rate\ (CR) \ = \ {}^{0.6118}/_{0.025}$$

$$= \mathbf{24.474}\ \boldsymbol{mil/year}$$

4.3.3 Rock wool 65°C

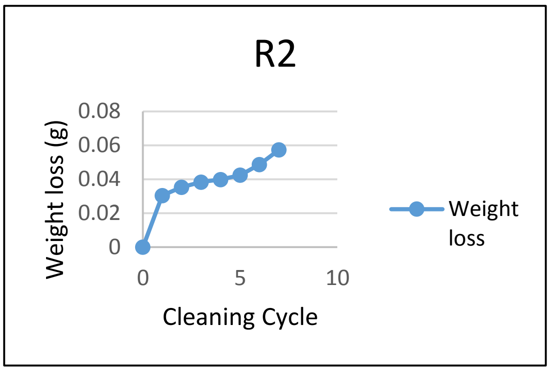
Ring 1

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	19.4894	-	0
1	19.4894	19.4523	0.0371
2	19.4894	19.4469	0.0425
3	19.4894	19.4446	0.0448
4	19.4894	19.4390	0.0504
5	19.4894	19.4380	0.0514
6	19.4894	19.4330	0.0564
7	19.4894	19.4325	0.0569
		In milligram	56.9



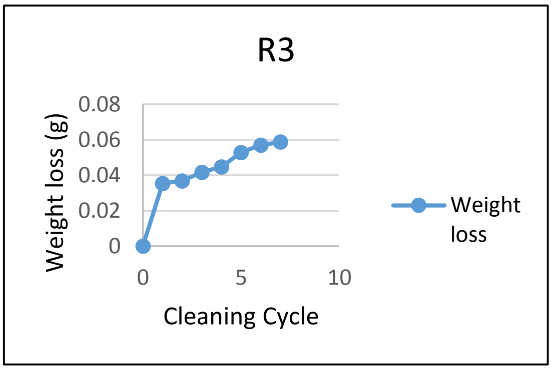
Ring 2

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	19.2433	-	0
1	19.2433	19.2130	0.0303
2	19.2433	19.2081	0.0352
3	19.2433	19.2050	0.0383
4	19.2433	19.2035	0.0398
5	19.2433	19.2010	0.0423
6	19.2433	19.1947	0.0486
7	19.2433	19.1860	0.0573
		In milligram	57.3



Ring 3

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	19.4471	-	0
1	19.4471	19.4117	0.0354
2	19.4471	19.4102	0.0369
3	19.4471	19.4054	0.0417
4	19.4471	19.4023	0.0448
5	19.4471	19.3942	0.0529
6	19.4471	19.3901	0.0570
7	19.4471	19.3884	0.0587
		In milligram	58.7



Corrosion Rate (CR) = $Corrosion\,rate\,mm/y = \frac{mass\,loss\,x\,87.6}{(area)(time)(metal\,density)}$

Average weight loss (mg) = 57.633 mg

$$= \frac{57.633x87.6}{(9.58)x(72)x(7.86)} = 0.9312\,\frac{mm}{year}$$

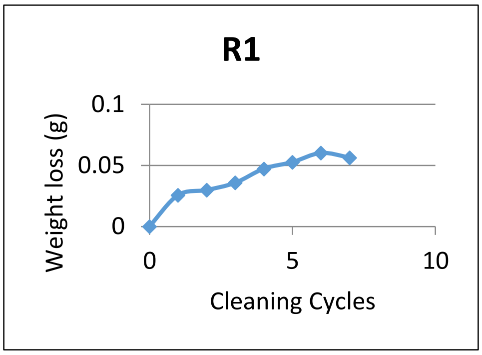
$$Corrosion\ Rate\ (CR)\ = {}^{0.9312}/_{0.025}$$

$$= \mathbf{37.248}\ \boldsymbol{mil/year}$$

4.3.4 Rock wool 90°C

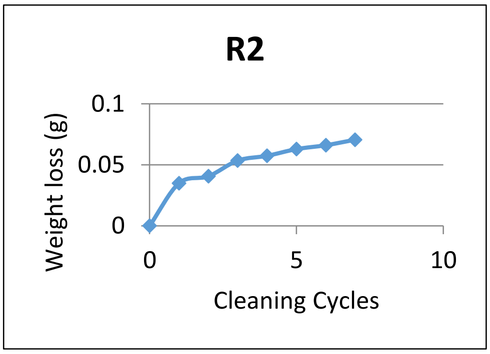
Ring 1

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	22.1063	-	0
1	22.1063	22.0807	0.0256
2	22.1063	22.0765	0.0298
3	22.1063	22.0706	0.0357
4	22.1063	22.0591	0.0472
5	22.1063	22.0537	0.0526
6	22.1063	22.0462	0.0601
7	22.1063	22.0499	0.0564
		In milligram	56.4



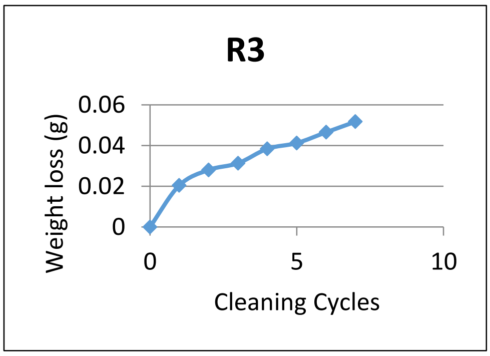
Ring 2

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	22.1427	-	0
1	22.1427	22.1078	0.0349
2	22.1427	22.1021	0.0406
3	22.1427	22.0892	0.0535
4	22.1427	22.0853	0.0574
5	22.1427	22.0798	0.0629
6	22.1427	22.0766	0.0661
7	22.1427	22.0721	0.0706
		In milligram	70.6



Ring 3

Cleaning Cycle	Initial Weight	Weight after cleaning	Weight loss
0	21.2602	-	0
1	21.2602	21.2397	0.0205
2	21.2602	21.2321	0.0281
3	21.2602	21.2288	0.0314
4	21.2602	21.2217	0.0385
5	21.2602	21.2189	0.0413
6	21.2602	21.2136	0.0466
7	21.2602	21.2084	0.0518
		In milligram	51.8



Corrosion Rate (CR) = $Corrosion\,rate\; mm/y = \frac{mass\; loss\; x\; 87.6}{(area)(time)(metal\; density)}$

Average weight loss (mg) = 59.6 mg

$$= \frac{59.6x87.6}{(9.58)x(72)x(7.86)} = 0.9630\,\frac{mm}{year}$$

$$Corrosion\ Rate\ (CR) = {}^{0.9630}/_{0.025}$$

$$= \mathbf{38.520}\ \boldsymbol{mil/year}$$

4.4 Impact of Temperature on Corrosion Rate

Based on the result obtained from the linear polarization resistance experiment, it were found that at higher operating temperature (121°C) for perlite insulation, the corrosion rate obtained was higher which is 13.5mpy compared to 10mpy corrosion rate at lower operating temperature (65°C).Other than that, reading obtained from rock wool insulation have been changed as the operating temperature to get 121°C setting temperature had failed. This problem happened due to the unforeseen circumstances of equipment, as the immersion heater did not function well and failed to reach the setting temperature of 121°C. Therefore, the data stated that at temperature of (90°C), corrosion rate obtained was in the average of 5.9 mil/year, compared to the corrosion rate of 3.7 mil/year for (65°C).

The result obtained from the experimental work done is corresponding with several references. [8, 10, and 12] Several references [1, 12, 13] states that CUI occurs at temperature in the range of -4°C to 175°C. API Recommended Practice 571 states that at metal temperature between the boiling point (100°C) and 121°C where water is less likely to vaporize and insulation stays wet longer, the corrosion becomes more severe. [9]

The corrosion rate calculated based on the mass loss test data was observed to be much higher than the corrosion rate from polarization resistance test. The author can see it from the data of perlite insulation for 65°C whereby it showed 12.43 mil/year of corrosion rate happened, compared to the 24.47 mil/year of corrosion rate of 121°C operating temperature. On the other hand, 37.248 mil/year of corrosion rate obtained for 65°C of rock wool insulation, compared to 38.520 mil/year corrosion rate for 90°C of operating temperature for rock wool insulation. In comparison of the data of linear polarization method and mass loss test method, the author can say that mass lost test method gave the higher data then linear polarization method. The polarization resistance test data provide rather conservative corrosion rates which were lower than actual plan data available. [10] The corrosion rate calculated from mass loss data resembles the actual plant data. [10]

CHAPTER FIVE: CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Table 5: Result Matrix for the Experiment

	Perlite Insulation		Rock wool Insulation	
Operating Temperature	**65°C**	**121°C**	**65°C**	**90°C**
LPR Method	10 mil/year	13.5 mil/year	3.7 mil/year	5.9 mil/year
Mass Loss Test	12.43 mil/year	24.47 mil/year	37.25 mil/year	38.52 mil/year

In this study, the main objective is to analyse the effect of operating temperature on the corrosion rate. This study divided the experimental work into two phases, Phase I and Phase II in order to achieve the objective. Phase I involve simulation of CUI according to ASTM 189-07 standard. The result obtain from lab experiment were compared to the result from ASTM 189-07 standard to ensure and also discover the accuracy of the experiment setup. The objective for this phase was established as the setup for this experiment conducted was correct. Phase II involve in experimental work which is in accordance with ASTM 189-07, with some modification which are to conduct the experiment at different operating temperatures. For this phase, perlite and rock wool insulation have been compared, and the results for linear polarization resistance stated that rock wool insulation gave lower corrosion rate compared to perlite insulation. For mass loss test, the results have been slightly different as the main cause for this was experimental error. The value obtained from experimental was higher than value in API Recommended Practice 581[13] might be because of the solution used in the experiment to represent the environment was not the same on several conditions such as pH, chloride content, iron content, and other chemical species that may be present even though the environment condition is the same which is a severe environmental condition.

The corrosion rate calculated based on the mass loss test data were much higher than corrosion rate from polarization resistance test because polarization resistance test data provide rather conservative corrosion rates while the corrosion rate calculated from mass loss data resembles the actual plant data[10].

Therefore, by considering only from LPR data obtained, due to some unforeseen circumstances, the author can conclude that rock wool insulation gave lower corrosion rate compared with perlite insulation. This data is closely related only to the impact of operating temperature to corrosion rate for corrosion under insulation phenomena.

5.2 Recommendation

In order to improvise the results that obtain from experiments, there are several things that have been highlighted to improve performance, such as:

1. Done at more various operating temperature.

   Although this study will shows that at higher temperature (121°C), the corrosion rate was higher compared to lower temperature (65°C), other operating temperature should be used as variable to further prove that the theory is right. The operating temperature should be various such as at lower temperature or at much higher temperature.

2. Using other type of insulation.

   In this study, the only insulation used was perlite and rock wool insulator. For future recommendation, different type of insulator should be used. The result of the experiment with different type of insulator can be compared in order to find the suitable type of insulator for any range of temperature.

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11. *ASTM G102 − 89 (Reapproved 2010): Standard Practice for Calculation of Corrosion Rates and Related Information from Electrochemical Measurements*. ASTM International.

12. *ASTM G1: Standard Practice for Preparing, Cleaning, and Evaluation Corrosion Test Specimens*. ASTM International.

13. *NACE TM0169/ASTM G31 − 12a: Standard Guide for Laboratory Immersion Corrosion Testing of Metals*. NACE International and ASTM International.

14. *ASTM G189-07: Standard Guide for Laboratory Simulation of Corrosion Under Insulation*. 2007, ASTM International.

APPENDICES

Table 6: Gantt Chart for FYP 1

2015 CORROSION UNDER INSULATION (CUI) EXPERIMENT															
No	**Description**	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	FYP Title Selection														
2	Project Introduction														
2.1	Literature Review														
2.2	Methodology														
2.3	Preliminary Research Work and Preparing Proposal														
3	Submission of Extended Proposal														
4	Confirmation on tool specifications														
5	Development of study on results for specimen														
6	Interim Report Preparation														
6.1	Project Introduction														
6.2	Literature Review														
6.3	Methodology														
7	Submission of Interim Draft Report														
8	Submission of Final Interim Report														
9	Preparation for experiment														

Progress		Milestone	

Table 7: Gantt Chart for FYP 2

2015 CORROSION UNDER INSULATION (CUI) EXPERIMENT															
No	**Description**	**Week**													
		1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**
1	Execution Phase														
2	Result and Analysis														
3	Progress Report Preparation														
3.1	Project Introduction														
3.2	Literature Review														
3.3	Methodology														
4	Submission of Progress Report														
3	Pre-SEDEX														
4	Submission of Draft Final Report														
5	Submission of Dissertation														
6	Submission of Technical Paper														
7	Viva														
8	Submission of Project Dissertation														

Progress		Milestone	