EVALUATION OF EFFECT OF OPERATING TEMPERATURE TO CORROSION UNDER INSULATION (CUI)

By

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13705

Dissertation submitted in partial fulfillment of
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CERTIFICATION OF APPROVAL

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(MECHANICAL)

Approved by,

………………………….
(Dr. Masdi Bin Muhammad)

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TRONOH, PERAK

May 2014

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 HAFIZ BIN ISMAIL)

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ABSTRACT

Corrosion under insulation (CUI) is a major common problem shared by all of the refining, power, industrial, petrochemical, onshore and offshore industries on a worldwide scale. CUI is a form of localized external corrosion that occurs in carbon manganese, low alloy, and austenitic stainless steel piping and vessels that occurs underneath externally clad /jacketed insulation due to the penetration of water[1]. 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. 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. The ring specimens were used to test electrodes in two separate electrochemical cells. Corrosion measurements were made using both electrochemical polarization resistances and mass loss data under isothermal test conditions. The corrosion rate at higher operating temperature (121°C) was found to be higher compared to corrosion rate at lower operating temperature (65°C).

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CHAPTER 1 : INTRODUCTION

1.1 Background

Corrosion under insulation (CUI) is one of the main problems 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 observed between the metal surface and the insulation on that surface as a result of water penetration. The sources of the water may come from rain water, leakage, deluge system water, wash water, or sweating from temperature cycling or low temperature operation[3].

Since the corrosion is hidden under the insulation, CUI is difficult to detect until the insulation is removed for inspection. To avoid CUI, it is very important to 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 fiber Doppler sensors which already have the explosion-proof characteristics[5].

1.2 Problem Statement

Corrosion under insulation (CUI) is typically difficult to identify because it lies hidden under insulation material until it becomes a serious problem especially in petrochemical plants that have been operating for a long time. This failure can be catastrophic in nature and can cause adverse economic effect in terms of downtime and repairs cost. Thus, it is best to prevent such catastrophic disaster from occurring.

That is why this study is very important because by studying the relationship between operating temperature and the corrosion rate, the corrosion rate due to CUI can be predicted and precautions can be made before the occurrence of CUI in pipeline which is very dangerous.

1.3 Objective and scope of study

The objective of this project is to establish the relationship between operating temperature and the corrosion rate.

The main activity to be conducted to achieve the objective of the study is:

- To analyze the effect of operating temperature on the corrosion rate based on ASTM G189-07.

The scopes of study for this project are based on the objective. The scopes of study are:

- To perform experimental work to gain corrosion rate based on ASTM G189-07
- To analyze the result and establish the relationship between operating temperature and the corrosion rate

CHAPTER 2 : LITERATURE REVIEW

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, intergranular corrosion, dealloying, erosion, microbial corrosion and etc. Early detection of corrosion is very crucial in order to maintain the condition of a component or system at desired level. With early detection, precaution measures can be applied before catastrophic damage occurs.

2.2 Corrosion under Insulation

Corrosion under insulation (CUI) is a serious issue faced by industry when moisture penetrates through the insulation due to ineffective barrier system. The moisture will accumulate between the material and insulation, resulting in deteriorates that leads to corrosion damages.

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

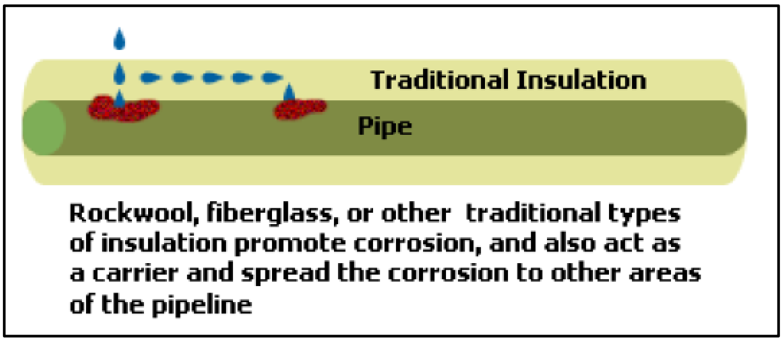

***FIGURE 2-1**: Corrosion under Insulation.[7]*

2.3 Mechanism of Corrosion under Insulation

Several conditions must fulfill in order for corrosion to occur. The initiation of corrosion of steel or other materials under insulation is due to the presence of water, oxygen and other corrodants. The presence of water and oxygen on the metal surface will cause electrochemical reaction that consists of an oxidation (via metal dissolution) and reduction reaction (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 2-2**. The reaction occurs are as follows[6]:

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

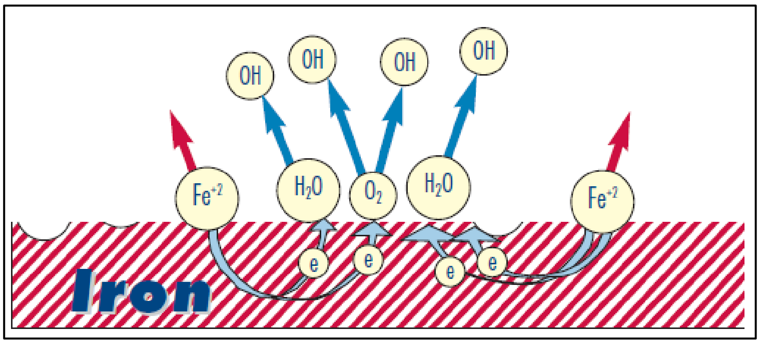

***FIGURE 2-2**: Corrosion Mechanism.[8]*

Ferric salt will form due to unstable in oxygenated solution. Hence, rust will be the final product:

$$4Fe(OH)_2 + O_2 \rightarrow 2Fe_2O_3 + 4H_2O$$

Oxygen and water are converted into hydroxide ions where the electrons in environments with water or moisture present. 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[9].

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 equipment, oxygen is needed while for chloride stress corrosion cracking (SCC) of 300 series stainless steel, chloride ions presence is needed[3]. Corrosion can also occur at the presence other corrodants such as acids, acid gases, strong bases and salts.

2.4.1 Moisture

Moisture can come from many sources where rainwater is the most common source of moisture to cause CUI. Next source of moisture is water vapor 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.

2.4.2 Operating temperature

One of the causes of corrosion under insulation (CUI) is operating temperature. Abavarathna et al.[10] 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.

The effect of operating temperature on corrosion of steel in water is shown in **Figure 2-3**. In an open system, the concentration of oxygen in water decreases with increasing temperature, thus decreasing the corrosion rate. In contrast, the corrosion rate in a closed system increasing with increasing temperature.

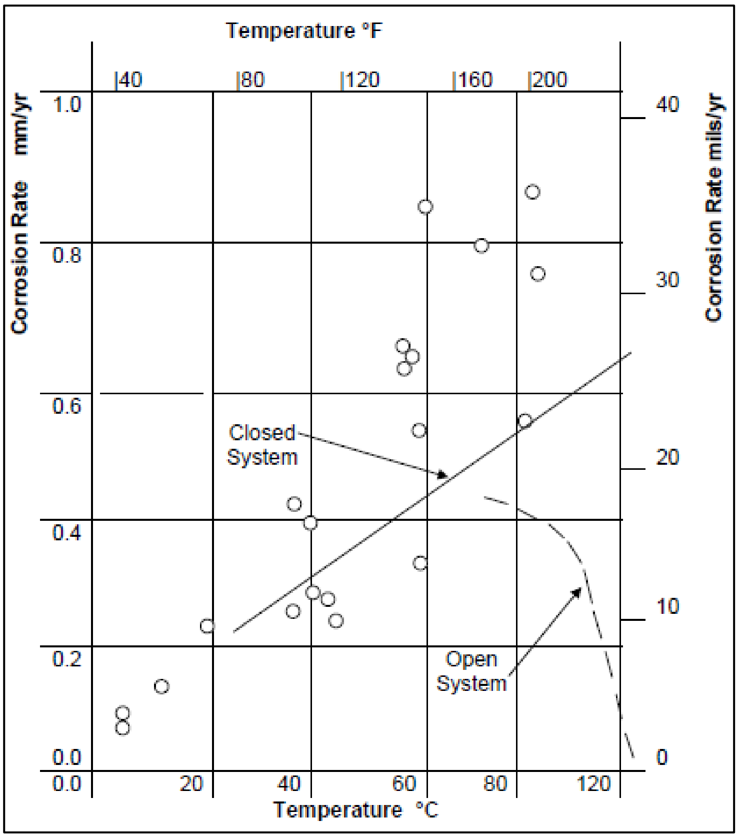

FIGURE 2-3*: Comparison of Actual Plant CUI Corrosion Rates Measurements (Open Data Points Shown is for Plant CUI) with Laboratory Corrosion Data Obtained in Open and Closed Systems[10, 11].*

For operating temperature above 150°C, most moisture that penetrate the insulation system will evaporates before it can get in contact with the metal surface to start the corrosion. For operating temperature below 0°C, the water that able to penetrate the insulation system will freeze and forms 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 the 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.

***TABLE 2-1**: Likely Risk of CUI For Carbon Steel Pipework, Without Trace Heating, Under Various Operating Regimes.[12]*

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

TABLE 2-2*: Corrosion Rate(mpy) for Calculation of the Damage Factor.*[13]

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 2-3*: Corrosion Rate (mm/y) for Calculation of the Damage Factor*[13].

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.

2.4.3 Oxygen (carbon steel piping) and chloride ions (SCC)

Oxygen is abundant and readily available in environment. Environments that provide airborne contaminants such as marine environments and cooling tower drift for chloride and stack emission for sulfur dioxide, SO_2, can accelerate corrosion. Chloride ions can also be found in a wide variety 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.

2.5 Prevention or Mitigation of Corrosion under Insulation

Mitigation is best achieved by using appropriate paints or coatings and maintaining the insulation or vapor 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 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. [9]

Besides, an inspection for corrosion under insulation should be structured and systematic approach should be done starting with prediction or analysis before looking for more invasive procedures. The inspection plan should consider several factors such as type and condition of coating used as well as the insulation materials. Operating temperature should also be considered as a factor contributing for the inspection plan. Although it is not usually possible to change the operating temperature, but the consideration should be given to remove the insulation on equipment where heat conservation is not as important. Additional prioritization can be added based several factors before inspection plan is made. Those factors are the physical inspection of the equipment, looking for evidence of insulation, mastic and/or sealant damage, signs of water penetration and rust in gravity drain areas around the equipment.

Multiple inspection technique can be utilized to produce the most cost effective approach, including:

i. Partial and/or full stripping of insulation for visual examination.
ii. Ultrasonic testing for thickness verification.
iii. Real-time profile x-ray (for small bore piping).
iv. Neutron backscatter techniques for identifying wet insulation.
v. Deep penetrating eddy-current inspection (can be automated with a robotic crawler).
vi. Infrared thermography looking for wet insulation and/or damaged and missing insulation under the jacket.
vii. Guided Wave Ultrasonic Testing.

CHAPTER 3 : METHODOLOGY

3.1 Research Methodology Flow Chart

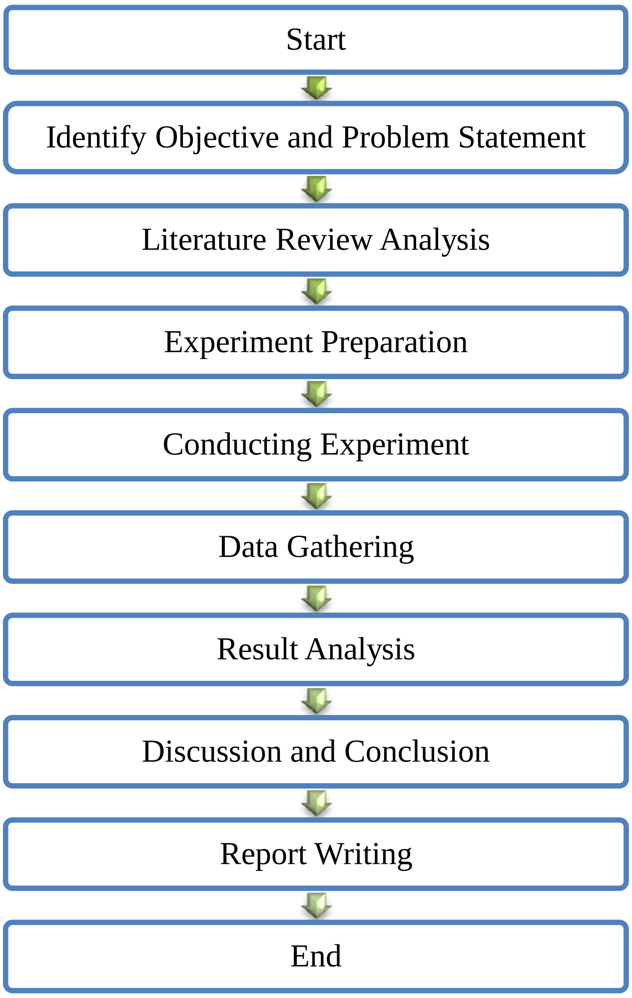

***FIGURE 3-1**: Research Methodology Flow Chart.*

3.2 Experimental Methodology Flow Chart

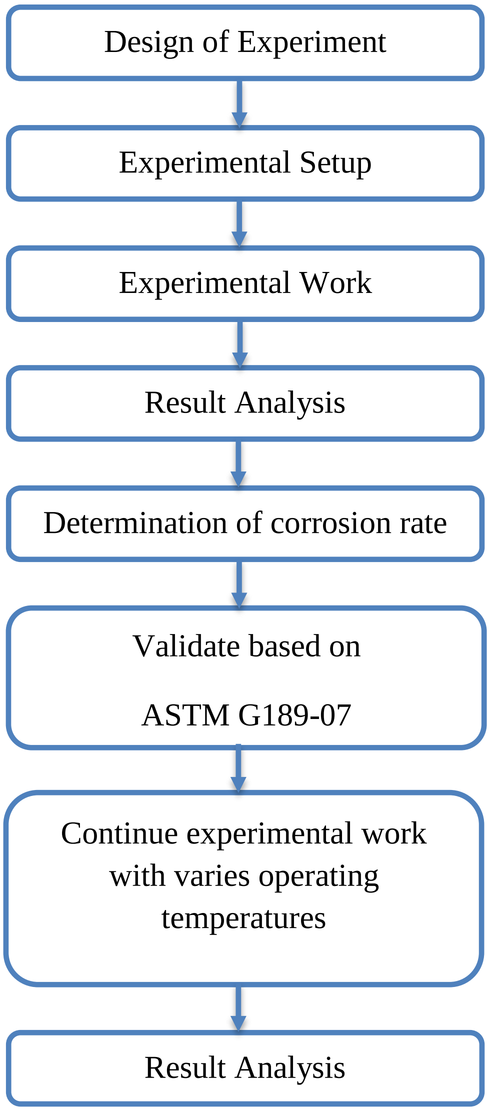

FIGURE 3-2*: Experimental Methodology Flow Chart.*

3.3 Experimental Work

For this study, the experimental work will be divided into two phase; phase I and phase II.

3.3.1 Phase I

In Phase I, the experimental work done was 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 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 24°C.

3.3.2 Phase II

In phase II, the experimental work done was CUI simulation based on the ASTM G189-07 standard with a few modifications were made. The modifications made were by using different 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, the type of insulation which is perlite was tested 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.

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

3.4 Experimental Apparatus

1. Carbon Steel Piping
   - Made in accordance with Specification A106/A106M, Grade B[14]
   - Nominal diameter pipe: 2 inch
   - Pipe thickness: 0.187 inch (4.75 mm)
2. Blind Flange Sections
   - Each end included a bolted flange pair consist of weld neck, threaded or lap joint flange and a blind flange and attached pipe section.
3. Ring Specimens
   - Made in accordance with Specification A106/A106M, Grade B[14]
   - Nominal diameter: 2 inch
   - Thickness: 0.187 inch (4.75 mm)
   - Width: 0.25 inch (6.35 mm)
   - Outer surface polished to a 600 grit finish
4. Nonconductive Spacer
   - Made from temperature resistant, non-conductive material (teflon).
   - Outer diameter: 2.5 inch (6.35 mm)
5. Internal Heater
   - Power: 400W
   - Nominal diameter: 0.625 inch (1.6 cm)
6. Heat Transfer Oil
   - Silicone Oil (Stable at the maximum intended temperature)
7. Temperature Controller
   - Able to control temperature to ±1°C

8. Potentiostat
   - In accordance to ASTM Practices G59[15] and G102[16]
   - Can determine at least ±20mV of Open Circuit Potential (OCP)
9. Micrometer Pump
   - Range of pumping rate from 0.5 to 1.5mL/min
10. Tubing in
    - Diameter: 0.125 inch (3.2 mm)
    - Made from corrosion resistant material
    - Connected to valves with on/off regulation on the outlets of the cell
11. Solution Reservoir
    - Made from High Density Polyethylene (HDPE) or glass
12. Solution (To represent environment)
    - 100 ppm of NaCl dissolve in reagent water with addition of H_2SO_4 to pH 6 (±0.1 pH unit) at 24°C[17]
    - 5 Liter of stock solution is made by adding 0.5 g of NaCl to 5 Liter of reagent water followed by addition of a small quantity of 1 M solution of H_2SO_4 in water using a dropper to attain the required pH
    - Represent an atmospheric condensate with impurities of chlorides and acids found in industrial and coastal environment[11]
13. Insulation
    - Water resistant molded perlite with low concentration of chloride (35-40 ppm)[18]

3.5 Experimental Procedure

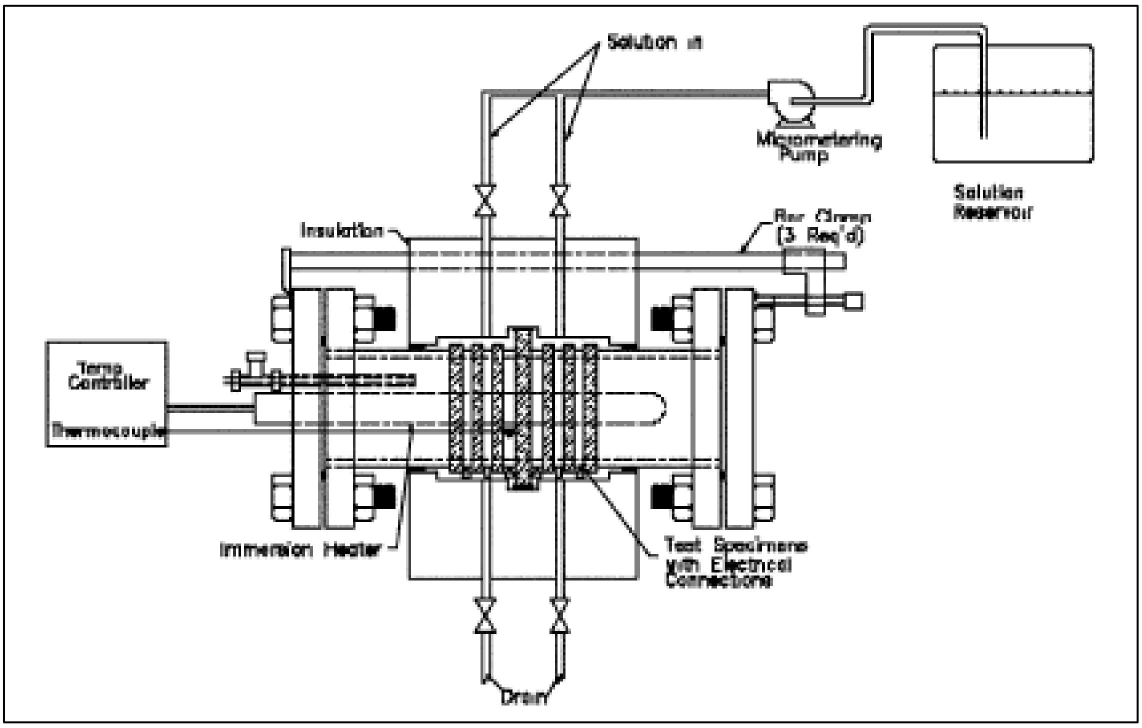

***FIGURE 3-3**: Schematic of CUI-Cell Experimental Setup.[11]*

__TABLE 3-1__: Specification for CUI Simulation phase I and Phase II

Specification	**Phase 1**	**Phase 2**
Environment	ASTM G189-07	ASTM G189-07
Piping Material	Carbon Steel Grade A106B	Carbon Steel Grade A106B
Piping diameter	2 inch	2 inch
Piping thickness	0.187inch	0.187inch
Insulation type	Perlite	Perlite
Type of Cycle	Isothermal	Isothermal
Operating temperature	65^{0}C	Temp 1: 65^{0}C Temp 2: 121^{0}C
Duration	72 hours	72 hours
Corrosion Measurement	Mass Loss Data, Electrochemical Polarization Resistance	Mass Loss Data, Electrochemical Polarization Resistance

__FIGURE 3-4__: CUI-Cell Experimental Setup.

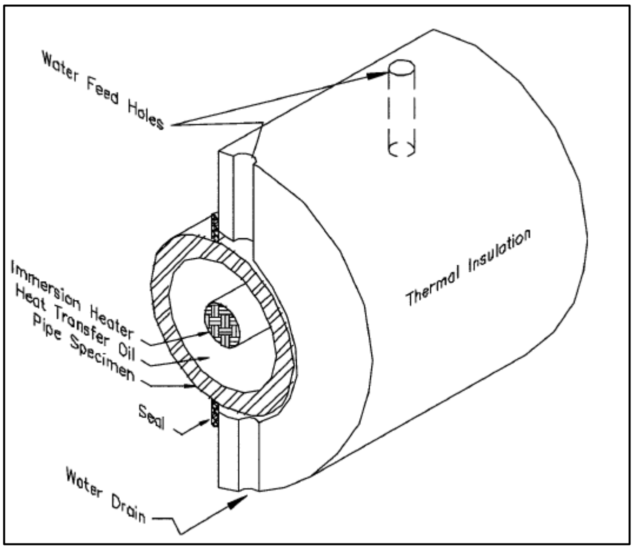

FIGURE 3-5: *Cross-section of CUI-Cell Showing Orientation of Thermal Insulation[11].*

1. The ring specimens is machined from the pipe material and prepared to the surface finish.
2. The CUI-Cell is assembled by placing alternate specimens and nonconductive spacers.

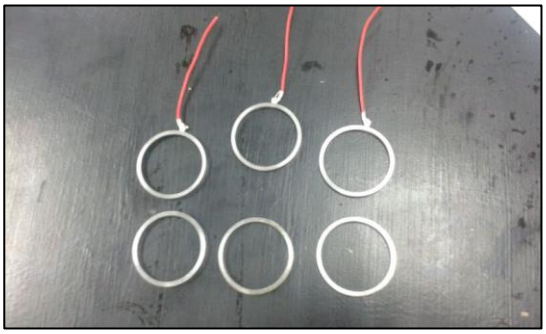

FIGURE 3-6*: Sample of Specimens.*

FIGURE 3-7*: Sample of Nonconductive Spacers*

3. The immersion heater, thermocouple and the extension tube to the oil reservoir is attached to the CUI-Cell. The internal volume of the CUI-Cell is filled with suitable heat transfer oil for the condition used, heated and checked for leaks.

FIGURE 3-8*: Immersion Heater.*

4. The thermal insulation is mounted in place and sealed to the central evaluation section of the CUI-Cell around its perimeter using silicone rubber or other inert sealing material compatible with the temperature and environment.
5. The valve on the outlet lines from CUI-Cell is closed and solution pumped into the annular space between the thermal insulation and the outer surfaces of the ring specimens through the two ports at the top using a micrometering pump.
6. Following addition of the solution, the apparatus is heated and the temperature stabilized at the initial temperature using the immersion heater and temperature controller.
7. The simulation is started when the initial temperature is stabilized which should not be longer than 1 hour after addition of the solution and the initiation of heating. The duration is completed when the cell is cooled to 38°C, which should not be longer than 2 hours after turning off the heater.
8. At the end of the exposure duration, the cell assembly is cooled to less than 38°C, drained and disassembled. The ring specimens is rinsed in distilled or deionized water to remove loose material and accumulated salts, and then dried with a non-chlorinated solvent.
9. The electrical contacts from the potentiostat to each of the two groups of the three ring specimens in the CUI-Cell.

10. The instantaneous corrosion rates of the two working electrodes should be obtained using the polarization resistance technique.
11. The corrosion rates for the cell are plotted versus time.

3.6 Polarization Resistance Test

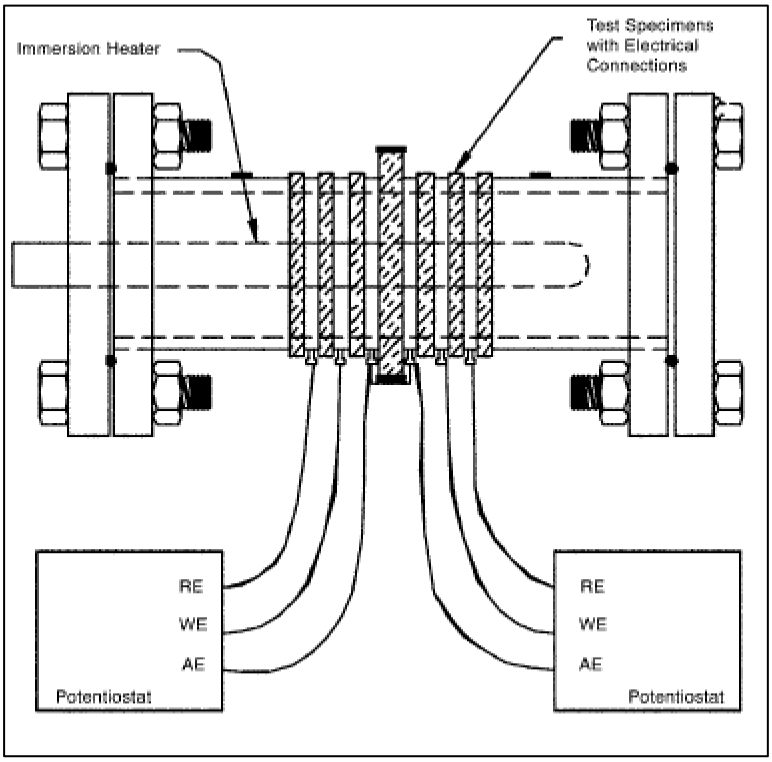

FIGURE 3-9*: Schematic of wiring of potentiostat to CUI-Cell Ring Specimens (Two Potentiostat Setup)[11].*

The potentiostat was used in accordance with ASTM Practices G59[15] and G102[16] 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 electrical contacts from the potentiostat to each of the two groups of three ring specimens in CUI-Cell were made as shown in **Figure 3-9**. The electrical connections to the specimens should be made outside of the wetted portion of the cell. The center ring specimen of each three specimen set in the CUI-Cell was used as the working electrode (WE) while the other two rings in each set of specimens was used as the auxiliary electrode (AE) and reference electrode (RE).

The instantaneous corrosion rates of the two working electrodes were obtained using the polarization resistance technique given in ASTM Practice G59[15]. The measurements were repeated at intervals of 30 minutes for the period of exposure.

3.7 Mass Loss Test

The ring specimens were 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 ($SnCl_2$), was prepared according to ASTM Practice G1[19]. The specimens were 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. The corrosion rate was calculated following the equation in ASTM Practice G31[20].

The difference in initial pre-exposure mass (M_i) and the post-exposure (after cleaning) mass (M_{f1}) for the ring specimens was calculated to obtain mass loss corrosion rate using the following equation from ASTM Practice G31[20]:

$$\text{Corrosion Rate} = (K \times M) / (A \times T \times D)$$

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).

3.8 Project Activity and Gantt chart

The Gantt chart for FYP of the project is in **Appendix 1**.

CHAPTER 4 : RESULT AND DISCUSSION

4.1 Phase I

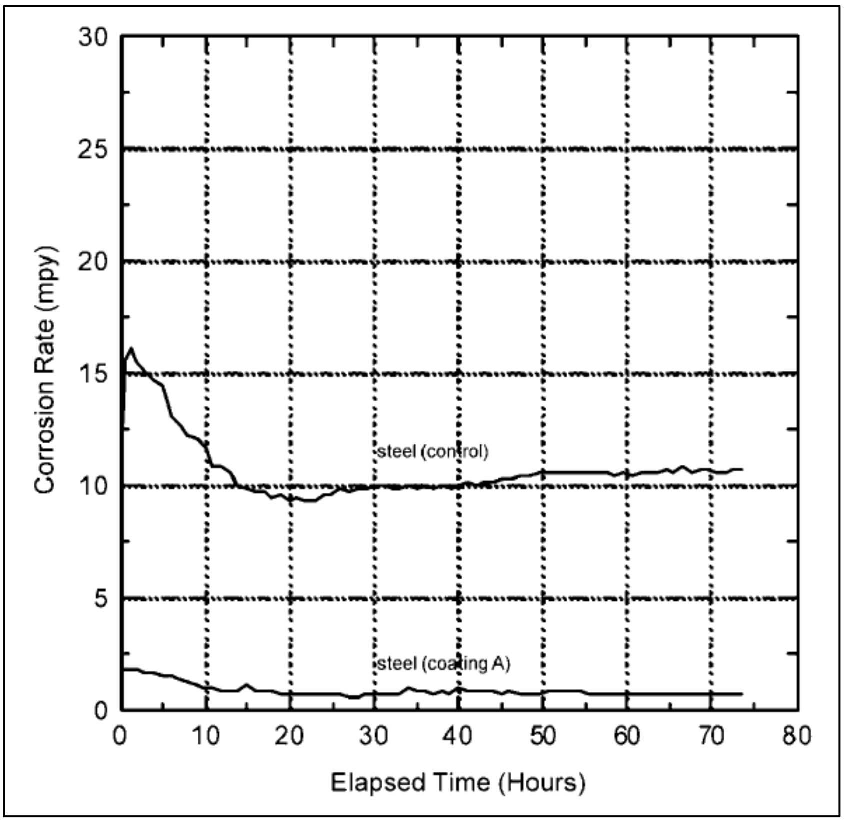

FIGURE 4-1*: Electrochemical Corrosion Rate Data versus Time for an Isothermal CUI Simulation at 65°C[11].*

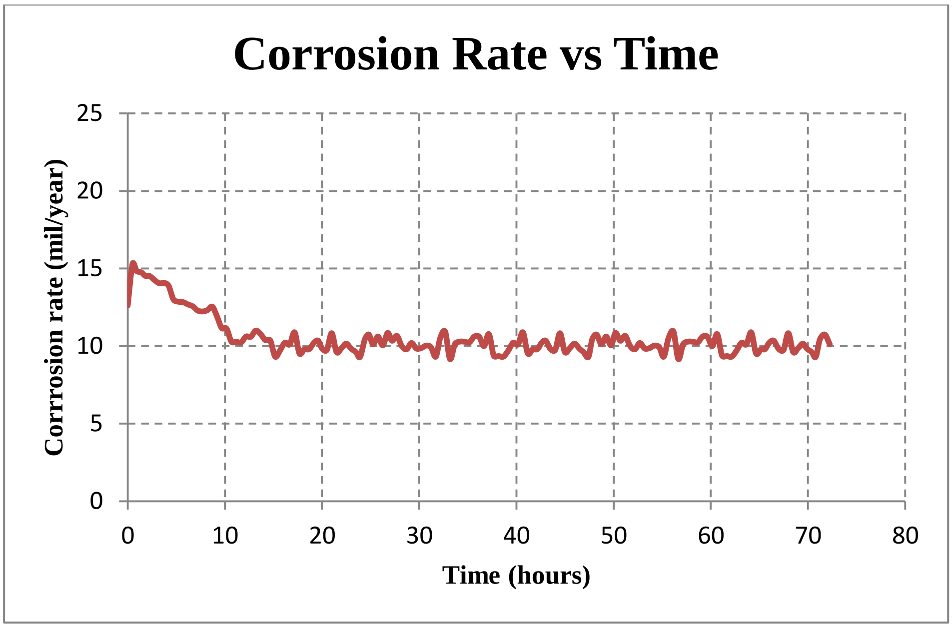

FIGURE 4-2: *Lab experimental result of Corrosion Rate versus Time at 65°C.*

Based on **Figure 4-2**, the result shows that at one (1) 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 in **Figure 4-1**, the trend of the graph obtained was similar to the graph in **Figure 4-1**. Thus, we 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 II

4.2.1 Polarization Resistance Test

4.2.1.1 Temperature at 65°C

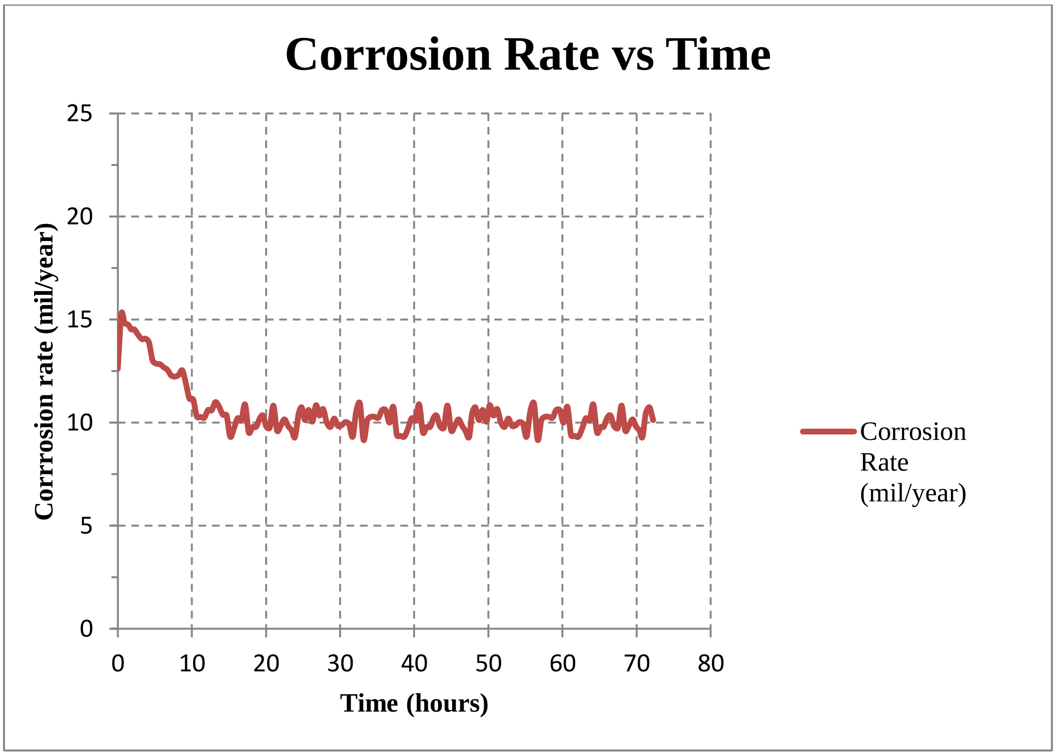

FIGURE 4-3*: Corrosion Rate versus Time at temperature 65°C.*

Based on **Figure 4-3**, the highest corrosion rate observed was at about the first hour which was about 15 mil/year mpy. The corrosion rate then decrease until about tenth hour and the corrosion rate is constant at range about 10 mpy. The corrosion rate obtained from potentiodynamic polarization resistance test is 10 mpy.

The same result was obtained by Abvarathna et al. in their experiment which was 10 mpy[10]. However, based on **Table 2-2** and **Table 2-3**, the corrosion rate based on the experiment environment which is a coastal and coastal environment is 18.57 mpy after interpolation used since the temperature used 65°C is the intermediate value[13].

The value obtained from experimental was lower than value in API Recommended Practice 581[13] might be due to 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.

4.2.1.2 Temperature at 121°C

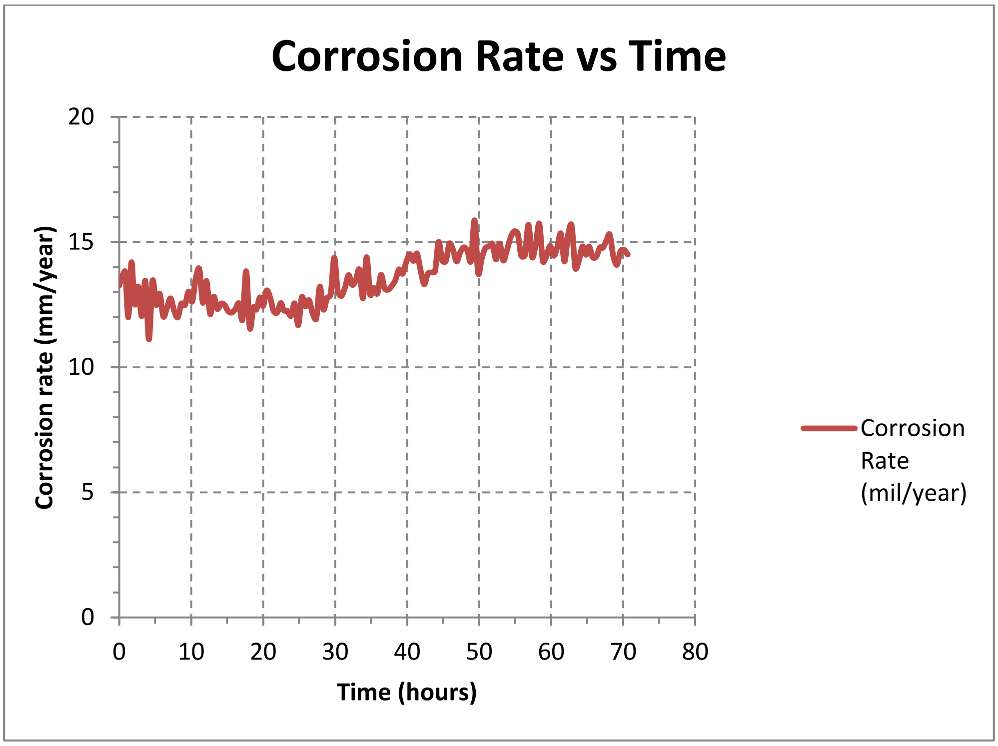

***FIGURE 4-4**: Corrosion Rate versus Time at temperature 121°C*

Based on **Figure 4-4**, the trend for the corrosion observed was in the range between 13 to 15 mpy. Thus, the average value of corrosion rate observed at 121°C was about 13.5 mpy.

Based on **Table 2-2** and **Table 2-3**, the corrosion rate based on the experiment environment which is a coastal and coastal environment is found to be 10mpy after interpolation used since the temperature used 121°C is the intermediate value[13].

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.

4.2.2 Mass Loss Test

The corrosion rate for mass loss test is done by using following equation:

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 (Average mass loss),

A = exposed area (9.5 cm^2),

T = time of exposure (72 h), and

D = density (7.86g/cm^3[19]).

The corrosion rate was calculated for both experiments at 65°C and 121°C as shown in **Table 4-1** and **Table 4-2** respectively.

***TABLE 4-1**: Table of Mass Loss Test at 65°C*

		Weight (grams)		
		Ring 1	**Ring 2**	**Ring 3**
Initial	**Mi**	23.6472	23.7837	23.3580
After Exposure	**Mf**	23.6797	23.8222	23.3935
Cleaning cycle	**1**	23.5897	23.7537	23.3042
	2	23.5481	23.7370	23.2814
	3	23.5167	23.7330	23.2423
	4	23.5028	23.7295	23.2395
	5	23.4933	23.7250	23.2382
	6	23.4792	23.7249	23.2280
	7	23.4787	23.7141	23.2277
Mass Difference		0.0325	0.0385	0.0355
Average Mass Loss		0.0355		
Corrosion Rate	**mm/year**	0.58	**mil/year**	22.95

***TABLE 4-2**: Table of Mass Loss Test at 121°C*

		Weight (grams)		
		Ring 1	**Ring 2**	**Ring 3**
Initial	**Mi**	23.4560	23.7226	23.5032
After Exposure	**Mf**	23.5636	23.8600	23.6105
Cleaning cycle	**1**	23.4413	23.6705	23.4915
	2	23.4378	23.6648	23.4855
	3	23.4343	23.6551	23.4782
	4	23.4280	23.6483	23.4728
	5	23.4236	23.6433	23.4682
	6	23.4212	23.6404	23.4653
	7	23.4173	23.6398	23.4623
Mass Difference		0.1076	0.1374	0.1073
Average Mass Loss		0.1174		
Corrosion Rate	**mm/year**	1.93	**mil/year**	75.90

4.3 Evaluation of Effect of Operating Temperature on Corrosion Rate

Based on the result obtained from the experiment, it was found that at higher operating temperature (121°C), the corrosion rate obtained was higher which is 13.5mpy compared to 10mpy corrosion rate at lower operating temperature (65°C). The result obtained from the experimental work done is corresponding with several references [9, 10, 12]. Several references[2, 12, 13] also 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 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 5 : CONCLUSION AND RECOMMENDATION

5.1 Conclusion

Corrosion under insulation (CUI) is a serious issue faced by industry especially petrochemical industry. CUI occurs when moisture penetrates through the insulation due to ineffective barrier system. The moisture will accumulate between the material and insulation, resulting in deteriorates that leads to corrosion damages. Problems such as major equipment outages and unexpected maintenance costs stemming from CUI, account for more unplanned downtime than all other problems[2].

In this study, the main objective is to analyze 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 the accuracy of the experiment setup. Phase II involve experimental work which is in accordance with ASTM 189-07 with modification done which is to conduct the experiment at different operating temperatures.

The result in Phase I showed the trend of corrosion rate graph obtained from the experiment was similarly compared to result in ASTM 189-07. Thus, the experimental setup and procedure done is valid for further experimentation. In Phase II, the corrosion rate at higher temperature (121°C) is higher compared to corrosion rate at lower temperature (65°C). Based on polarization resistance test done, the corrosion rate at 65°C and 121°C were 10 mpy and 13.5mpy respectively. The corrosion rate calculated based on mass loss test for 65°C and 121°C were 22.95mpy and 75.90 mpy respectively.

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].

5.2 Recommendation

Despite of what this study had achieved, there is a lot of improvement in order to produce better outcomes such as:

1. Done at more various operating temperature.
   Although this study showed that at higher temperature (121°C), the corrosion rate was higher compared to lower temperature (65°C), other operating temperature should be use 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 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.

CHAPTER 6 : REFERENCES

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CHAPTER 7 : APPENDIX

Appendix 1

FYP Gantt Chart