EVALUATION OF EFFECT OF INSULATION MATERIALS TO CORROSION RATE FOR CORROSION UNDER INSULATION (CUI)

By

MOHD AFIQ BIN MOHAMMAD SAIF

15304

Dissertation submitted in partial fulfillment of the

requirements for the

Bachelor of Engineering (Hons)

(Mechanical Engineering)

JANUARY 2015

Universiti Teknologi PETRONAS

Bandar Seri Iskandar

31750 Tronoh

Perak Darul Ridzuan

ABSTRACT

Corrosion under insulation (CUI) is external corrosion due to the collection of water in annulus space between the insulation and the metal surface. CUI cannot be eliminated, but it can be managed. A suitable insulation material is required in order to control the CUI. In this project, a study of the impact of insulation material to corrosion rates will be performed. The test will be conduct by using several types of material for the insulation to analyze the corrosion rates. The Objective of this project is to analyze the result and establish the relationship between insulation material and the corrosion rate base on the data obtained following the guideline in API 581. The test is based on recently published ASTM G189-07 Standard Guide for Laboratory Simulation of Corrosion under insulation. 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 mass loss data under isothermal test conditions. Several experiments been done to measure the corrosion rate at different material insulation which is Rockwool, Perlite, and Calcium Silicate. By using Rockwool insulation material, has the lowest corrosion rate compared with Perlite and Calcium Silicate insulation material.

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CHAPTER 1 INTRODUCTION

1.1 Background of Study

Corrosion under insulation (CUI) is external corrosion due to the collection of water in annulus space between the insulation and the metal surface. Plus, pipe insulation are one of the safety precaution for piping which can control any properties that related to the pipe such as energy transfer, sounds, leakage and etc.[1] CUIT is a major common problem on a worldwide basis that is shared by all the industrial that using pipe transportation. The corrosion process is well understood but yet CUI often goes undetected until the damage is significant.

CUI cost studies have shown that 40 to 60% of pipe maintenance costs are caused by CUI and approximately 10% of the total maintenance budget is spent repairing damage from CUI.

Corrosion rate is a test for measuring corrosion weight loss. The method involves exposing a clean weight piece of metal or alloy to the corrosive environment for a specified time followed by cleaning to remove corrosion products and weighing the piece to determine the loss of weight.
In this study, three materials have been choosing to test the impact material to corrosion rates.

1.2 Problem Statement

CUI is a localized external corrosion occurring in equipment made of insulated carbon and low-carbon steels. For this corrosion to occur water must collect in the insulation and oxygen must be present. It is most common in processing plants and refineries that operate at very high temperatures.

Corrosion rate is the speed at which any metal in a specific environment deteriorates. It also can be defined as the amount of corrosion loss per year in thickness. The speed or rate of deterioration depends on the environmental conditions and the type and condition of the metal under reference.

Insulation materials contribute to CUI in the following three ways[6]:

i. Providing an annular space which can collect water and other corrosive media.
ii. Leaching out contaminants that accelerate corrosion process, and
iii. Wicking and/or absorbing water and holding it against the substrate.

One of the main weapons for the designer of industrial insulation systems are understood element is the choice of insulation material. Historically, hot insulation products have been divided into categories of wetting and non-wetting, or "hydrophobic" materials. The distinction is important because, as pointed out in NACE Standard RP0198-98:

"*Because CUI is a product of wet metal exposure duration, the insulation system that holds the least amount of water and dries most quickly should result in the least amount of corrosion damage to equipment.*"

More recent European monograph states flatly:

"*Insulation that minimizes water ingress and does not retain water can effectively act as a barrier to CUI.*"[9]

In this study, several materials need to be test as insulation. Then, the corrosion rate for every material to be taken for analyzes and forecast.

1.3 Objective

The main objective of this study is to perform the impact of insulation material to corrosion rates for CUI test on three different materials. In order to achieve the objective, all of main scopes of activities are depending on ASTM G189-07 (standard Guide for Laboratory Simulation of CUI).

Furthermore, there are certain parts of scopes of studies that play an important task to achieve the objective. The scopes of studies are:

1. To execute experimental work to gain corrosion rate base on ASTM G189-07.
2. To analyze the result and establish the relationship between insulation material and the corrosion rate base on the data obtained.

1.4 Scope of Study

The following are the scope of study:

1. Fabricate six (6) pieces of ring specimen made from carbon steel pipe grade A106B by using milling machine plus fabricate screw hole using tapping screw driver.
2. Conduct the test based on ASTM G189-07: Standard Guide for Laboratory Simulation of Corrosion under Insulation, 2007, ASTM International.
3. The corrosion rate will determine by using weight loss method based on ASTM G1 Standard Practice for Preparing, Cleaning, and Evaluation Corrosion Test Specimens.

CHAPTER 2 LITERITURE REVIEW

2.1 Corrosion

Corrosion can be defined as degradation, deterioration or destruction of materials that occurs when it reacts with its environment. 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 etc..[6] Early detection of corrosion is very important in order to maintain the condition of a component or system from desired certain level. With early detection precaution measures can be useful so that huge damage can be preventing from occurs.

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

2.2 Corrosion under Insulation

The corrosion under insulation war has been fought for many years in the petrochemical industry. The corrosion process is well understood but yet CUI often goes undetected until the damage is significant. CUI cost studies have shown that 40 to 60% of pipe maintenance costs are caused by CUI and approximately 10% of the total maintenance budget is spent repairing damage from CUI.[2]

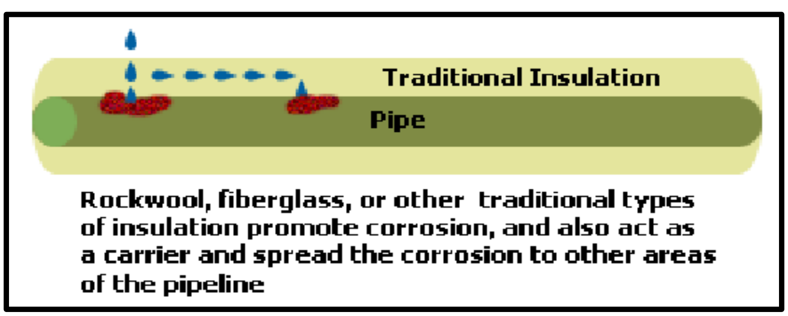

Figure 1: *Corrosion under Insulation*

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.

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 $(OH)_{2}$.[3] Subsequent reactions form a mix of magnetite (Fe_3O_4) and hematite (Fe_2O_4). This red-brown mixture of iron oxides is rust or known as corrosion.

2.3 Type of Insulation

The main purpose of insulating pipelines is to prevent heat passage from steam or hot-water pipes to the surrounding air or from the surrounding air to cold-water line. Hence, decrease probability one of the main factor to corrosion which is temperature.

Insulation materials categorized[5] into one of five major types:

1) Cellular
2) Fibrous
3) Flake
4) Granular, and
5) Reflective

.

I. *Cellular* insulations are composed of small individual cells either interconnecting or sealed from each other to form a cellular structure. Glass, plastics, and rubber may comprise the base material and a variety of foaming agents are used. Cellular insulations are often further classified as either open cell or closed cell. Generally, materials that have greater than 90% closed cell content are considered to be closed cell materials.

II. *Fibrous* insulations are composed of small diameter fibers that finely divide the air space. The fibers may be organic or inorganic and they are normally (but not always) held together by a binder. Typical inorganic fibers include glass, rock wool, slag wool, and alumina silica. Fibrous insulations are further classified as either wool or textile-based insulations. Textile-based insulations are composed of woven and non-woven fibers and yarns. The fibers and yarns may be organic or inorganic. These materials are sometimes supplied with coatings or as composites for specific properties, such as weather and chemical resistance, reflectivity, etc.

III. *Flake* insulations are composed of small particles or flakes which finely divide the air space. These flakes may or may not be bonded together. Vermiculite, or expanded mica, is flake insulation.

IV. *Granular* insulations are composed of small nodules that contain voids or hollow spaces. These materials are sometimes considered open cell materials since gases can be transferred between the individual spaces. Calcium silicate and molded perlite insulations are considered granular insulation.

V. *Reflective* Insulations and treatments are added to surfaces to lower the long-wave emittance thereby reducing the radiant heat transfer to or from the surface. Some reflective insulation systems consist of multiple parallel thin sheets or foil spaced to minimize convective heat transfer. Low emittance jackets and facings are often used in combination with other insulation materials.

Insulation materials or systems may also be categorized by service temperature range.

Table 1: *Insulation categories according to temperature range application.*

APPLICATION CATEGORY	TEMPERATURE RANGE ($^{O}F/^{O}C$)
Cryogenic	(-50 & below/ -45 & below)
Thermal: - Refrigeration, chill water and below ambient - Medium to high temperature	(-50 to +75 / -45 to +23) (+75 to +1200 / +23 to +650)
Refractory	($\geq$ +1200 / $\geq$ +650)

For the experiment base on that have been done by Research Officer (RO) Mr Masri Asmi Bin Mahed, there are 3 types of insulation been use for this experiment.

i. Rockwool
ii. Calcium Silicate
iii. Perlite

Both Calcium Silicate and Perlite insulation are Granular type of insulation which composed of small nodules which may contain voids or hollow spaces. While, Rockwool are Fibrous type of insulation. This composed of small diameter fibers which finely divide the air space. The fibers may be perpendicular or parallel to the surface being insulated, and they may or may not be bonded together.

2.3.1 Rockwool

Figure 2: *Rockwool Insulation*

Rockwool insulation products are made from stone wool – a blend of naturally occurring volcanic diabase rock. It's the special ingredient that ensures rockwool insulation protects against unwanted noise, fire, and provides unrivalled durability at no cost to the environment. Base on ASTM C547, Rockwool is mineral fiber preformed pipe insulation for up to 120°F (93°C).[19]. It is made comprised of steel slag (over 75%) with some basalt rock (25% or less). In some plants the recycled steel slag makes up almost 100% of the content. Blow-on application will seal wall cavities similarly to wet-blown cellulose offering superior insulating service compared to batts.

Weighs more than fiberglass (Rockwool is 1.2 pounds per square foot for R-30 versus 0.5 pounds for fiberglass). It is less likely to become airborne. Rockwool is the only insulation that will stop fire.

2.3.2 Perlite

Figure 3: *Perlite Insulation*

Perlite insulation is defined by ASTM as insulation composed principally of expanded perlite and silicate binders. It may also contain reinforcing fibers. Perlite Pipe and Block Insulations are covered by ASTM C 610. The standard covers the material for operating temperature between 80° to 1200°F.[18]Perlite pipe insulation is supplied as hollow cylinder shapes split into half or quarter sections or as curved segments.

Perlite is normally finished with a metal or fabric jacket for appearance and weather protection. The specified maximum thermal conductivity both block and pipe insulation is 0.48 Btu-in/ (h ft^2 °F) at a mean temperature of 100°F. The standard also contains requirements for flexural (bending) strength, compressive strength, and weight loss by tumbling, moisture content, linear shrinkage, water absorption after heat aging, surface-burning characteristics, and hot surface performance.

Typical applications include piping and equipment operating at temperatures above 250°F, tanks, vessels, heat exchangers, steam piping, valve and fitting insulation, boilers, vents and exhaust ducts. Perlite insulation is often used where water entering an insulation system may cause corrosion problems or process problems. Examples of this would be wash down areas, deluge testing, pipes that cycle in temperature, stainless steels that are susceptible to stress corrosion cracking.

2.3.3 Calcium Silicate

Figure 4: *Calcium Silicate Insulation*

Calcium Silicate thermal insulation is defined by ASTM as insulation composed principally of hydrous calcium silicate, and which usually contains reinforcing fibers. The standard contains three types classified primarily by maximum use temperature and density.

Table 2: *The standard limits the operating temperature between 80° to 1700°F.*[17]

Type	Maximum Use Temp (°F) and Density
I	Max Temp 1200°F, Max Density 15 pcf
IA	Max Temp 1200°F, Max Density 22 pcf
II	Max Use Temp 1700°F

Calcium Silicate pipe insulation is supplied as hollow cylinder shapes split in half lengthwise or as curved segments. Special shapes such as valve or fitting insulation can be fabricated from standard sections. Calcium Silicate is normally finished with a metal or fabric jacket for appearance and weather protection.

The specified maximum thermal conductivity for Type 1 is 0.41 Btu-in/ ($h \cdot ft^2 \cdot °F$) at a mean temperature of 100°F. The specified maximum thermal conductivity for Types 1A and Type 2 is 0.50 Btu-in/ ($h\ ft^2\ °F$) at a mean temperature of 100°F.

The standard also contains requirements for flexural (bending) strength, compressive strength, linear shrinkage, Surface-burning characteristics and maximum moisture content as shipped.

Typical applications include piping and equipment operating at temperatures above 250°F, tanks, vessels, heat exchangers, steam piping, valve and fitting insulation, boilers, vents and exhaust ducts.

2.4 Influence Factor to corrosion rate

Four elements need to be present for corrosion to occur and collectively referred to as the corrosion cell: an anode (+), a cathode (-), a metallic conductor and an electrolyte. Changing the potency of the electrolyte affects the rate of corrosion. Corrosion rates are determined by a variety of factors; however, seven influence factors do play an overwhelmingly important role in determining corrosion rates in CUI.[6]

- **Operating Temperature**: Corrosion reactions are electrochemical in nature and usually accelerated with increasing temperature. During operating in any piping system, corrosion proceeds faster in warmer environments than in cooler ones.

- **Coating**: Coating is the key barrier between the steel surface and its environment. Therefore, the condition of the coating is crucial. As coatings degrade generally as depends of age, the older the coating, the greater the probability of CUI.

- **Cladding and insulation condition**: Both cladding and insulation are supposedly the tools to improve endurance of piping to corrosion, any condition that will inhibit those tool function can lead to corrosion as it endurance no longer functional.

- **Insulation type**: From water absorbing ability point of view between Fiber-type insulation material and expended perlite plus foam of glass with a closed-cell structure. Fiber type of insulation such as mineral wool and fiberglass are easily absorb water which commonly used for hot insulation system while expended perlite and glass don’t absorb much as fiber type of insulation. Hence will also lead to CUI.

- **Available corrosion allowance**: This depends on the size of potential place corrosion to occur. CUI failure depends on the tolerance of the component to wall loss before it will fail not be determined by the wall thickness. Therefore the thicker the wall and more corrosion allowance will reduce possibility CUI to occur.

- **External coil and steam tracing**: the existence of steam tracing adds to lead to CUI since it may start leaking and provide a source of water for the corrosion process. It does depend on the material reaction to certain temperature that causes corrosion to occur.

- **External environment**: Water needs to penetrate the insulation material and interaction the metal substrate surface in order CUI to occur. Like water, oxygen increases the rate of corrosion. Corrosion can take place in an oxygen-deficient environment, but the rate of the corrosion reaction (destruction of the metal) is generally much slower.

In this test, insulation materials will be the main parameter on CUI that may contain materials and additives that can accelerate corrosion rate.

CHAPTER 3: METHODOLOGY

3.1 Project Activities

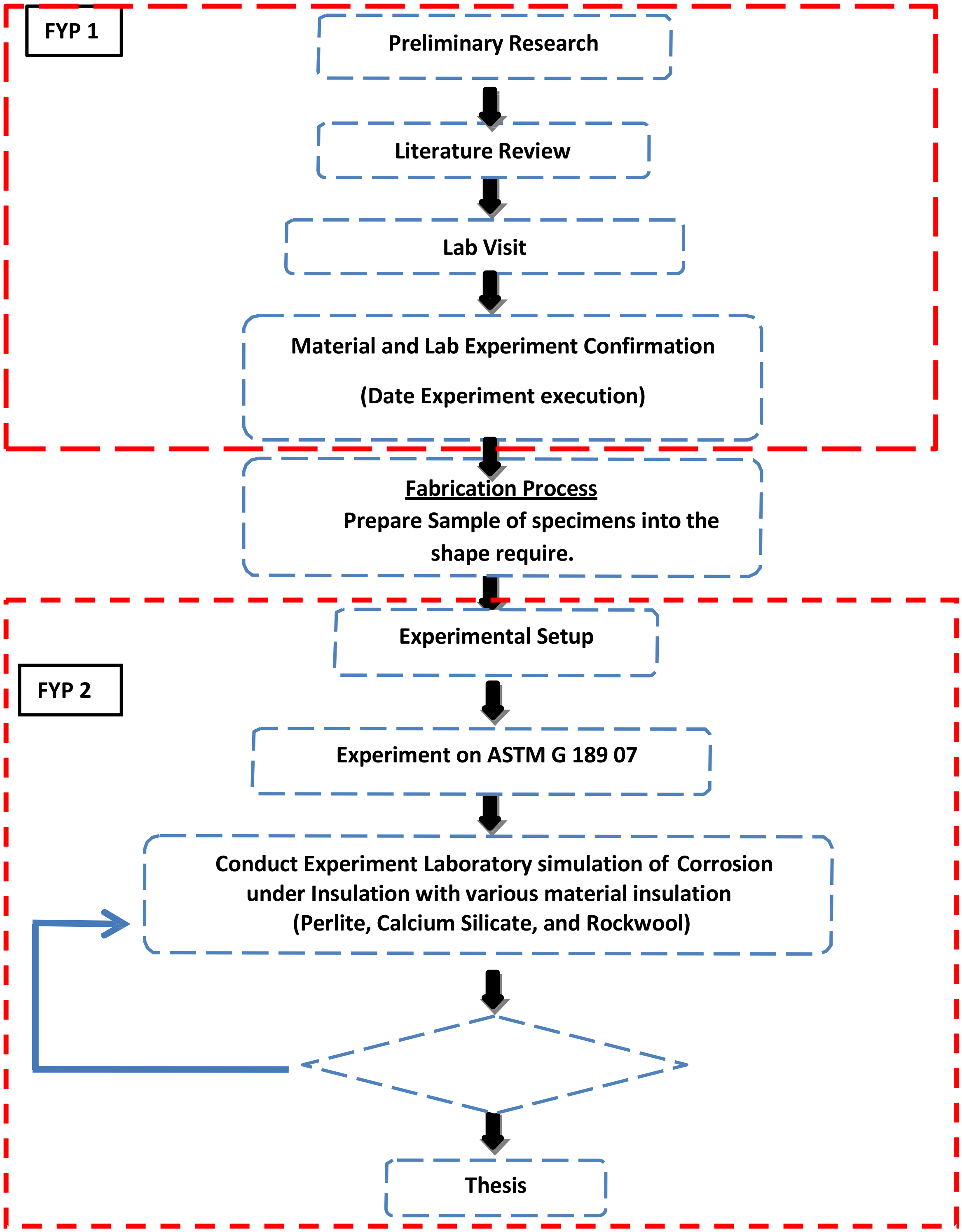

Figure 5: *Project work Flowcharts*

The project activities shown in Figure above are a brief overview of the work flow for this project. It started with defining problem and objective of the project before carry out with data gathering. Data gathering or preliminary research was done because it is important to understand the basic principles and background of the project. Lab visit has been conduct to familiarize the experiment with guide by R.O. Mr Masri Asmi Bin Mahed.

3.2 Experimental methodology Flowchart

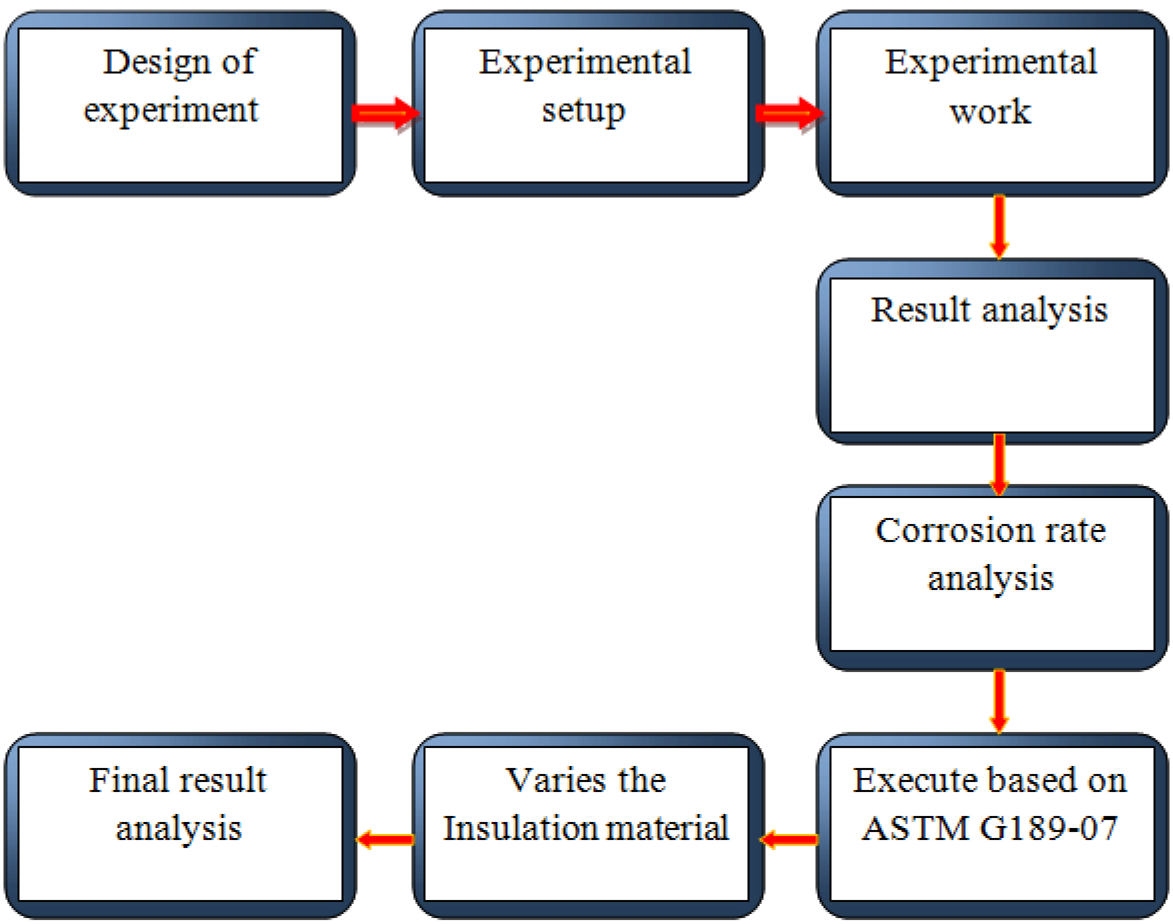

Figure 6: *Flowchart for Experimental Methodology*

3.3 Experimental work

The experiment work will be carried out by CUI recreation focused around the ASTM G189-07 standard. The result acquired from the reproduction is computed for the corrosion rate. The corrosion rate figured will be checked and compare with the ASTM G189-07 standard for approval.

Based on ASTM G189-07, particular test environment is needed to deliver a quickened contact environment. The solution utilized comprise of 100ppm Nacl dissolved in reagent water, acidified with expansion of H_2SO_4 to pH 6 (±0.1 pH unit) at 24^oC and the insulation type is Perlite for the first experiment.

In the next two experiments, there are few modifications been made from the guideline of standard ASTM G189-07. The modifications made by using different types of insulation material. This experimental work is done to check the effect of the material insulation on the corrosion rate.

The operating temperature is same with first experiment which is 65^oC, that will be test to study the effect on corrosion rate. However, the other two insulation materials to be test to study their effect on corrosion rate are Rockwool and Calcium Silicate. 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^oC. This solution 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 using mass loss techniques.

3.4 Experimental Apparatus

Table 3: *Experimental Apparatus*

No	Item	Detail
1	Carbon Steel Piping	Big Bore (OD 2in, thickness 0.187in) Grade A106/A 106M 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	Internal heater	400W, 0.625in nominal diameter heater, heat transfer oil of at least 100ml capacity (thermal conductive silicone oil)
5	Temperature Controller	can control temperature to $\pm 1^{O}C$
6	Potentiostat	Can determine at least ±20mV of OCP
7	Micrometering Pump	Pump rate from 0.5 to 5mL/min
8	Tubing for	0.125in made from corrosion resistant material + valves with on/off regulation
9	Solution Reservoir	Reservoir made from High density polyethylene (HDPE) or glass.
10	Solution: represent environment / Wether chamber	0.5g of NaCl + 5L of reagent water + 1M of H_2SO_4 to pH 6 (±0.1)
11	Insulation	Water resistant molded perlite with low concentration of chloride (35-40ppm) Mineral wool, calcium silicate (NACE paper 08036) Cellular Glass N31A, N34A, Calcium Silicate

3.5 Experiment Procedure

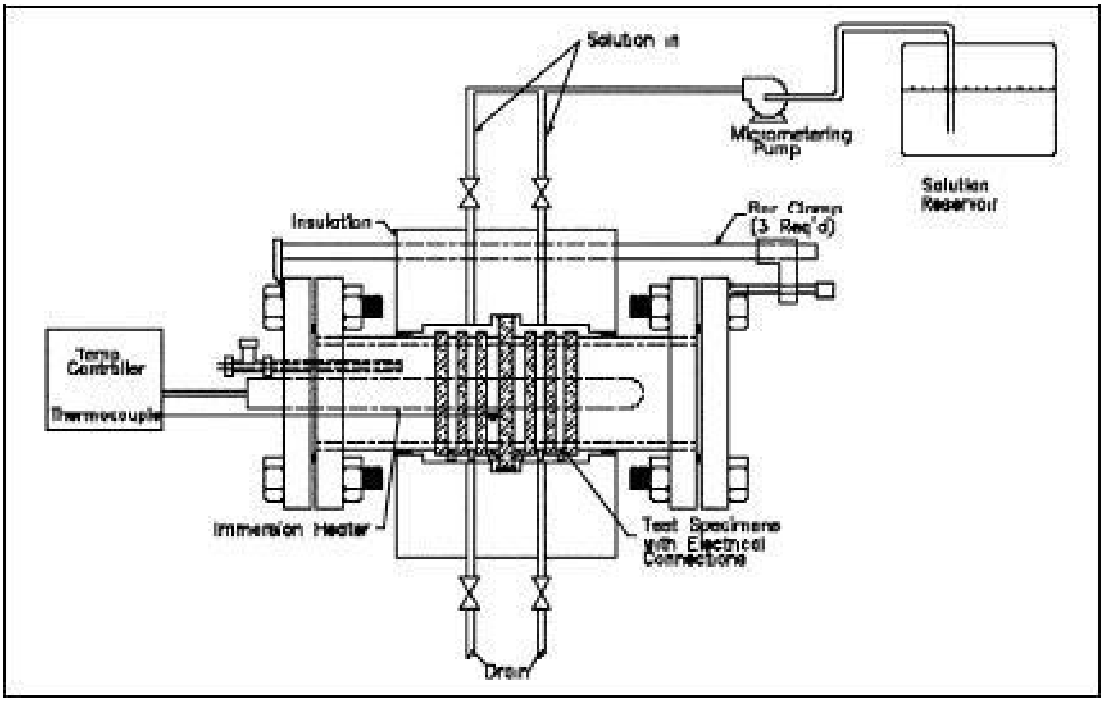

Figure 7: *Schematic of CUI-Cell Experimental Setup*

Table 4: *Specification for CUI Simulation*

Environment	ASTM G189-07	Piping Material	Carbon Steel Grade A106B
Piping diameter	2 inch	Corrosion Measurement	Mass Loss Data
Piping thickness	0.187inch		

Isothermal, Temperature @ 65°C, 72 Hours			
Specification	Experiment		
	1	2	3
Insulation material	Perlite	Calcium Silicate	Rockwool
Temperature Range (°C)	27 - 649	27 - 927	(-18) - 1035
Thickness (mm)	25.4 - 114.3	25 - 75	31 - 33
Thermal Conductivity	0.058 - 0.140	0.059 - 0.094	0.035 - 0.09
Price (US $)	150 - 200 / Cubic Meter	10 - 120 / Piece	0.2 - 5.5 / Square Meter

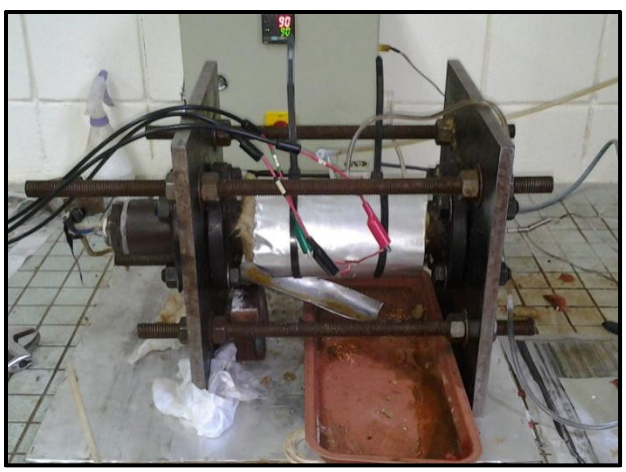

Figure 8: *CUI-Cell Experimental Setup.*

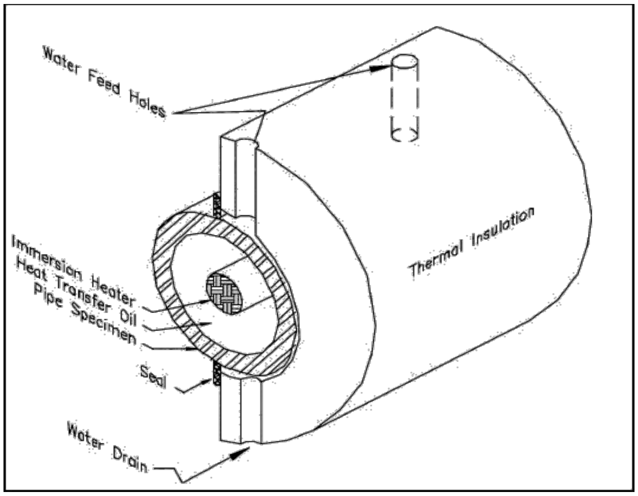

Figure 9: *Cross-section of CUI-Cell Showing Orientation of Thermal*

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 10: *Sample of Specimens*

Figure 11: *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.
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

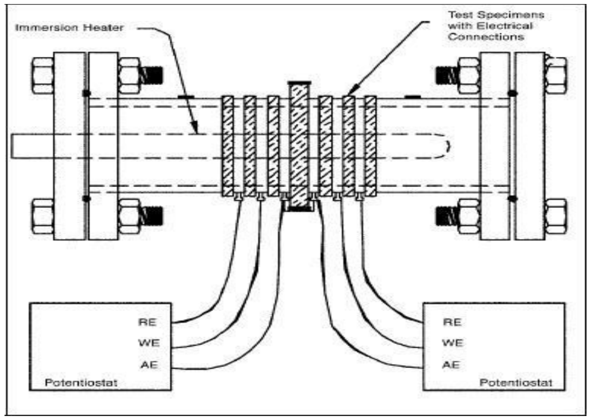

Figure 12: *Schematic of wiring of potentiostat to CUI-Cell Ring Specimens (Two Potentiostat Setup)*

The potentiostat was used in accordance with ASTM Practices G59 and G102 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 12**. 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. The measurements were repeated at intervals of 30 minutes for the period of exposure.

However due to the problem of accuracy, the result of this method will be neglected.

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, 20g 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:

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

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).

CHAPTER 4: RESULT AND DISCUSSION

4.1 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 (mmpy: 8.76×10^4),

nass loss),

A = exposed area ($9.58cm^2$),

T = time of exposure (72 h), and

D = density ($7.86g/cm^3$).

The corrosion rate was calculated for all three experiments by using Perlite, Calcium Silicate, and Rockwool insulation material as shown in **Table 5, Table 6** and **Table 7** respectively.

4.1.1 Experiment 1 – Perlite

Table 5*: Table of Mass Loss Test at 65°C for Perlite insulation Material*

		Weight (grams)		
		Ring 1	**Ring 2**	**Ring 3**
Initial	**Mi**	23.6474	23.7837	23.3580
After Exposure	**Mf**	23.8484	23.8918	23.5238
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(g)		0.2010	0.1081	0.1658
Average Mass Loss(mg)		158.3		
Corrosion Rate	**mm/year**	2.56	**mil/year**	102.4

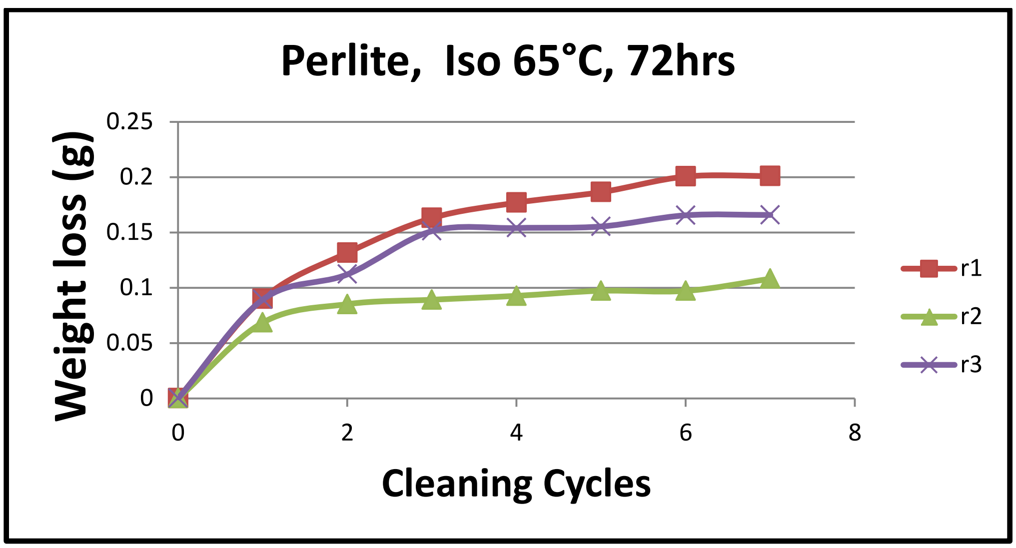

Figure 13: *Weight loss versus cleaning cycle, by using Perlite material insulation*

4.1.2 Experiment 2 - Calcium Silicate

Table 6: *Table of Mass Loss Test at 65°C for Calcium Silicate Insulation Material*

		Weight (grams)		
		Ring 1	Ring 2	Ring 3
Initial	Mi	22.3766	22.3941	22.3632
After Exposure	Mf	22.5370	22.5405	22.5127
Cleaning cycle	1	22.3253	22.3471	22.3189
	2	22.3057	22.3296	22.2988
	3	22.2897	22.3118	22.2829
	4	22.2722	22.2969	22.2681
	5	22.2558	22.2793	22.2495
	6	22.2329	22.2641	22.2346
	7	22.2181	22.2498	22.2174
Mass Difference(g)		0.1604	0.1464	0.1495
Average Mass Loss(mg)		152.1		
Corrosion Rate	mm/year	2.46	mil/year	98.4

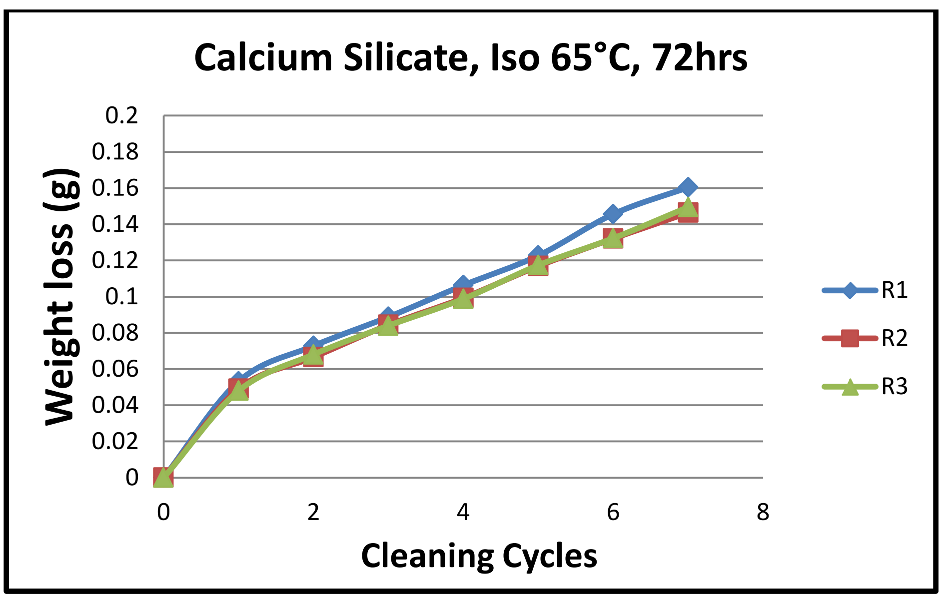

Figure 14: *Weight loss versus cleaning cycle, by using Calcium Silicate material insulation*

4.1.3 Experiment 3 – Rockwool

Table 7: *Table of Mass Loss Test at 65°C for Rockwool Insulation Material*

		Weight (grams)		
		Ring 1	**Ring 2**	**Ring 3**
Initial	**Mi**	19.4824	19.2433	19.4471
After Exposure	**Mf**	19.5323	19.2589	19.4501
Cleaning cycle	**1**	19.4523	19.1930	19.4117
	2	19.4469	19.1881	19.4102
	3	19.4446	19.1850	19.4054
	4	19.4390	19.1806	19.4023
	5	19.4380	19.1770	19.3942
	6	19.4330	19.1752	19.3901
	7	19.4325	19.1748	19.3884
Mass Difference		0.0499	0.0685	0.0587
Average Mass Loss		59.03		
Corrosion Rate	**mm/year**	0.086	**mil/year**	3.44

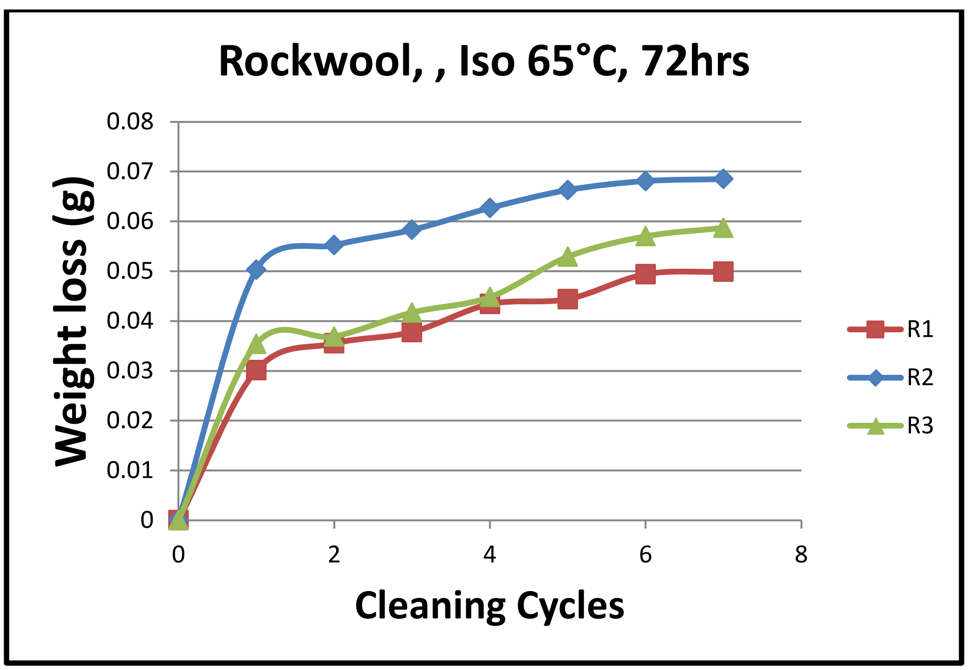

Figure 15: *Weight loss versus cleaning cycle, by using Rockwool material insulation*

4.2 Evaluation of Effect of Insulation Materials on Corrosion Rate

Based on the result obtained from the experiment, it was found the lowest corrosion rate obtained among three types of insulation are Rockwool which is 0.086mpy compared to Perlite and Calcium Silicate (2.56mpy and 2.46mpy respectively). However, based on the both result obtained by perlite and calcium silicate has proven data obtained from referencee[7,9] state that, CUI for carbon steel may occur between 1.5 to 3.0mm/yr. For this test, Rockwool proven to be a better pipe insulation material compared to perlite and calcium silicate. The significant cause Rockwool obtained the lowest corrosion rate is having a high water absorption compare to perlite and calcium silicate insulation material. Hence, the result obtained support the statement which are insulation materials contribute to CUI by absorbing water and holding it against the substrate.

The corrosion rate calculated based on the mass loss test data. The data obtained from polarization resistance test had to be neglected due to accuracy problem which the result obtained show significant different even though compared to standard procedure. However, the corrosion rate calculated from mass loss data resembles the actual plant data.

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 [7].

In this study, the main objective is to analyze the effect of insulation material on the corrosion rate. This study there has three experiments has been conduct based on simulation of CUI according to ASTM 189-07 standard. The experiment divided by three experimental works via varies the insulation material which is Perlite, Calcium Silicate, and Rockwool.

The result showed by using Rockwool insulation material has the lowest corrosion rate is 0.086mpy compared corrosion rate obtained by using Perlite and Calcium Silicate insulation material (2.56mpy and 2.46mpy respectively). The major cause Rockwool achieved the lowest corrosion rate is having a high water absorption compare to Perlite and Calcium Silicate.[9]

Even though experimental by using Rockwool material insulation has proven having lowest corrosion rate obtained, it doesn’t mean Rockwool are the better insulation material compare with Perlite and Calcium Silicate. Both Perlite and Calcium Silicate insulation obtained the high corrosion rate due to its characteristic that is water resistant hence it allow the numerous amount of corrodent solution flow into the pipe surface.

5.2 Recommendation

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

I. Investigate the insulation material compound.
   As concern, insulation that contains water leachable can influence the corrosion rate. The study are in assessing composition reaction of the material towards the condition corrosion study.

II. Varies the method in determining corrosion rate.
   Hence the LPR method error, others method in determining corrosion rate can be apply in this study such as Electrical Resistant measurement, Hydrogen Penetration Monitoring and etc.

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CHAPTER 7 APPENDIX

7.0 Project Gantt chart and Key Milestones

Final Year Project 1															
2014 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	Litreture Review														
2.2	Methodology														
2.3	Preliminary Research Work and Preparing proposal														
3	Submission of Extended Proposal														
4	Lab Visit														
5	Development of experiment strategy														
6	Interim report Preparation														
6.1	Project Introduction														
6.2	Litreture Review														
6.3	Methodology														
7	Submission of Interim Draft Report														
8	Submission of Final Interim Report														
9	Preparation for experiment														

Final Year Project 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														
1.1	Preparation for experiment														
1.2	Phase 1 Perlite														
1.3	Phase 2 Rockwool														
1.4	Phase 2 Calcium silicate														
2	Result and Analysis														
3	Pogress Report Preparation														
3.1	Project Introduction														
3.2	Litreture Review														
3.3	Methodology														
4	Submission of Pogress Report														
5	Pre-SEDEX														
6	Submission of Draft Final Report														
7	Submission of Dissertation														
8	Submission of Technical Paper														
9	Viva														
10	Submission of Project Disertation Report														

Pogress Milestones

Figure 16: *Gantt chart and Key Milestones of Final Year Project*