EVALUATION OF COATING PERFORMANCE FOR CORROSION UNDER INSULATION (CUI) PREVENTION

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CERTIFICATION OF APPROVAL

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Approved by,

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UNIVERSITI TEKNOLOGI PETRONAS
TRONOH, PERAK
September 2012

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 the original work contained herein have not been undertaken or done by unspecified sources or persons.

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WAN MUHAMMAD FARIS BIN WAN SOHAIMI

ABSTRACT

Corrosion under insulation (CUI) is one of the major problems that that can lead to unexpected downtime to industry. Main corrosion prevention of CUI is by coating applied to the required industrial standard. In reality, the coating quality varies which affects the coating performance under insulation. Hence, the performance of coating is dependent on the physical condition of coating. Thus, this project is carried out to evaluate the coating performance of different coating quality for CUI prevention. The objective of the project is to evaluate the performance of three samples of coating quality under simulated CUI condition. The first coating sample was the good coating sample as per standard, PTS.30.48.00.31. The second coating sample was non-conformance coating condition in terms of coating thickness, and the last sample was physically-damaged coating. The performance of the samples was evaluated using electrochemical impedance spectroscopy method. Based on the impedance distribution data from EIS testing the best coating performance was obtained by the good coating condition sample, followed by thinner off spec coating condition and physical damaged coating condition. The impedance of good coating and thickness off spec decreased slightly with immersion time. However the impedance of damage coating decreases significantly with immersion time. The experiment results concluded that proper coating application is very important to obtain long lasting and high quality coating. Damage on coating and thinner off specification of coating will affect the performance of coating in protecting the metal from corrosion especially in corrosion under insulation environment.

ACKNOWLEDGEMENT

In the Name of Allah, The Most Gracious and Merciful, praise to Allah, He is without doubt the Almighty. Eternal blessing and peace upon the Glory of the Universe, our beloved prophet Muhammad (S.A.W) and his family and companions. First and foremost, thanks to the Almighty for giving me the strength to carry out the Final Year Project for Mechanical Engineering course without casualties. A deep gratitude goes to author's supportive family that given him the motivation on completing this project throughout two semesters.

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The author would also like to extend his thanks to all other lecturers that show their cooperation to the project. Not to mention, my gratitude towards the course mates in providing ideas and guidance on helping the project solutions involving software simulation and design application. Finally, the author wish to thank to those who has directly or indirectly involve in this project, for their continuing supports and motivation during undertaking of this project.

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CHAPTER 1:
PROJECT BACKGROUND

1.1 Background of Study

Corrosion under insulation (CUI) is a corrosion that occurs on external of piping or vessels underneath the jacketed insulation [1]. CUI is one of the biggest problems in industry that can lead to unexpected downtime. The detection of CUI is expensive because its occurrence of corrosion is difficult to detect unless the insulation is removed.

The corrosion under insulation can happen by two means [2]: moisture trapped due to inconsistency peak temperature that will lead to condensation process underneath the insulation. The second reason due to rain water penetration through weak points in the cladding and reach onto the surface of pipe under the insulation. When the moisture or water gets trapped under the insulation and is not allowed escaping the surface of hot pipe or vessel, the electrochemical reactions will occur which mean accelerating the corrosion process. At this point the corrosion will begin and continue to worsen over time [2].

In order to prevent CUI, many methods are used in industry. The most common method is by coating. Good application of coating usually performs satisfactory throughout the life of the pipe. However, in reality the condition of the coating sometimes not in accordance to the specification. Thus, the performance of coating is dependent on the physical condition of coating.

1.2 Problem Statement

Coating is the main corrosion prevention method for insulated pipe. However, in reality the condition of the coating sometimes is not in accordance to the specification. Hence, the performance of coating is dependent on the physical condition of coating. Thus, this project is carried out to evaluate the coating performance of different coating condition for CUI prevention.

1.3 Objective and Scope of Study

The objective of the project is to evaluate performance of different coating quality under simulated CUI condition. The coating samples are as below:

i. Good coating sample as per standard, PTS.30.48.00.31.P;
ii. Non-conformance coating in terms of coating thickness; and
iii. Physically-damaged coating. (scratched)

1.4 Relevancy of Project

The project addresses a real industry problem affecting insulated piping and equipment. Knowledge domain of corrosion and materials falls under material specialization. The project uses modern technology such as EIS. Electrochemical Impedance Spectroscopy is an electrochemical technique which use AC current through the sample at different frequencies. The changing of frequency will generate impedance spectrum which provide the corrosion rate data of the coating samples.

1.5 Feasibility of Project

In this project, the author used EIS analysis to compare the corrosion rate of different coating condition sample. The analysis using EIS method require a lot of time to generate results. Each sample testing requires two or three weeks to evaluate its performance. Due to the limitation of time, the author has performed the EIS testing on three samples of coated pipe.

CHAPTER 2:
LITERATURE REVIEW

A study done by Exxon Mobil Chemical that was presented to the European Federation of Corrosion in September of 2003 indicated that the corrosion under insulation is the most significant factor of extension of holes in refineries and chemical inductions. The study also said that 40 to 60 percent of maintenance costs is related to the corrosion of pipelines because of corrosion under the insulation [2].

Corrosion under insulation occur in-between metal pipe and insulation. This type of corrosion is difficult to detect and can be very dangerous compared to other types of corrosion as the corrosion is occurred underneath the insulation. Detection of corrosion under insulation is very expensive and complicated.

Figure 2.1: Corrosion Under Insulation [1]

As stated in background of study, the corrosion under insulation can happen by two means [1]:

1. Moisture trapped due to inconsistency peak temperature that will lead to condensation process underneath the insulation. In closed systems, the increasing temperature can lead to electrochemical reactions which mean accelerating the corrosion process. The situation will be different in open systems as the increasing temperature will cause evaporation that will eliminate the corrosive environment.

2. The second reason which is most common causes of CUI problems is rain. The rain will cause water to penetrate within the weak points in the system and reach onto the surface of pipe under the insulation.

When water and oxygen are present in the metal surface, the metals or alloys will prefer to be in ionic state rather than remain in an elemental state. Corrosion occurs when the metal atoms give up electrons and enter an ionic state. Below are the two common iron oxidation reactions [3]:

$$Fe = Fe^{2+} + 2e^{-} \text{ and } Fe = Fe^{3+} + 3e^{-}$$

The site of oxidation reaction takes place is called as anode. The water that contains dissolved oxygen and the presence of the free electrons on steel surface will lead to reduction reaction:

$$O_2 + H_2O + 4e^{-} = 4OH^{-}$$

The OH^- then reacts with Fe^{2+} and Fe^{3+} to form $Fe(OH)_2$ and $Fe(OH)_3$. Lastly the reformation of the H_2O and the precipitation of the Fe_2O_3 oxide will occur:

$$4Fe + 6H_2O + 3O2 = 4Fe(OH)_3 = 6H_2O + 2Fe_2O_3 \text{ (precipitation)}$$

There are four factors that will lead the steel to corrosion: water, oxygen, corrosive chemical(s), and a suitable temperature [4]. Oxygen play an important role in the corrosion process as the corrosion is impossible without the oxygen around. This means the corrosion can be prevented if the environment beneath the insulation is keep dry all the time.

Some types of insulation contain chloride, and if this chemical is exposed to the moisture, they will get mixed and appear on the surface of metal and this corrosive environment can result holes or cracks on the surface of pipe [5].

The corrosion under insulation can be detected using inspection methods. Some of the present corrosion under insulation detection methods are [6]:

1. Profile Radiography – expose the small section of pipe wall to radiography. Effective but limited to small areas of pipe only. During the inspection, the inspection area must be free from all living things during the inspection period.

2. Ultrasonic Thickness Measurement – need to cut enough holes to get reliable result. Effective but expensive and limited to small area.
3. Insulation Removal – remove the insulation and check the surface condition. May require eddy current or liquid dye penetrant inspection. The most effective, expensive and time consuming methods.
4. Infrared - can be used to detect damp spots in the insulation using temperature difference between the dry insulation and the wet insulation. Basically the corrosion will happen in the areas beneath the wet insulation.
5. Neutron Backscatter – to detect wet insulation on pipes and vessels using radioactive source. The hydrogen nuclei will attenuate the energy of neutrons if there is moisture in the insulation.

There are plenty of effective ways to prevent corrosion under insulation (CUI) on pipes that operate above ambient temperature. The three most popular methods are pipes coating, perfect type of insulation and maintaining the insulation systems from water. Below are the details of four effective ways to prevent corrosion under insulation [6]:

1. Protective jacketing – the first line defence that keeping out water from the insulation. The perfect design, installation, and maintenance of protective jacketing are always critical in preventing CUI.

2. Insulation system maintenance – the second line defence from corrosion. The systems must be well maintained from water especially for insulated pipe that is uncoated, has an original insulation system of the same age, and is located in rainy climate.

3. Protective coating – the third line defence from corrosion. Coating protect steel pipe from water, air and corrosive chemicals. There are two types of coatings; thermal spray aluminium (TSC) coating and organic coating. The organic coating is widely used to coat the pipes under 300^{o}F. Based on article, "Corrosion Under Insulation: Prevention Measures" (Insulation Outlook, October 2007), Dr. Hira S. Ahluwalia, TSA coating is better than organic coating. TSA coating is effective up to temperature of 1000^{o}F. However, this type of coating is very expensive compared to organic coating.

4. Insulation materials – the quality of insulation materials will determine the corrosion rate under the insulation. If the insulation is good, the water will not intrude thus the corrosion will not happen. Under certain circumstances, water with dissolve corrosive materials of insulation does intrude and corrode the pipe.

The performance of coated metal underneath the insulation at high temperature has caused recurrent failing and the corrosion under insulation is usually unpredictable. One of the laboratory methods to evaluate performance of coating is by EIS.

Electrochemical impedance can provides information on the physical and electrochemical behaviour of the coating. The impedance corroding information is usually measured by applying an AC potential or a small excitation signal to coating samples.

The EIS device can produce two types of data presentation which is Nyquist Plot and Bode Plot. If the real part is plotted on the X-axis and the imaginary part is plotted on the Y-axis of a chart, we get a "Nyquist Plot".

Nyquist Plots have one major weakness. The frequency is not recorded at any data point on the plot. The frequency data is very important for this project as low frequency is the key performance indicator for coating analysis [7].

Another popular presentation method is the Bode Plot. The impedance is plotted with log frequency on the X-axis and both the absolute values of the impedance ($|Z|=Z_0$) or the phase-shift on the Y-axis. Unlike the Nyquist Plot, the Bode Plot does show frequency information.

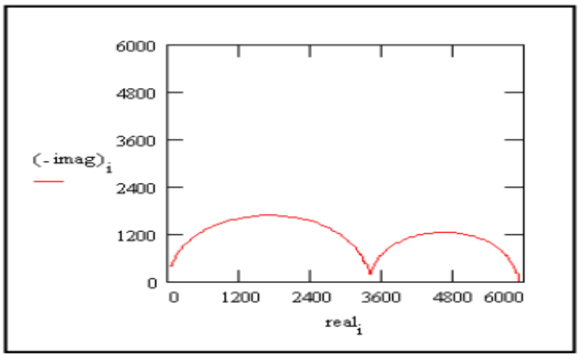

Figure 2.2: Nyquist Plot [8]

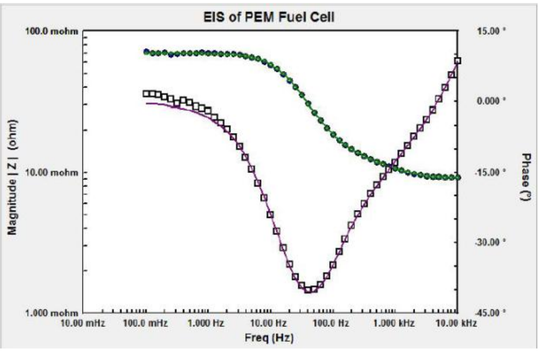

Figure 2.3: Bode Plot [8]

Electrochemical cells are usually be modelled using a single electrical circuit element. Most of the circuit elements in the model are common electrical elements such as resistors, capacitors, and inductors. In this project, the coating sandwiched between the coated metal and the electrolyte can be represented by an electrical circuit [9].

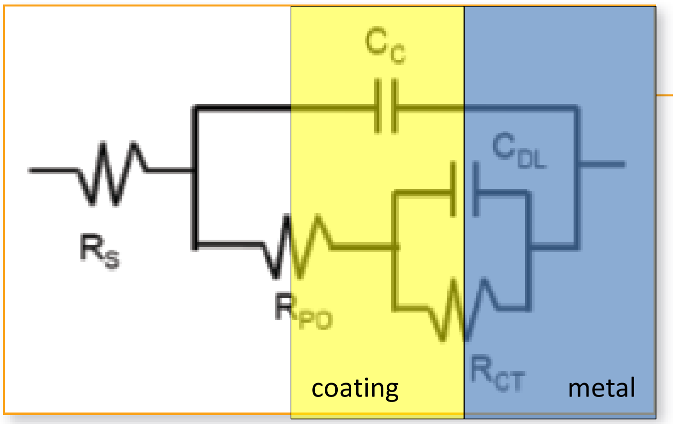

Figure 2.4: Electrochemical Cell of Coating Metal [8]

Table 2.1: Details of Electrochemical Cell

C_c = capacitance of the impact coating	C_{dl} = double layer resistance
R_{po}=R_p = pore resistance	R_{ct} = change transfer resistance
R_s = solution resistance	

Figure 2.2 shows the equivalent circuit of coated metal when undergoing electrochemical impedance spectroscopy testing. Table 2.2 below shows the common electrical elements of the circuit.

Table 2.2: Impedance Conversion

Component	**Current Vs.Voltage**	**Impedance**
resistor	E= IR	Z = R
inductor	E = L di/dt	Z = jωL
capacitor	I = C dE/dt	Z = 1/jωC

Here $\omega = 2\pi f$, where f is frequency and j is $(-1)^{1/2}$

For equivalent circuit of coated metal, the calculation of the equivalent impedance is:

$$Z(\omega) = R_s + \frac{R_p}{1+\omega^2 R_p^2 C_d^2} - j\frac{\omega R_p^2 C_d}{1+\omega^2 R_p^2 C_d^2} = Z'(\omega) - jZ''(\omega),$$

Based on table2.2, the impedance of a resistor is independent of frequency and has no imaginary component. However, the impedance of an inductor increases as frequency increases.

Other than that, the inductors have an imaginary impedance component. The impedance versus frequency behavior of a capacitor is opposite to that of an inductor. A capacitor's impedance decreases as the frequency is raised.

The transportation of water and oxygen through the coatings pores is referred as the pore resistance (R_p). This pore resistance can be magnified or lessened by the anodic and cathodic activity of corrosion inhibitors present in the film [8].

The changes in pore resistance can change the overall impedance of electrochemical cells. The pore resistance in a coating is difference from one coated metal to another depending on their condition and ability to constrain the corrosion processes.

At low frequencies ($\omega \to 0$), it becomes

$$Z(\omega) = R_s + R_p$$

As the author mention before, the bode plot results from EIS testing will shows the total impedance versus frequency graph. Based on equation 6, the total impedance is equal to solution resistance and pore resistance at low frequencies level.

Notice that solution resistance will not change too much with time. However the pore resistance of the coating will be lessened. Therefore the impedance at low frequency (0.1 Hz) was used as the key indicator in evaluating the coating performance in EIS testing [7].

Below is the coating performance result from the previous study by Mike O'Donoghue and Emilio Cano.

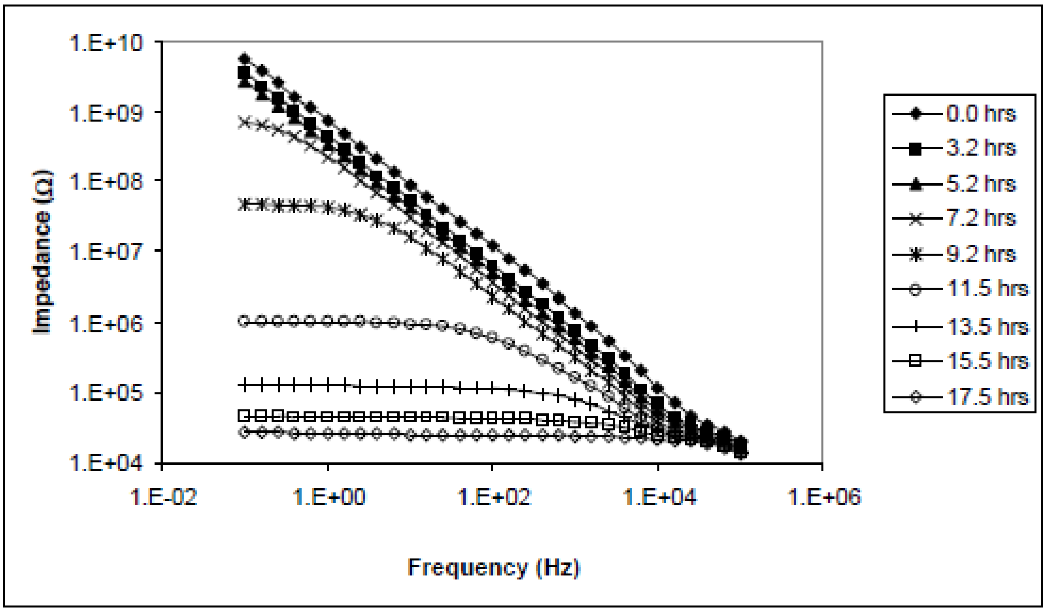

Figure 2.5: Impedance result for epoxy coating with TiO_2 pigment

Figure 2.5 shows the bode plot results of EIS measurements for epoxy coating with TiO_2 pigment using the stripping solution as the test electrolyte. The result shows the impedance value is decreasing with time as the result of initiation of under-film corrosion.

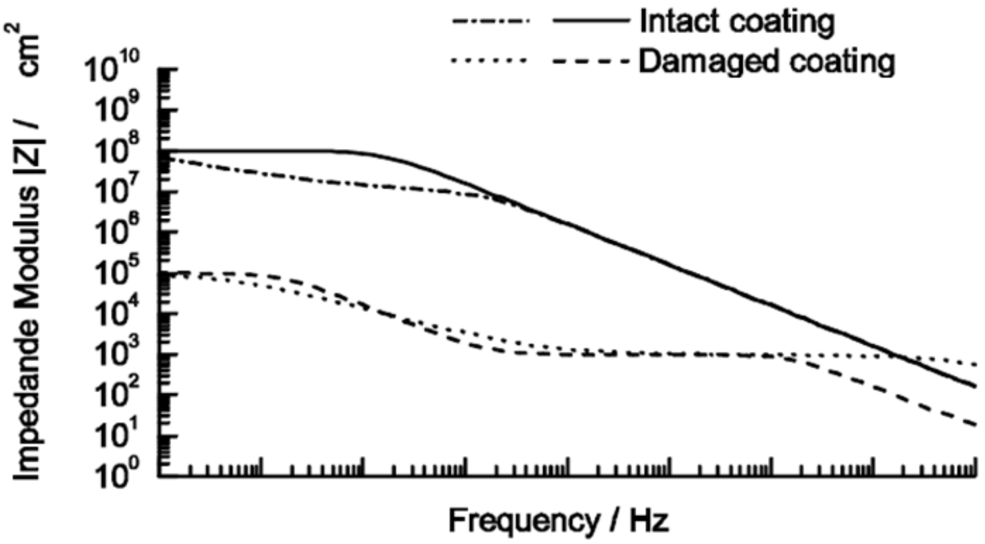

Figure 2.6: Impedance results for intact coating and damaged

Figure 2.6 shows two distinctive Bode plots of a good, smooth and intact coating and another two plots equivalent to a damaged coating where the electrolyte reaches the metal interface (one of them modelled using pure capacitors and the other using constant phase elements, CPE).

The damage coating sample shows low value of impedance compare to intact coating. The results show that the damaged coating has reducing the strength of bonding between the coating particles. It means the pore resistance of the coating is weak and the water can easily penetrate through the coating thus lead to rusting on metal.

CHAPTER 3:

METHODOLOGY

3.1 Overall Project Flow

The overall project flow is shown in Figure 3.1 below:

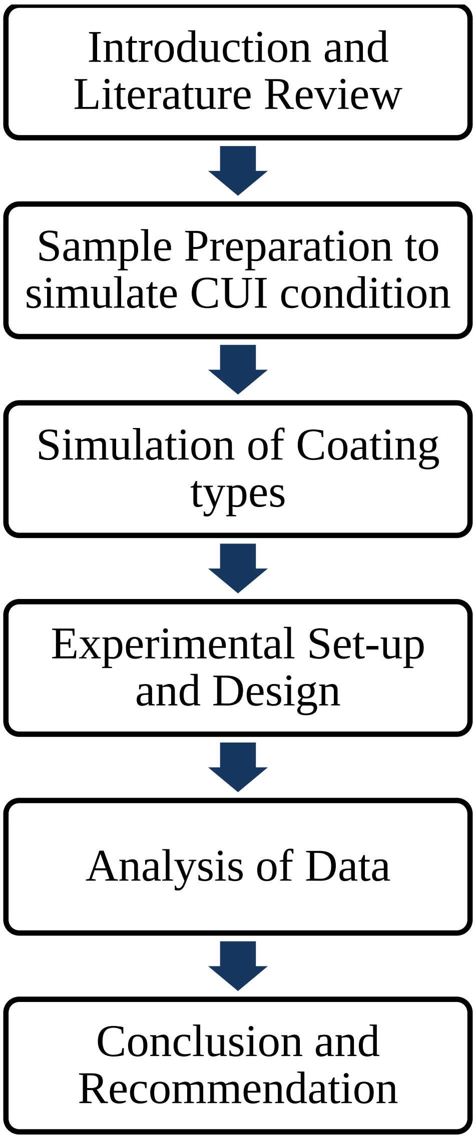

Figure 3.1: Research methodology

3.2 Project Activities

Simulation of Pipe Samples

The project activities were started after all the research about corrosion under insulation is done to avoid any mistakes during the activities. The samples are made from carbon steel scrap pipeline that is available at UTP Centre for Corrosion Research. The sample is a combination of scrap pipe mounted with hose and copper wire as picture below.

Figure 3.2.1: Pipe sample

Continuity Testing

The continuity of the sample has been tested using Multitester which specialized for continuity tester but cheaper, more basic devices, generally with a simple light bulb that lights up when current flows.

A continuity test is the checking of an electric circuit to see if current flows. A continuity test is performed by placing a small voltage across the chosen path. For this project, the continuity is tested to determine the soldering between copper wire and pipe sample is good and connected.

The author has prepared 12 samples of pipe coating from carbon steel X2 material. The continuity of the sample has been tested using Multitester. During the experiment, two samples have failed the continuity testing.

The continuity of sample is tested to determine the connectivity of soldering between copper wire and pipe sample. Sometimes a solder joint is broken between the joint and this will lead to failure in experiment.

Surface Grinding

The surface grinding is done on samples to clean its surface from dirt and rust before it goes through spray coating process. There are two ways to clear the rust; surface grinding and grit blasting. The author used surface grinding method with grade 180 of grinding paper to grind the samples.

Figure 3.2.2: Surface grinding machine

Surface Roughness Testing

After the samples were grinded, the roughness average of samples was measured using profilometer. Profilometer is a measuring instrument used to measure a surface's profile, in order to quantify its roughness.

Figure 3.2.3: Profilometer

According to manufacturing report from Rust-Anode Technical Data Sheet (April 2004.), the ideal surface preparation for spray painting should have roughness average of 18.25mm. The author has done the roughness testing to the sample using profilometer machine to check its roughness average.

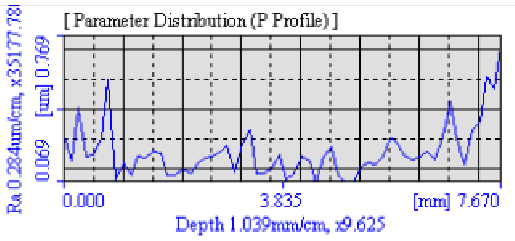

Figure 3.2.4: Surface Roughness graph

Table 3.2.1: Surface Roughness result

Parameter	Result	Judgment	Error Besides Pe...
Ra	13.871um		

The result of roughness average (Ra) of the samples is about 13.87 which are closed to the ideal surface preparation. It means that the surface roughness of samples is acceptable. After the roughness test is done, all samples were coated with Jotazinc as a primer layer. Then the sample was dried for 12 hours.

Painting Physical Condition

Three types of coated pipe sample have been prepared; good coating as per specification, thinner off spec and damaged coating.

Figure 3.2.5: Sample 1 – Coating according to standard

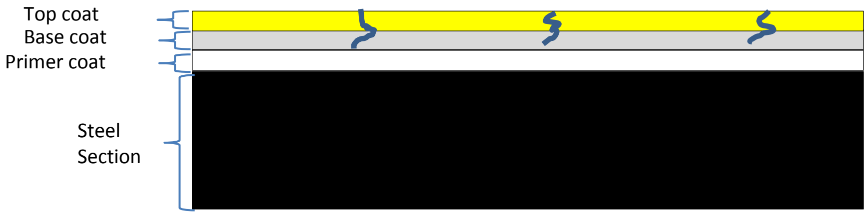

Figure 3.2.6: Sample 2 – Damaged coating sample

Figure 3.2.7: Sample 3 – Thinner off spec coating sample

Table 3.2.2: Painting and Sample Specification

DESCRIPTION		SURFACE PREP	NO OF COAT	TYPE OF PAINT	DFT	JOTUN	
Sample Type : CARBON STEEL X52		**Active Surface Area: 14.6 cm^2**					
5A	**INITIAL & MAINTENANCE**		1 st	Inorganic Zinc Silicate	75	Jotazinc	
(1)	**Painting 110 - 250^{O}C**	Sa 2 ½	2 nd	Modified Silicone Acrylics	30	Solvalitt	
			3 rd	Modified Silicone Acrylics	30	Solvalitt	

Sa 2 ½ - Shotblasting standards guidelines
DFT- Dry Film Thickness (microns)
IP – International Paint
PTS – Petronas Technical Standard

Source: PTS.30.48.00.31.P/ REV. 3 AUG. 2001

Drying Process

The drying process was carried out at two different conditions in order to investigate the effect of different drying process on coating performance. During the experiment, the good samples were placed in dry box that has fixed temperature of 39°C and the scrap samples were placed in a normal room that has room temperature of 28°C.

The observation has been made after 12 hours of curing time. Notice that the author used the scraps samples that failed the continuity testing and the good samples are the sample samples that passed the continuity testing.

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Figure 3.2.8: Drying process in dry box result

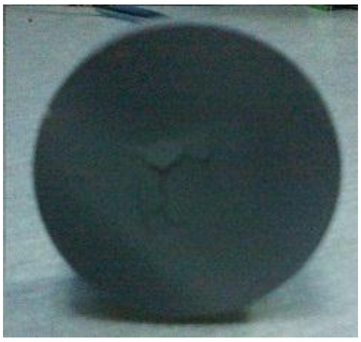

Figure 3.2.9: Drying process in normal room result

The samples that were placed in dry box had shown good quality of coating surface. However the scrap samples that were placed in normal room had shown surface crack. The result shows the importance of stable temperature and cleanliness of air during the drying process in order to get high quality of surface coating.

Experimental Set-up

The coating samples will be analysed using electrochemical impedance spectroscopy method. The activities will be held at high temperature environment. The analysis require one to two weeks to generate results depend on the ability of samples to corrode. Below is the test matrix of experiment:

Table 3.2.3: Test Matrix

Corrosion rate measurement	**Electrochemical Impedance Spectroscopy**
Temperature	**80°C**
pH	**6**
Electrolyte	**1% NaCl**
Duration	**1-2 weeks**

Cell Setup

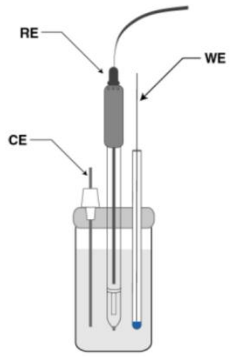

Figure 3.2.10: EIS setup

1. Equip a clean electrochemical cell with a RE reference electrode and a CE/RE auxiliary/counter electrode.
2. Carefully mount the sample WE working electrode in the cell as well.
3. Fill the electrochemical cell with 3.5% Sodium Chloride solution. Make sure that all three electrodes are immersed in the solution.
4. Connect the cell with the potentiostat.
5. Adjust the experiment settings to match your requirement, click on the PERFORM button to initiate the experiment.
6. After acquiring a satisfactory result, save it on the disk or print it out on the printer.

3.3 Key Milestone

Table 3.3: Key Milestone

Week	Objectives
FYP I	
5	Completion of preliminary research work
6	Submission of extended proposal
9	Completion of proposal defence
13	Submission of Interim draft report
14	Submission of Interim report and completion in preparing the coating samples
	FYP II
5	Finalized the design for micro heat exchanger
8	Submission of progress report
9	Completion of modelling and simulation
11	Pre-SEDEX
12	Submission of draft report
13	Submission of technical paper and dissertation
14	Oral presentation
15	Submission of project dissertation

Table 3.3 shows the key milestone for the project which is the objective that must be achieved within the specified week.

3.4 Gantt Chart

Table 3.4: Gantt Chart for FYP Implementation

	FYP 1														FYP 2														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Title Selection	■																												
Submission of Extended Proposal		■	■	■	■	■																							
Proposal Defense and Progress Evaluation								■	■																				
Submission of Interim Draft Report										■	■	■	■																
Submission of Interim Report													■	■															
Preparation of Coating Samples									■	■	■	■	■	■															
Corrosion Testing of Coating Sample 1														■	■	■	■												
Corrosion Testing of Coating Sample 2																	■	■	■	■									
Corrosion Testing of Coating Sample 3																				■	■	■	■						
Analysis of Data																				■	■	■	■	■	■				
Submission of Progress Report																						■							
Conclusion and Recommendation																								■	■				
Pre-SEDEX																									■				
Submission of Draft Report																										■			
Dissertation																											■		
Oral Presentation																												■	
Submission of Project Dissertation																													■

Table 3.4 shows the Gantt chart for the project implementation for FYP I and FYP II. Based on the Gantt chart, the project is feasible to be completed within the given amount of time

3.5 Tools / Method

The methods that were used in this project are surface grinding, spray painting, surface roughness testing, connectivity testing and electrochemical impedance spectroscopy testing.

CHAPTER 4:

RESULT AND DISCUSSION

Elecrochemical Impedance Spectroscopy Testing Result

Electrochemical impedance can provides information on the physical and electrochemical behavior of the coating. The impedance corroding information is measured by applying an AC potential or a small excitation signal to coating samples. The coating is act as capacitor that can store a limit amount of current inside its body. The high impedance value from EIS testing was indicative of a superior performing coating with good barrier properties.

In case of epoxy coatings, the value of impedance increases after immersion in the electrolyte. This event indicates the beginning of detachment of the coating from the substrate because of adhesion loss. In the case of our samples, a high value of impedance were obtained on early data readings of the experiment, the gradual increase in the value of impedance is due to solution penetration between the coating and steel surface. For that reason, the data reading is taken starting on day 2 of the experiment.

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Case 1: Good coating sample

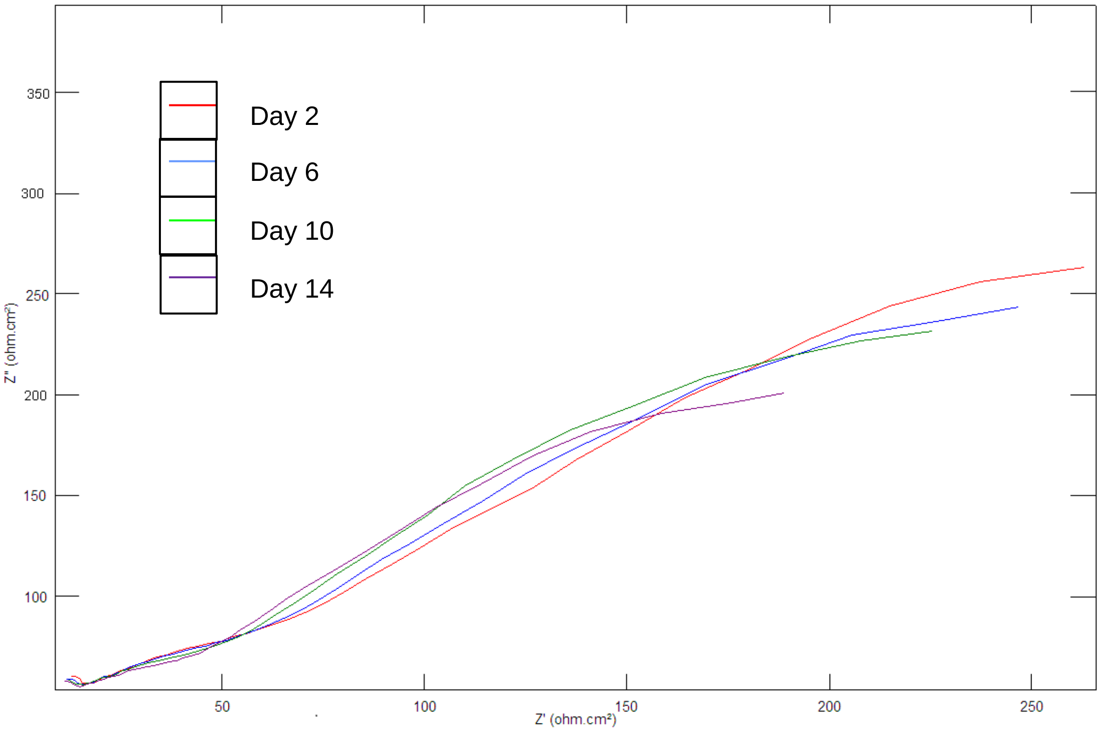

Figure 4.1: Nyquist Plot for good coating condition

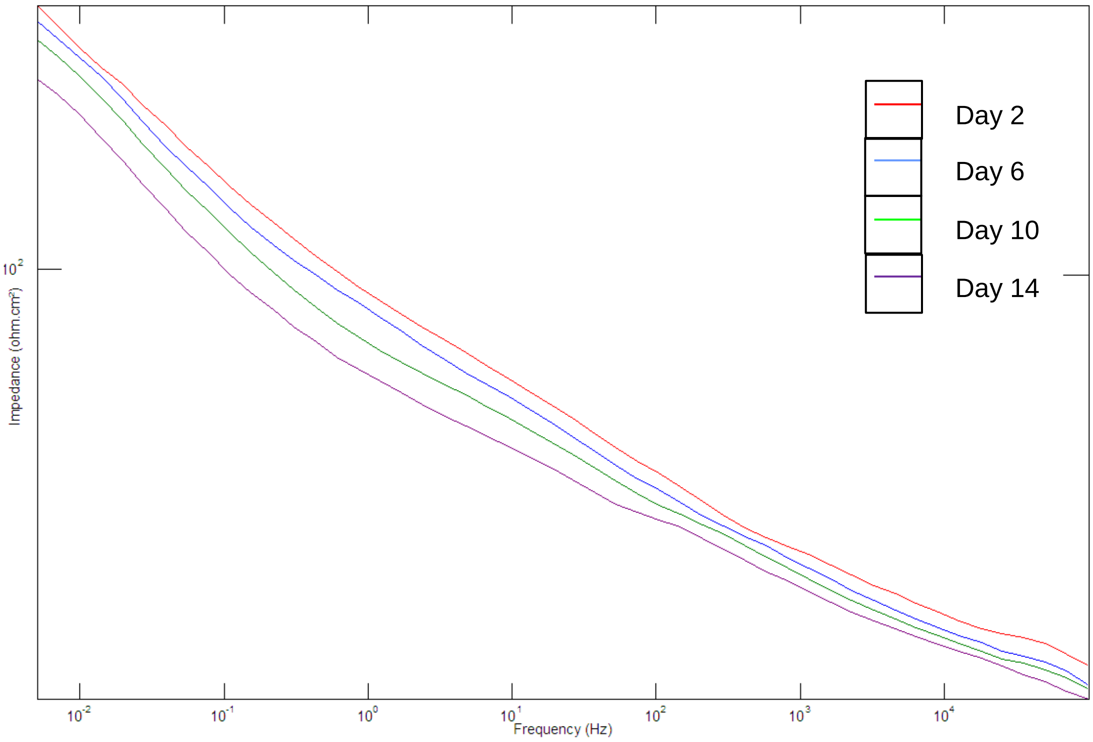

Figure 4.2: Bode Plot for good coating condition

Figure 4.1 shows the Nyquist plots for good coating sample as per specification PTS.30.48.00.31.P/ REV. 3 AUG. 2001. The readings were taken every four days starting on day two until day 14.

The Nyquist plots for good coating sample shows an initial shape of one semicircle. Please refer to Figure 4.1. The fully developed plot showed two semicircles because the coated specimen has two capacitances, one is from the coating and another one is from the double layer on the substrate beneath the coating. The beginning of the second semicircle is seen after day 6 of the experiment.

Figure 4.2 shows the Bode plot for good coating sample as per specification PTS.30.48.00.31. The impedance value was taken at low frequency domain. The early stage of the test showed highest value of coating impedance indicating good performance of the coating system. However, the impedance value is decreasing with time indicates the diminishing of coating performance.

Case 2: Thinner off spec coating sample

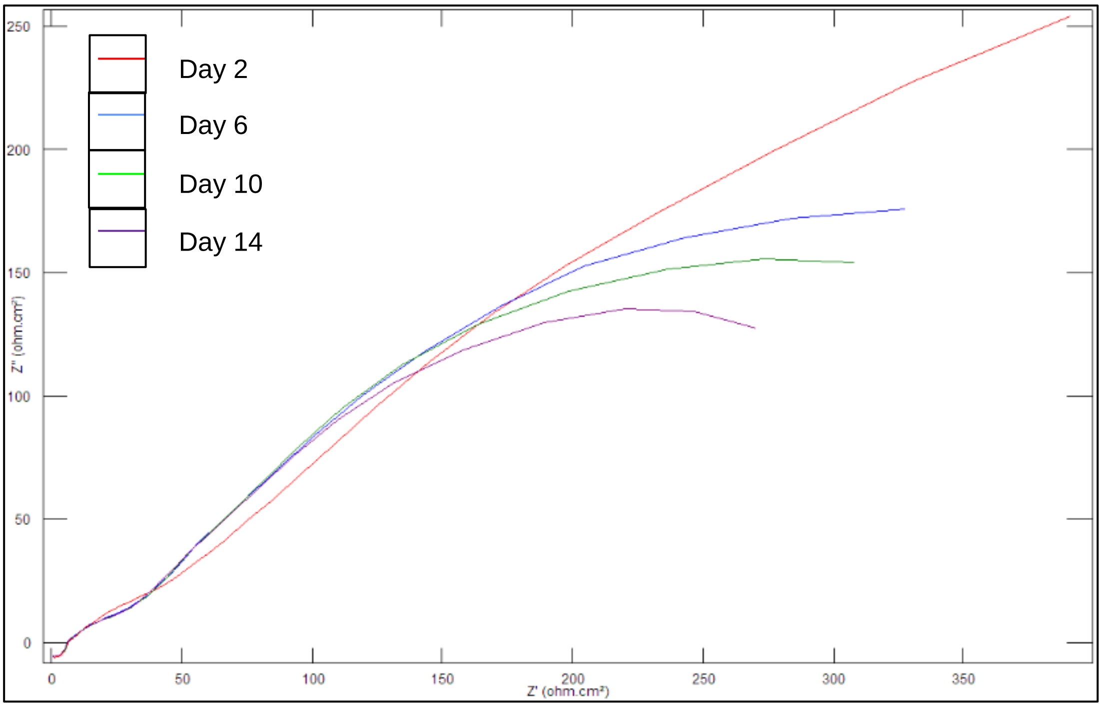

Figure 4.3: Nyquist Plot for thinner off spec coating condition

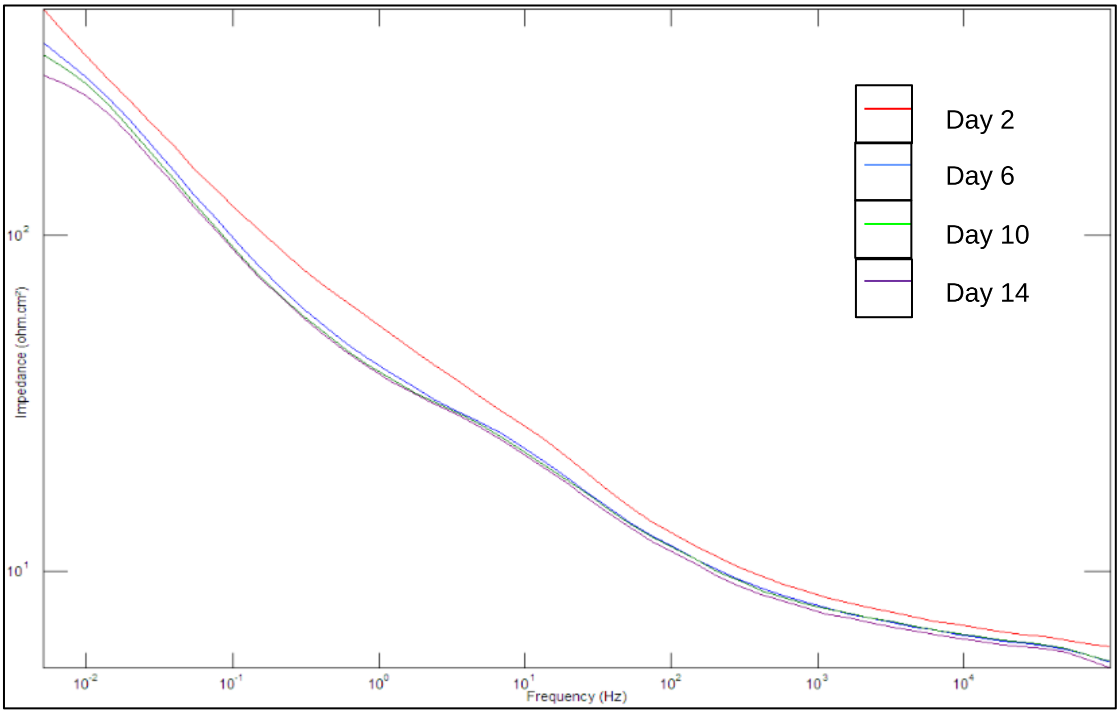

Figure 4.4: Bode Plot for thinner off spec coating condition

Figure 4.3 shows the Nyquist plots for thinner off spec coating sample. The readings were taken every four days starting on day two until day 14.

The Nyquist plots for thinner off spec coating sample shows an initial shape of one semicircle. Please refer to Figure 4.3. The beginning of the second semicircle is seen after day 6 of the experiment.

Figure 4.4 shows the Bode plot for thinner off spec coating sample. The impedance value was taken at low frequency domain. The early stage of the test showed highest value of coating impedance indicating good performance of the coating system in the early stage. However, the impedance value is decreasing with time indicates the diminishing of coating performance.

Case 1: Physical damaged coating sample

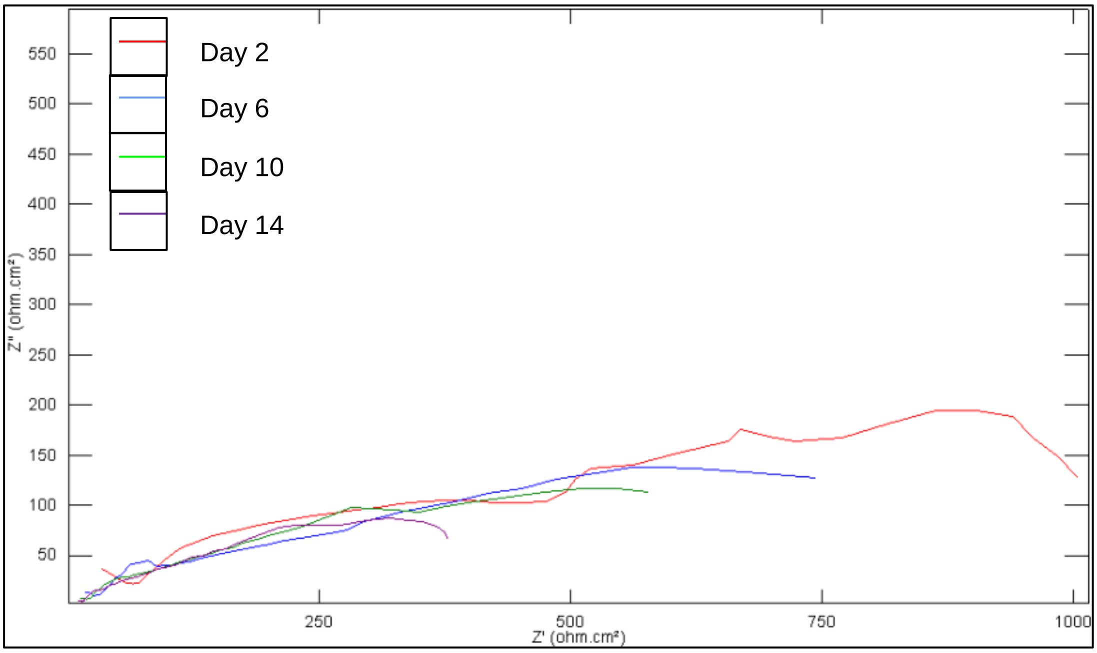

Figure 4.5: Nyquist Plot for physical damaged coating condition

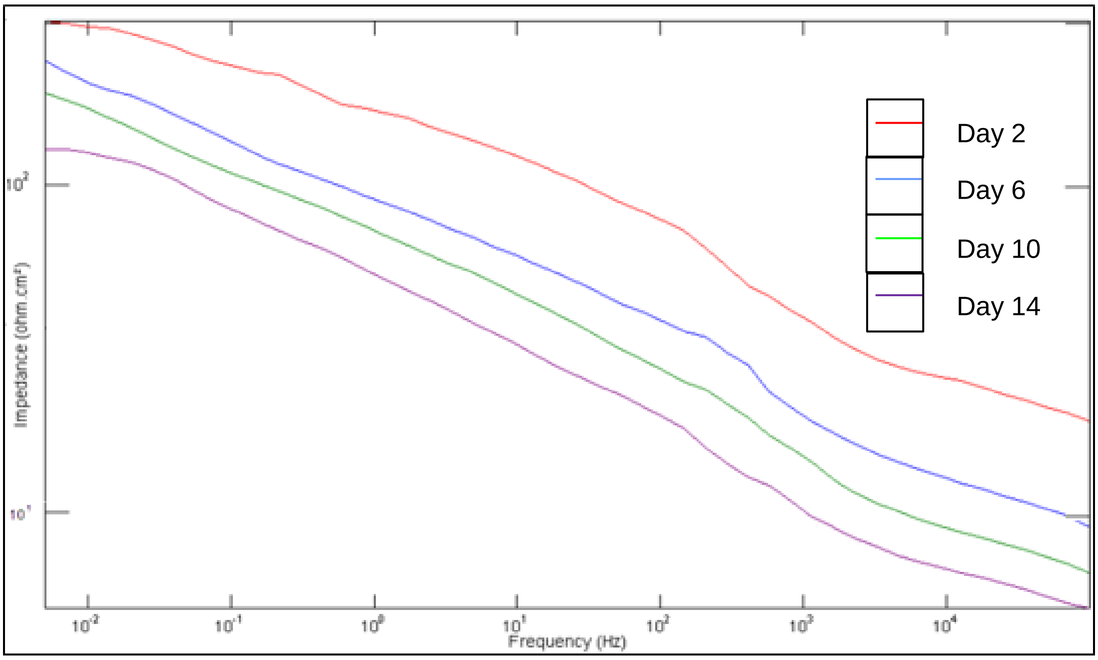

Figure 4.6: Bode Plot for physical damaged coating condition

Figure 4.5 shows the Nyquist plots for physical damaged coating sample. The readings were taken every four days starting day two until day 14.

The Nyquist plots for physical damaged coating sample shows irregularities in graph pattern. Please refer to Figure 4.6. The irregularities pattern means that the damage on coating has weak and unstable coating impedance. The beginning of the second semicircle is seen after day 2 of the experiment which is earlier than good coating sample and thinner off spec coating sample.

Figure 4.6 shows the Bode plot for physical damaged coating sample. The impedance value was taken at low frequency domain. The early stage of the test showed highest value of coating impedance indicating good performance of the coating system. However, the impedance value is decreasing with time indicates the diminishing of coating performance.

During the early stage of the test, the coating impedance value was highest. However, the coating impedance value is gradually decreasing with time.

The good coating and thinner off spec coating shows small decreasing changes in impedance value between the readings compared to damage coating condition sample. Please refer to Figure 4.2, Figure 4.4 and Figure 4.6.

The high decreasing changes in impedance value means that the pore resistance of the coating is weak and the water can easily penetrate through the coating thus lead to rusting on metal pipeline.

Nyquist plot for damage coating sample shows irregularities in graph pattern. Please refer to Figure 4.5. The irregularities pattern means that the damage on coating has weak and unstable coating impedance. It shows that the damage coating has the worst performance compared to the other two type of coating condition.

The Nyquist plots for good coating and thinner off spec coating sample shows an initial shape of one semicircle. Please refer to Figure 4.1 and Figure 4.3. The fully developed plot will shows two semicircles. The beginning of the second semicircle is seen after 6 days of the experiment for both samples.

Good coating and thinner off spec coating sample shows the same peak value of impedance in early stage of the test. However, the good coating sample has higher peak impedance compared to thinner off spec coating sample in the last stages of the experiment. It shows that the good coating condition is better than thinner off spec condition.

If the coating performance is evaluated by order, the best coating performance will be the good coating condition sample, following by thinner off spec condition and lastly is damaged coating condition.

CHAPTER 5:

CONCLUSION

The coating performance for different coating condition had been evaluated using EIS method. Based on the impedance distribution data from EIS testing the best coating performance was obtained by the good coating condition sample, followed by thinner off spec coating condition and physical damaged coating condition. The impedance of good coating and thickness off spec decreased slightly with immersion time. However the impedance of damage coating decreases significantly with immersion time. The experiment results concluded that proper coating application is very important to obtain long lasting and high quality coating. Damage on coating and thinner off specification of coating will affect the performance of coating in protecting the metal from corrosion especially in corrosion under insulation environment. Non-conformance coating condition in terms of coating thickness and physically-damaged coating will affect the performance of coating in protecting the metal from corrosion especially in corrosion under insulation environment.

5.1 Recommendations

The detail inspection is recommended before installing new pipe underneath the insulation as the pipe performance will eventually reduce when the damage or thinner off spec is happened on pipe coating.

There are a lot of sources that lead to corrosion under insulation such as the type of jacketing, the maintenance system of insulation and the type of insulation material. The author plans to do the study and research regarding the above matter if there is time.

CHAPTER 6:
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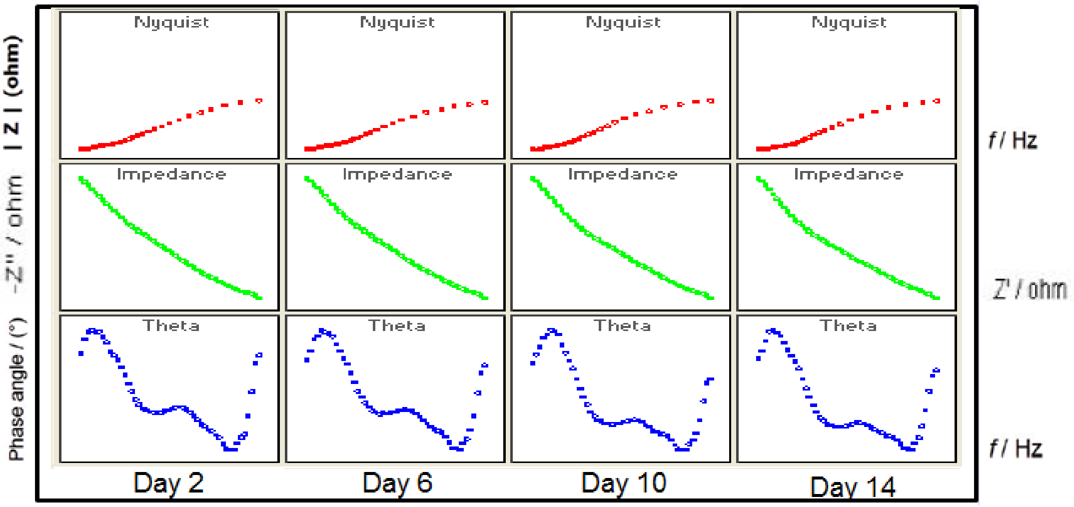
APPENDICES

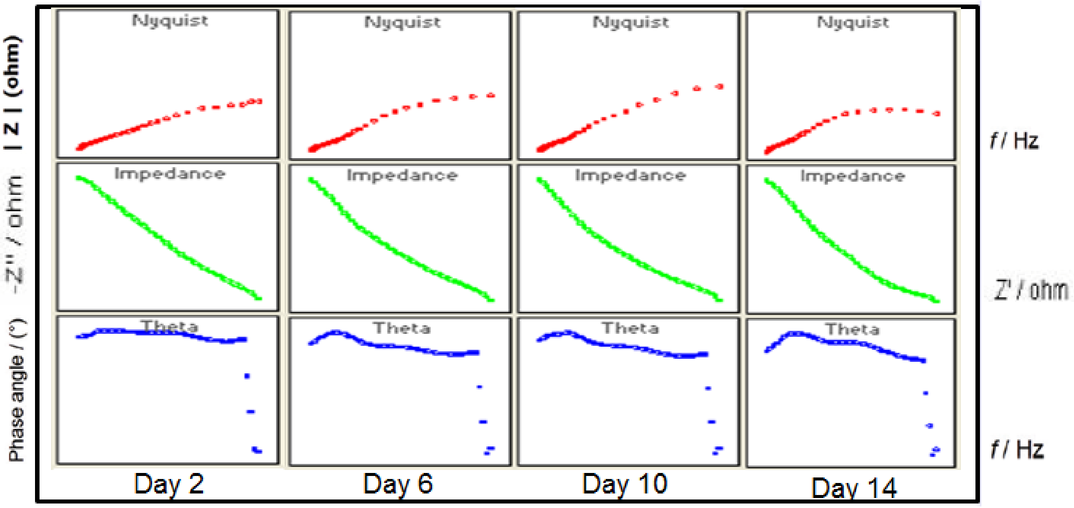
JOB SAFETY ANALYSIS

Title Job Operation:	Spray Painting	Date:	5/11/12	Ref. No.:	CCR/JSA/XX
Title of Person Who Does The Job:	~~Technical Assistant~~/ Students/ ~~Graduate Assistant/ Technician~~	Employee Observed:		Rafida Ahmad Jaal	
Location:	Block I				
Department/Program:	Mechanical Engineering	Prepared by:		Wan Muhammad Faris b Wan Sohaimi	
Section/ Lab:	Corrosion Laboratory	Approved by:		AP Ir Dr Mokhtar Che Ismail	

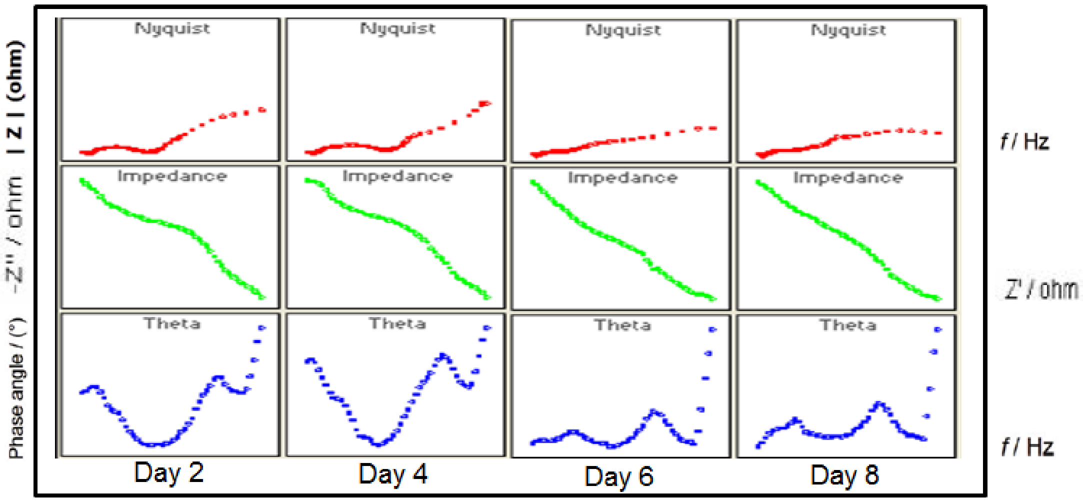
Sequence of Basic Job Steps	Potential Accidents or Hazards	Recommended Safe Job Procedure
1. Turn on the air compressor	Electrical Shock	Proper wiring and grounded
2. Adjust the regulator on the compressor	Hand injury	Wear gloves
3. Attach the air hose coupling to the sprayer	Paint leakage	Attach it securely and tightly
4.Fill the paint cup about 2/3 of the way with paint and lock it onto the sprayer	Splash, skin contact	Wear lab coat or apron (if necessary)
5. Spray the paint 5-10 inches from the surface	Inhalation	Wear mask if needed



Appendix B: EIS graph result for good coating condition sample



Appendix C: EIS graph result for thinner off spec coating condition sample



Appendix D: EIS graph result for damage coating condition sample