COMPARISON STUDY OF CORROSION MEASUREMENT TECHNIQUE

FADLI BIN MISLAN@MISHADI

UNIVERSITI MALAYSIA PAHANG

COMPARISON STUDY OF CORROSION MEASUREMENT TECHNIQUE

FADLI BIN MISLAN@MISHADI

This thesis is submitted as a partial fulfilment of the requirements for the award of the Bachelor of Mechanical Engineering

Faculty of Mechanical Engineering UNIVERSITI MALAYSIA PAHANG

JUNE 2013

UNIVERSITI MALAYSIA PAHANG

Б

]	BORANG PE	NGESAHAN STATUS TESIS*		
JUDUL: <u>A</u>	STUDY OF DY CRA	YNAMIC CHARATERISTICS FOR CK IDENTIFICATION DENCALIAN: 2000/2012		
C	SESI J	PENGAJIAN: <u>2009/2013</u>		
Saya	FADLI BIN M	(HURUF BESAR)		
mengaku men Perpustakaan	nbenarkan tesis (Sar dengan syarat-syara	jana Muda/ Sarjana / Doktor Falsafah)* ini disimpan di t kegunaan seperti berikut:		
 Tesis adalah hakmilik Universiti Malaysia Pahang (UMP). Perpustakaan dibenarkan membuat salinan untuk tujuan pengajian sahaja. Perpustakaan dibenarkan membuat salinan tesis ini sebagai bahan pertukaran antara in pengajian tinggi. **Sila tandakan (√) 				
	SULIT	(Mengandungi maklumat yang berdarjah keselamatan atau kepentingan Malaysia seperti yang termaktub di dalam AKTA RAHSIA RASMI 1972)		
	TERHAD	(Mengandungi maklumat TERHAD yang telah ditentukan oleh organisasi/badan di mana penyelidikan dijalankan)		
\checkmark	TIDAK TERH	IAD		
		Disahkan oleh:		
(TANDAT Alamat Tetap	ANGAN PENULIS)	(TANDATANGAN PENYELIA)		
<u>LOT 4715,JI</u> ,KG BKT KI KAPAR SEI	LN HJ SUBARI ERAYONG, 42200 ANGOR.	DR YULI PANCAASMARA (Nama Penyelia)		
Tarikh:		Tarikh: :		
CATATAN: * **	Potong yang tid Jika tesis ini SU berkuasa/organi dikelaskan seba	lak berkenaan. JLIT atau TERHAD, sila lampirkan surat daripada pihak isasi berkenaan dengan menyatakan sekali tempoh tesis ini perlu gai atau TERHAD.		
•	Tesis dimaksud Penyelidikan, a penyelidikan, a	kan sebagai tesis bagi Ijazah doktor Falsafah dan Sarjana secara tau disertasi bagi pengajian secara kerja kursus dan tau Laporan Projek Sarjana Muda (PSM).		

EXAMINER'S DECLARATION

UNIVERSITI MALAYSIA PAHANG

FACULTY OF MECHANICAL ENGINEERING

I certify that the project entitled "*Comparison Study of Corrosion Measurement Technique*" is written by Fadli Bin Mislan@Mishadi. I have examined the final copy of this report and in my opinion, it is fully adequate in terms of language standard, and report formatting requirement for the award of the degree of Bachelor Engineering. I herewith recommend that it be accepted in partial fulfilment of the requirements for the degree of Bachelor Mechanical Engineering.

(Januar Parlaungan Siregar)

Examiner

Signature

SUPERVISOR DECLARATION

I hereby declare that I have checked this thesis and in my opinion, this report is satisfactory in terms of scope and quality for the award of the degree of Bachelor of Engineering (Mechanical).

Signature : Name : DR. YULI PANCA ASMARA Date : 25 JUNE 2013

STUDENTS'S DECLARATION

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

Signature	:
Name	: FADLI BIN MISLAN@MISHADI
ID Number	: MA09065
Date	: 25 JUNE 2013

In the name of ALLAH, Most Gracious, Most Merciful

To my beloved my family also to all my friends

ACKNOWLEDGEMENT

Firstly, my highest gratitude goes to God because of His mercy and kindness my final year project has successfully finished within the time provided. Many things I have learned throughout a year especially in corrosion process that is how it can occur, how to prevent it and so on. These experiences gained will be very useful for my future career. I hope that all information gained from my final year project may benefit to others especially Universiti Malaysia Pahang (UMP) student and staff for reference and research.

Special gratitude to Associate Supervisor, Dr Yuli Panca Asmara for giving me the opportunity and assigned me to do a final year project under his supervision. I would like to record my deep appreciation and sincere gratitude to him for granting me precious knowledge and an opportunity to perform my final year project.

Last but not least I would like to thank to my family and my friend especially who have assisted me in completing this final year project.

ABSTRACT

Corrosion monitoring tests were carried out to compare some of electrochemical techniques and non-electrochemical technique to measuring the corrosion rate and to study the uncertainty of the these techniques. Each of technique have their errors from the experimental method and equation of the theory. In atmospheric condition, 3.5% wt of NaCl will be used as solution for electrochemical techniques, while for weight loss will immersed in that solution at certain time of period. The data from electrochemical method were analyzed by using Ivman software and to be compare the result of each technique. The experiment were carried out at atmospheric condition and at room temperature.

ABSTRAK

Ujian pemantauan kakisan telah dijalankan untuk membandingkan beberapa teknik elektrokimia dan teknik bukan elektrokimia untuk mengukur kadar kakisan dan mengkaji ketidaktentuan teknik-teknik ini. Setiap teknik mempunyai kesilapan mereka daripada kaedah eksperimen dan teori . 3.5 % NaCl akan digunakan sebagai penyelesaian untuk teknik elektrokimia, manakala kaedah hilang berat akan ditenggelamkan dalam larutan NaCl untuk tempoh masa tertentu. Data daripada kaedah elektrokimia dianalisis dengan menggunakan perisian Ivman dan untuk membandingkan hasil daripada setiap teknik. Eksperimen telah dijalankan pada keadaan atmosfera dan pada suhu bilik.

TABLE OF CONTENTS

			Pages
EXAMINER DE	CLARA	TION	ii
SUPERVISOR'S	DECLA	RATION	iii
STUDENT'S DE	CLARA	ΓΙΟΝ	iv
ACKNOWLEDG	EMENT	°S	vi
ABSTRACT			vi
ABSTRAK			vii
TABLE OF CON	TENTS		viii
LIST OF TABLE	S		xii
LIST OF FIGUR	ES		xiii
LIST OF SYMBO	DLS		XV
LIST OF ABREV	IATION	IS	xvi
CHAPTER 1	INT	RODUCTION	
	1.1	Study background	1
	1.2	Problem Statement	2
	1.3	Objectives of Study	2
	1.4	Scopes of Study	2

2.1	Introd	uction	3
2.2	Metho	ods in measuring corrosion rate	3
	2.2.2	Linear Polarization Resistance	4
2.3	Uncer	tainties in corrosion measurement using	
	Electr	ochemical technique	6
	2.3.1	Linear Polarization Error	7
	2.3.2	Tafel Slope Uncertainties	8
	2.3.3	Polarization Limitation	10
	2.3.4	Effect of Scan Rate	11
	2.3.5	Charger Transfer Reaction Effect on Tafel Plot	13

CHAPTER 3 METHODOLOGY

3.1	Introduction	17
3.2	Flow chart of work progress	18
3.3	Experiment Procedure	19
	3.3.1 Non-Electrochemical (Weight Loss)	19
	3.3.2 Electrode	19
	3.3.3 Specimen Preparation	20
	3.3.4 Cell Solution	20

3.4	Corrosion rate measurement	20
	3.4.1 Weight Loss	21
	3.4.2 Tafel Method	21
	3.4.3 Linear Polarization Resistance	23
3.5	Test Procedure	24
3.6	Calculating Corrosion Rtae Value, Rp and	Error 25

CHAPTER 4 RESULTS AND DISCUSSIONS

4.1	Introduction	26
4.2	Result	26
	4.2.1 Weight Loss Method	26
	4.2.2 Tafel Method	27
4.2.3	Linear Polarization Resistance	34
4.3	Discussion	40

CHAPTER 5 CONCLUSIONS AND RECOMMENDATIONS

5.1	Introduction	42
5.2	Conclusion	42
5.3	Recommendations	42

REFERENCES

APPENDICES

А	Gantt chart of FYP 2	45
В	Polarization Behaviour of a metal (M) in	
	Acid solution	46

43

LIST OF TABLES

Table No	o. Title	Page
3.1	Carbon Steel X52 chemical composition.	20
3.2	Parameter of potensiostat	22
4.1	Result for weight loss	26
4.2	Parameter results for constant potential voltage and different scan rate.	31
4.3	Results of Rp and CR for constant potential voltage and different scan rate.	31
4.4	Result of errors for constant potential different(Eintial:-0.5v, Efinal:0.5) and different scan rate.	32
4.5	Result of tafel parameter value for different potential and constant scan rate $15 mV/s$	33
4.6	Result of Rp and CR value(different potential, constant scan rate)	33
4.7	Error of Tafel's parameter(Different potential, constant scan rate)	34
4.8	Parameter and error value(same potential different, different scan rate)	38
4.9	Result of LPR parameter value and error (different potential, constant scan rate 15mV/s	39

LIST OF FIGURES

Figure N	o. Title	Page
2.1	Potential versus Current Density	6
2.2	Effect of Tafel slope assumptions (B) on corrosion rate	9
2.3	An ambiguous of Icorr	12
2.4	Effect of scan rate on Potential and Current density	12
2.5	An ideal Tafelplot	13
2.6	The shift in the curve α as the potential is made more positive	14
2.7	Effects of assumption in assuming B values.	16
2.8	Flow Chart of Progress	18
3.1	Schematic of the experimental test cell and the electrodes configurations	24
4.1	The Tafel graph of scan rate 15mV/s	27
4.2	The tafel graph of scan rate 20mV/s	28
4.3	The tafel graph of scan rate 25mV/s	29
4.4	The combination of tafel graph of scan rate 15,20 and 25mV/s	30
4.5	Combining Tafel Graph(Different potential, constant scan rate)	32
4.6	LPR graph for scan rate 15mV/s	35
4.7	LPR graph for scan rate 20mV/s	35
4.8	LPR graph for scan rate 25mV/s	36

4.9	Graph of same potential different and different scan rate	37
5.0	LPR graph for constantscan rate and different potential	38

LIST OF SYMBOLS

%	Percentage
°C	Degree Celsius
cm	Centimeter
g	Gram
l	Liter
μ	Micro
m	Meter
mm	Millimeter
mm/y	Milimeters per year
Ba/ Bc	Tafel slope(anodic and cathodic), mV/decade
С	Capacitance, F
CR	Corrosion rate
Е	Potential, V
E∘	Initial Potential
E_{f}	Final Potential
Ecorr	Corrosion Potential,mV
I _{corr}	Corrosion Current Density, $\mu A/cm^2$
Μ	Molecular weight, g/mol
R	Resistance, ohms
R _p	Polarization Resistance
Т	Temperature, °C

LIST OF ABBREVIATIONS

А	Area
С	Carbon
Ca	Calcium
Cl	Chlorine
Cr	Chromium
Cu	Copper
D	Density
e	Electron
Н	Hydrogen
HCl	Hydrochloric Acid
H ₂ O	Hydrogen Oxide (Water)
K	Constant for corrosion rate
Na	Sodium
NaCl	Sodium Chloride
Ni	Nickel
O ₂	Oxygen gas
OH-	Hydroxyl
Р	Phosphorus
S	Sulphur
Si	Silicon
Т	Time of exposure
W	mass
Zn	Zinc

CHAPTER 1

INTRODUCTION

1.1 STUDY BACKGROUND

Corrosion can be defined as degradation of quality properties in a material due to the chemical reaction between the components of the material and the surrounding. Metal corrosion results in the deterioration of functional properties such as mechanical properties and mechanical strength.

There are many techniques in measuring corrosion rates such as weight loss and electrochemical method. As a result of the development of the fundamental understanding of corrosion electrochemistry, fast and accurate potentiostats, and computer technology, a suite of electrochemical techniques exists for the study of corrosion. These techniques provide the technologist with the ability to monitor corrosion rates in service, giving early warning of conditions that could adversely affect performance and integrity. They also provide the experimentalist with the ability to determine corrosion rate with high sensitivity, assess rate controlling mechanisms, and in some cases make life predictions. Furthermore, variations in electrochemical techniques and in-novative cell designs allow researchers to probe mechanisms and develop new and improved materials.

1.2 PROBLEM STATEMENT

A method to interpret corrosion current based on an electrochemical reaction is, recently, still under review. Tafel extrapolation, and linear polarisation (LPR), for example, are valid for any certain conditions, which are the electron transfer is fast, reversible reaction, similar accessibility, and equal diffusion coefficients. Oftenly, those conditions are difficult to achieve which lead to mis calculation and result uncertainties in prediction corroson rate. Thus, calculating uncertainty in measuring corrosion rate is important to give correction factors to the experimental data. It can also predict the erroneous data recorded from laboratory test.

1.3 OBJECTIVES

The objective of the study is to compare the experimental data recorded by several corrosion test, which are: LPR, Tafel and Weight Loss method. This research is also aimmed to investigate the uncertainties of those corrosion experiments in the same time calculate their erroneous data of corrosion with assuming conditions of pH, temperature, and acetic acid are to be constant.

1.4 SCOPE OF STUDY

- 1) The material used is carbon steel X52.
- 2) Corrosion rate of the material used is measured by weight loss method, and electrochemical technique (Linear Polarization Resistance and Tafel method.
- 3) The corrosion rate of each method are analyzed and compare to get the most efficient and lowest uncertainty.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter discussed on literature review of the theory of electrochemical method, tafel slope. It also discussed about the uncertainties in corrosion measurement using electrochemical method and the error of each method. The chapter starts with the introduction of corrosion measurement technique that have been involved in determining corrosion rate. Further, the experimental need to be conducted by using given method in order to make comparison by analyzing their uncertainties and error that have been occured. Thus, it will give a proven which those technique is most efficient by comparing the uncertainty and error value. By using same temperature, pH and acetic acid as parameter, the experiment will be conducted based on the methodology to achieve the objective of this project.

2.2 METHODS IN MEASURING CORROSION RATE

There are many methods in measuring corrosion rates, such as electrochemical and weight loss method. For this study, the electrochemical method consist of Linear Polarization Resistance (LPR) and Tafel method. By using electrochemical methods, it is possible to monitor as well as understand the actual electrochemical process taking place on the metal surface. Unlike weight loss method, electrochemical are fast in determining and analyzing the electrochemical properties. The electrochemical and weight loss methods used for this study are described in the following sub-sections.

2.2.2 LINEAR POLARIZATION RESISTANCE

Linear Polarization Resistance (LPR) is an affective electrochemical method in measuring corrosion rate. This method monitoring the relationship between electrochemical potential and current generated between electrically charged electrodes in a process stream allows the calculation of the corrosion rate. LPR is the most effective in aqueous solutions, and has proven to be a rapid response technique. The theory for LPR state that electrical conductivity (the reciprocal of resistance) of a fluid can be related to its corrosiveness. A two or three electrode probe is needed to be inserted into the process system, with the electrodes being electrically isolated from each other and the process line. A small potential in range of 20 mV is applied between the elements and the resulting current is measured. The polarization resistance is the ratio of the applied potential and he resulting current level. The measured resistance is inversely related to the corrosion rate. The electrical resistance of any conductor is given by:

Eq. (2.1)

$$R = \frac{V}{I} \tag{2.1}$$

Where R is effective instantaneous resistance, V is applied voltage and I is instantaneous current between electrodes. Free corrosion potential is the potential measured when no current flows through the electrode. This linear current-potential response is due to the exponential relation of anodic and cathodic currents of a corroding electrode to potential, derived from Butler-Volmer equation. Over a small potential range (<20 mV), the difference between cathodic and anodic exponential curves is almost linear (Bard, 2001). This linear dependence was first noted by Stern (1957) and he derived an equation known as Stern-Geary equation. He related the slope of the linear region to the Tafel slopes and corrosion current. Stern-Geary equation ;

Eq. (2.2)

$$R_p = \frac{B}{i_{corr}} = \frac{(\Delta E)}{(\Delta i)} \Delta E \to 0$$
(2.2)

 R_p is the polarization resistance, i_{corr} is the corrosion current. The proportionality constant, *B*, for a particular system can be determined empirically (calibrated from separated weight loss measurement). B can be calculated from b_a and b_c that are anodic and cathodic Tafel slopes respectively.

Eq. (2.3)

$$B = \frac{b_{a.}b_{c}}{2.3(b_{a+}b_{c})} \tag{2.3}$$

The Tafel slopes themselves can be evaluated experimentally using real polarization plots. The corrosion currents estimated using these techniques can be converted into penetration rates using *Faraday's* law. Equation 2.2 served as an important tool for a new experimental approach to study the electrochemistry of corrosion reactions. The Linear Polarization Resistance (LPR) technique is based on the above mentioned theoretical fact. It is a non destructive method used for calculating polarization resistance which in turn used for calculating corrosion rate.

LPR technique generates a plot of current verses potential over a small potential range. In this method the metal sample is polarized step-wise, starting below the corrosion potential (usually -20 mV) and ending above the corrosion potential (usually +20 mV). The plot of current versus potential is linear, the slope of which gives the polarization resistance (Rp). The polarization resistance is inversely proportional to the uniform corrosion rate and can be used in the Stern-Geary equation to determine the corrosion current and corrosion rate as shown in Figure 2.1.



Figure 2.1 : Potential versus Current Density

Source: Gasem, 2005.

The advantage of LPR technique is that data acquisition can be done quicker compared to other electrochemical methods. This method is non destructive since the potential applied the sample is very small. The main demerit of this technique is that it needs Tafel data to calculate the corrosion rate, which must be obtained either from literature or from other experiments.

2.3 UNCERTAINTIES IN CORROSION MEASUREMENT USING ELECTROCHEMICAL TECHNIQUE

Tafel equations are method to calculate the corrosion rate based on electrochemical process which relates to electron flow and other potential. Although this method has been applied intense, but theoretically it contains problems openly to discuss. So far, researchers have applied a different assumption regarding calculating corrosion rate based on LPR technique. Even more, Streeter stated that Tafel equation is only valid at the tubular flow electrode when axial and radial diffusion are insignificant (Streeter, 2006). An uncertainty also arises from the Tafel experiment error, systematic and stochastic error. It can be calculated an un-acceptable absolute error of 27% -30% (Fritz, 2004).

Identification and measurement of error are important to minimize a noisy data and design a better experiment which may be able to find a better solution. This discussion will comment how researchers apply the method in reporting the corrosion data compared with experiment's data.

2.3.1 LINEAR POLARIZATION ERROR

Tafel's method is considered the correlation between current density versus over-voltage. By using a linear polarization technique (LPR), corrosion rate for mild steel is calculated by the formula (2.4):

Eq. (2.4)

$$CR = 0.503 \frac{\beta_a \beta_c}{(\beta_a + \beta_c)} * \frac{1}{R_p}$$
(2.4)

Thus, relative deviation of corrosion rate calculated due to component variable can be expressed as (2.5):

Eq. (2.5)

$$\frac{\delta CR}{CR} = \left[\frac{\delta(CR)}{\delta T}\right]\frac{\delta T}{CR} + 2\left[\frac{\delta(CR)}{\delta E}\right]\frac{\delta E}{CR} + 2\left[\frac{\delta(CR)}{\delta I_{app}}\right]\frac{\delta I_{app}}{CR} + 2\left[\frac{\delta(CR)}{\delta a}\right]\frac{\delta a}{CR}$$
(2.5)

Then Fritz made a derivation expression above to become Equation (2.6):

Eq. (2.6)

$$\frac{\partial CR}{CR} = \left[\frac{m_1}{\beta_a} + \frac{m_2}{\beta_c}\right] \delta T - \frac{2}{E} \delta E + \frac{2}{I_{app}} \delta I_{app} - \delta_a$$
(2.6)

This formula means that overall uncertainty variable in the corrosion calculation by LPR technique is due to instrumentation (potential, applied current, working electrode surface area) and Tafelslope (β). By making an assumption that Tafel slope is in certain value, Fritz accounted an error of 27%. In additional to effect of preparation solution and changing of specimen surface, he recorded a total error of 34%. Such LPR technique has uncertainties as described above.

2.3.2 TAFEL SLOPE UNCERTAINTIES

Refer to Equation (2.6) which Fritz calculated an absolute error, it seems still to have a un-considered of uncertainty. The other uncertainties are erroneous from deviation due to an assumption of an exact value of the Tafel slope (β). So far, this slope is under discussion intensifying. As presented in Figure 1, It shows a different perception of slope that bring an addition to uncertainty corrosion rate calculation of 20% (Mokhtar, 2005).

Tafel slope in LPR equation demonstrates a calculation instantaneous corrosion rate. There are two slopes which consist of anodic and cathodic slope to calculate corrosion rate.

Eq. (2.7)

$$\beta_{a} = \frac{2.303 \text{RT}}{\alpha_{a} \text{F}}$$
(2.7)

Eq. (2.8)

$$\beta_c = \frac{2.303RT}{\alpha_c F} \tag{2.8}$$

Where β_a and β_c is anodic and cathodic Tafel slope, respectively, and α is coefficient of electron transfer. The coefficient of transfer electron of α is usually taken about 0.5 (Chemberlain, 1995). While cathodic and anodic Tafel slope (β_{anodic} , $\beta_{cathodic}$) is about 30 mV/decade to 100 mV/decade, respectively. They did not give an alternative value of those constants. The use of rate anodic and cathodic Tafel constants were assumed of 60 and 120 mV/s during the experiments of solution contained different Acetic Acid concentration (Hedges, 1999). This value was also followed by many other researchers. A range of 60 – 120 for both cathodic and anodic Tafel slope in activation regime (Denny, 1996). Further, it mentioned a similarity factor of α which is the difference value of β_{anodic} and $\beta_{cathodic}$. In his discussion, it is analyzed that the maximum error will occur in the greatest difference of α .

A constant value of 25 mV for B value in the solution experiment contained CO₂ gas and Acetic species. β_{anodic} , $\beta_{cathodic}$ can not be considered individually and effects of α for different temperature and different composition concentration, as well as different flow rate regime. It, so far, seems to be acceptable (Mokhtar, 2005).



Figure 2.2 Effect of Tafel slope assumptions (B) on corrosion rate

Source: Yuli, Application of Response Surface Design, 2010.

Approximation of Tafel slope by Mokhtar is in contrast with Keith George and Srdjan Nesic observations (George, 2004). These opponent researchers suggested that Tafel slope must change according to degree of temperature, composition and concentration. They found that when no acetic acid was present, the value of $b_a = 40$ mV/dec and $b_c = 120$ mV/dec. But in solution with acetic acid, ba is 80 mV/dec. The different composition of acetic acid and CO₂ caused different value of anodic Tafel slope. In general, Tafel slope increased with increasing of pH and decrease with increasing species concentration. The range value of anodic slope was 25 mV/dec to 120 mV/dec.

The role of other species such as H_2S in solution contained acetic acid and CO_2 . (Veloz, 2002). Tafel slope value increase with the presence of 0.104 M H₂S. Tafel anodic slope goes up from 93 mV/dec to 135 mV/dec and from 262 mV/dec to 235 mV/dec for cathodic slope.

Temperature is also contributed to change Tafel slope behavior (Fransson, 2005). The increased of temperature from 20° C to 95° C had given an increase result of $b_a = 50 \text{ mV/dec} - 56 \text{ mV/dec}$ (anodic slope) and $b_c = 15 \text{ mV/dec} - 207 \text{ mV/dec}$ (cathodic slope).

2.3.3 POLARIZATION LIMITATION

Anodic and cathodic Tafel slopes to calculate corrosion rate is obtained by Tafel plot. By conducting a potentio-dynamic sweeps from \pm 10 mV refer to open circuit potential, polarization curves is plotted. Potential and current relationship regime is governed by a corrosion reaction. Then, the free corrosion potential and potential corrosion (E_{corr} and I_{corr}) point occurs at the mixed point of intersection of anodic and cathodic current. Accuracy of polarization plot is mostly influenced by scan rate and solution dynamics.

2.3.4 EFFECT OF SCAN RATE

Because of unstability composition solution and dynamics electrochemical reaction, the Tafel plot results an unhopefully linearity region. There has been, sometimes, more than one possibility for Tafel slope line. One of the factors influenced Tafel plot is scan rate. Effect of different scan rate makes a different potential and current plot as shown in Figure 2.3. These feature plots are under user control. Conducting a very slow of scan rate will cause an unstable plot. While, the fast scan will result an uncomplete electrochemical reaction process, the specimen is not allowed time to reach a stable potential.

Satpati observed a different scan rate that has caused a different result on his data as shown in Figure 2.4 (Satpati, 2005). When lowest scan rate was applied to zircaloy in NaCl solution, pit initiated at edges. It initiates at the scratch at intermediate scan rate. But, uniform distribution of pits was seen at higher scan rates. He correlated this behavior with thickness of passive film formed and its changes of potential during scanning.

ASTM recommends a standard test (G59) for potentiodynamic polarization test with the scan rate of 0.6 V/h (0.16 mV/s) from $\Delta E = -30$ mV to $\Delta E = +30$ mV and back to $\Delta E = -30$ mV. The plot should be linear, go through the origin. The curves recorded for the forward and reverse scans should be identical. However, with any reasons, researchers did not conduct that recommended rate., .For examples, Papavinasan (Papavinasam, 1999), Bill Hedges (Hedges, 1999), are the researcher who run scan rate of 0.5 mV/s, 1 mV/s, 0,1 mV/s respectively. Keith and George did a sweep of 0.2 mV/s rate.



Figure 2.3: An ambiguous of Icorr





Figure 2.4: Effect of scan rate on Potential and Current density

Source: Satpati, Potential Scan Rate Dependent Pitting Corrosion, 2005.

2.3.5 CHARGER TRANSFER REACTION EFFECT ON TAFEL PLOT

An ideal curve is reached when relationship both of E and log (i) in a linear curve. When $\alpha = 0.5$, this value gives a symmetry plot at a corrosion potential or zero over-voltage (Figure 2.5).



Figure 2.5: An ideal Tafel plot

Source: ASTM G 5-94.

The fact that an ideal of Tafel plot is quite difficult to obtained. It has to have stable reaction kinetics and both reduction and oxidation energy barrier is identical. Such that the total of α must be one. When standard free energy is not the same, bring the shift of Tafel slope to asymmetry plot. Tafel slope described by Fenton in Figure 2.5) show the case of a one-electron transfer reaction is asymmetry (Fenton, 2006).



Figure 2.6: The shift in the curve α as the potential is made more positive

Source: Fenton, . Fuel Cell Technology Short Course, 2006.

Marcus, as reported by Petrii, developed a theory of the transfer coefficient as a function of over voltage and reorganization energy for adiabatic reactions as expressed as equation (2.9).

Eq. (2.9)

$$\alpha = \frac{1}{2} - \frac{F\eta}{2\lambda} \tag{2.9}$$

For diabatic reaction, homogenous electron transfer and over potential near to zero, Marcus wrote a more simple equation as following (2.10).

Eq. (2.10)

$$\alpha \approx 1 - n(\acute{\epsilon}) \tag{2.10}$$

Where, $\dot{\epsilon}$ is the effective energy level. If $\dot{\epsilon}$ in the significantly lower than Fermi level, the condition is called as an activation-less discharge which is near to zero for α value. According to Marcus equation, a prediction of 0.5 value of α for zero overvoltage has a maximum error in the interval of ~ 0.05 λ/F .

The deviation of charge transfer coefficient from 0.5 can be explained by modern theory (Petrii, 2006). The prediction is there are some source that causes transfer coefficientbehavior deviate from 0.5. Firstly, effect of intra-molecular reorganization energy as can be expressed in the equation (2.11). If $\lambda_{in} / \lambda_s <<1$, then the transfer coefficient exceeds 0.5 at zero over-voltage. For the opposite limit $\lambda_{in} / \lambda_s >>1$, the transfer coefficient below 0.5 at zero over-voltage.

Eq. (2.11)

$$\alpha \approx \frac{1}{2} \left(1 \pm \frac{\dot{\lambda}_{in}}{\lambda_s} \right) - \frac{F\eta}{2\lambda_s}$$
(2.11)

Where, λs is the solvent reorganization energy, $\vec{\lambda}$ and $\vec{\lambda}$ refer to the intramolecular reorganization energy for reduction and oxidation, respectively.

Further, Petrii discussed factors influenced transfer coefficient. They considered effects of intramolecular reorganization, orbital overlap, reactant quantum modes and solvent dynamics. The main conclusion is that majority α can be near to 0.5 and overvoltage independence at η equal to 0. However, there are many examples which transfer coefficient falling beyond 0.45-0.55.

Effect of α assumption ranged from 0.44-0.56 make a different value of B Tafel slope as pictured at figure 5 below. This different assumption of α has increased an uncertainty of corrosion rate about 5%.



Figure 2.7: Effects of assumption in assuming B values.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this proposed investigation, prediction corrosion rate is calculated under atmospheric environment. The temperature, pressure, pH and the concentration of the solution are assume to be constant in atmospheric condotion. For non-electrochemical method (weight loss), three specimen of carbon steel will be used in this experiment. While for electrochemical, the experiment was conducted by using potensiostat and analyzed by using Ivman in determining the corrosion rate, Rp value and calculating the error.

Laboratories corrosion experiments were conducted using carbon steel X5 exposed in atmospheric environments at the pressure condition of 1 bar and at room temperature at 23°C.

3.2 FLOW CHARTOF WORK PROGRESS



Figure 2.8: Flow Chart of Work Progress

3.3 EXPERIMENTAL PROCEDURE

The experiment used in determine corrosion rate value are devide into to types non-electrochemical and electrochemical technique. Non-electrochemical is used weight loss, while electrochemical used are Linear Polarization Resistance (LPR) and Tafel method.For electrochemical, The Tafel graph get form Potensiostat analyzed by using Ivman software.

3.3.1 NON-ELECTROCHEMICAL (WEIGHT LOSS)

Three specimen of Carbon Steel X52 were to be cut into dimension (2 cm x 2 cm x 0.5 cm). Then, the specimen were drilled to to make a hole at the centre. The area of the specimen are 11cm^2 . Then, the surface of the specimen were polished successively with 240, 400 and 600 grit SiC paper.

After that, the specimen need to be rinsed with alcohol and degreased using acetone to remove away oil or other burss on the surface. The specimen then need to be weighted. Then, the specimen immersed in NaCl solution 3.5% wt about 2 weeks (168 hours).

After two weeks, the specimen were taken out and cleaning with HCL acid to remove the corrosion product and burrs at the surface. The specimen reweighted again and the mass loss can be calculated to get the corrosion rate value.

3.3.2 ELECTRODE

A three-electrode set-up was used in all electrochemical experiments. A carbon steel was mounting with resin in cylindrical shape and employed as the working electrode. Glass cell was fitted with graphite electrodes as an auxiliary electrode and a Saturated Chemical Electrode (SCE) as a reference electrode.

3.3.3 SPECIMEN PREPARATION

The working electrodes are carbon steels X52 which have chemical compositions as can be seen in Table 3.1. It is a rectangular shape of (2 cm x 0.5 cm) that give area about 1 cm². Before immersion, the specimen surfaces are polished successively with 240, 400 and 600, 1200 grit SiC paper, rinsed with alcohol, and degreased using acetone.

 Table 3.1: Carbon Steel X52 chemical composition.

Chemical	С	Si	Mn	Р	S	Cr	Mo	Ni	Cu
constituent									
Composition	1.00	0.168	0.601	0.003	0.0266	0.108	0.014	0.0737	0.280
(wt. %)									

3.3.4 CELL SOLUTION

The experiments will be performed in static solutions condition. The total pressure is 1 bar, the temperature was 22°C (room). Initially, glass cell is filled with 1 liter of distilled water and 3.5% wt NaCl was stirred with magnetic stirrer. After the solution was prepared, the pH was measured to reach the pH setting 4. Monitoring of pH is used to determine whether the solution is in equilibrium.

3.4 CORROSION RATE MEASUREMENTS.

Measurement of corrosion rate of each method will be calculated and analyzed by using their formula. Ivman will analyzed LPR and Tafel method automatically by using the Tafel graph from Potentiostat.

3.4.1 WEIGHT LOSS

The unit used for this calculation in determining the corrosion rate is mm/y. The formula for weight loss is: Eq. (3.1)

$$CR : (K \times W)/(A \times T \times D)$$
 (3.1)

Where:

 $K = a \text{ constant } (8.76 \text{ x } 10^{-4})$

T = time of exposure in hours

 $A = area in cm^2$

W = mass loss in grams

 $D = Density in g/cm^3$

3.4.2 TAFEL METHOD

Tafel method was used in to predict the polarization resistance (R_p) and corrosion rate value (CR). The Tafel is an equation in electrochemical kinetics relating the rate of an electrochemical reaction to the overpotential. The technique can be used to determine icorr, which in turn can be used to calculate the corrosion rate. Scans are performed close to the open circuit potential (-500 mV for an anodic scan and +500 mV for a cathodic scan). The corresponding trace must have a point where the current measured is equal to zero.

Data from potensiostat will be analyzed by using Ivman with using tafel method. Same with LPR method, the parameter used in potensiostat were done with using two experiment method that will give different results to obtain the tafel graph are shown in Table 3.2.

Experiment	1			2					
Potential Different (voit) E _{initial} : -0.5 V	$E_{initial}$: -0.5 V	$E_{\text{final}}: 0.5 \text{ V}$		1) E _{initial} : -0.5 V	E_{final} : 0.5 V	2) $E_{initial}$: -1 V	E_{final} : 1 V	3) E _{initial} : -1.5 V	E_{final} : 1.5 V
Scan rate (mV/s) 1) 15	1) 15	2) 20	3) 25	15					
Sampling time (s) 1) 67	1) 67	2) 50	3) 40	1) 67	2) 133	3) 200			
Density (gm/cm ³) 7.85	7.85			7.85					
Sample Area (cm ²) 1	1			1					
Equivalent weight 27.92	27.92			27.92					

Table 3.2 : Parameter of potensiostat

3.4.3 LINEAR POLARIZATION RESISTANCE

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

Eq. (3.2)

$$I_{corr} = \frac{b_a b_c}{R_p 2.303(b_a b_c)}$$
(3.2)

Eq. (3.3)

$$R_{p} = \frac{B}{i_{corr}} = \frac{(\Delta E)}{(\Delta i)_{\Delta E \to 0}}$$
(3.3)

Eq. (3.4)

$$B = \frac{b_a \cdot b_c}{2.3(b_a \cdot b_c)} \tag{3.4}$$

Corrosion rate = I_{corr} 3272 EW/ ρA

Where:

CR : Corrosionrate (mm/y)

I_{corr} : Corrosion current (amps)

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

EW : The equivalent weight in grams/equivalent

 ρ : Metal density (grams/cm³)

A : Sample area (cm^2)

3.5 TEST PROCEDURE

3.5.1 POTENSIOSTAT SET UP

During the experiment, the corrosion potential and LPR of the cylindrical rod were measured every 15 minutes during 10 hours. The reading of the corrosion rate was determined using potentiostat WonaTech using scan rate of 15, 20 and 25 mV/s. The procedure is similar to that described in ASTM G 5-94 - standard reference test method for making potentiostatic and potentiodynamic polarization measurements and ASTM G 102 - practice for calculation of corrosion rates and related information form electrochemical measurements.

The typical experimental arrangement for the static test is illustrated in Figure 3.1.



Figure 3.1: Schematic of the experimental test cell and the electrodes configurations.

3.6 CALCULATING CORROSION RATE VALUE, R_p UNCERTAINTIES AND ERROR IN EXPERIMENTS

Identification and measurement of error is conducted by using mathematical formula. The discussion will comment how re-searchers apply the method in reporting the corrosion data compared with experiments data. Based on the error calculation, it will be recommended the use of the method which is satisfied statistically.

The basic steps for measurement errors and uncertainty calculation are outlined below.

- 1. Define the Measurement Process.
- 2. Identify the error sources.
- 3. Select the appropriate error distributions
- 4. Estimate process uncertainties.

CHAPTER 4

RESULTS AND DISCUSSION

4.1 INTRODUCTION

In this chapter will discuss mainly about the result of the project, analysis and discussion about the project and all problems encountered during the whole project was been carried out.

4.2 RESULT

4.2.1 WEIGHT LOSS METHOD

For weight loss method, the specimen were cleaning to remove the corrosion product with using HCL acid to remove the corrosion product at the surface of the specimen. Then, the specimen was reweighing to get the value of weight loss. The corrosion rate are determined further by making the average corrosion rate value of 3 specimen. The result of weight loss is shown in Table 4.1.

Table 4.1: Result for weight loss

No of Specimen	Before (grams)	After (grams)	Weight Loss (grams)
1	18.919	18.823	0.096
2	18.765	18.663	0.102
3	18.834	18.741	0.093

The total average weight loss is 0.097 grams. Then, the calculation of corrosion rate of weight loss in mm/y:

4.2.2 TAFEL METHOD

The data obtained from potentiostat were analyzed by Ivman software to predict the value of polarization resistance, (R_p) and corrosion rate, (CR). By using scan rate 15, 20 and 25 mV/s and constant potential different, $E_{initial}$: -0.5 V and E_{final} : 0.5 V, the parameter value get from data is in Figure 4.1.

Potential Different(V) vs Log Current (I)

Tafel



Figure 4.1: The Tafel graph of scan rate 15 mV/s.

From Figure 4.1, the Tafel graph show that the interception of anodic current (blue line) and cathodic current (green line) give E_{corr} and I_{corr} value. E_{corr} value can be predict as -756.71754 x 10⁻³ while the I_{corr} value is 14.9668 x 10⁻⁶. The anodic Tafel slope (B_a) value is 0.16076 volts/decade and cathodic Tafel slope (B_c) is 0.19846 volts/decade. The red line Tafel slope shows the corrected of Tafel slope after fitted.



Potential Different(V) vs Log Current (I)

Figure 4.2 : The tafel graph of scan rate 20 mV/s.

From Figure 4.2, the Tafel graph show that the interception of anodic current (blue line) and cathodic current (green line) give E_{corr} and I_{corr} value. E_{corr} value can be predict as -825.35116 x 10⁻³ while the I_{corr} value is 36.12041 x 10⁻⁶. The anodic Tafel slope (B_a) value is 0.19160 Volts/decade and cathodic Tafel slope (B_c) is 0.18798 volts/decade. The red line Tafel slope shows the corrected of Tafel slope after fitted.



Potential Different(V) vs Log Current (I)

Figure 4.3: The tafel graph of scan rate 25 mV/s.

From Figure 4.3, the Tafel graph show that the interception of anodic current (blue line) and cathodic current (green line) give E_{corr} and I_{corr} value. E_{corr} value can be predict as -825.41628 x 10⁻³ while the Icorr value is 125.72699 x 10⁻⁶. The anodic Tafel slope (B_a) value is 0.17998 volts/decade and cathodic Tafel Slope (B_c) is 0.20665 volts/decade. The red line Tafel slope shows the corrected of Tafel slope after fitted.



Figure 4.4 : The combination of Tafel graph of scan rate 15, 20 and 25 mV/s.

Figure 4.4 is a combination ideal graph of Tafel that show the different value of scan rate which gives inconsistent value of E_{corr} and I_{corr} value. The graph shows that the E_{corr} value becomes lower from scan rate 15 and 20 mV/s. But, the inconsistent and error from experiment makes the E_{corr} value not stable where the E_{corr} value rises when the scan rate is 25 mV/s. Same with the Icorr value of the three Tafel graph, the I_{corr} also become lower from scan rate 15 mV/s to 20 mV/s. The I_{corr} was rise again when the scan rate is 25 mV/s.

The data obtained from potentiostat were analyzed by Ivman to predict the value of polarization resistance, R_p and corrosion rate, CR. By using scan rate 15, 20 and 25 mV/s and constant potential different, $E_{initial}$: -0.5 V and E_{final} : 0.5 V. The parameter value, results and errors get from data as in Table 4.2.

Parameter	Scan rate value (mV/s)						
	15 20		25				
Ecorr	-756.7175 x 10 ⁻³	-825.35116 x 10 ⁻³	-825.41628 x 10 ⁻³				
I _{corr}	14.96688 x 10 ⁻⁶	36.12041 x 10 ⁻⁶	125.72699 x 10 ⁻⁶				
Ba	0.16076	0.19160	0.17998				
B _c	0.19846	0.18798	0.20665				

Table 4.2: Parameter results for constant potential voltage and different scan rate.

Table 4.2 shows the true correctness results of data after the Tafel slope have been fitted. The results show that E_{corr} and I_{corr} value become lower due to increa-sing in scan rate. While, B_a and B_c was increasing with the increasing value of scan rate.

Table 4.3: Results of R_p and CR for constant potential voltage and different scan rate.

Scan rate (mV/s)	Rp (ohm)	CR (mm/y)
15	2577	0.177731
20	1141	0.42035
25	332.225	1.463

Table 4.3 shows the results of R_p and CR value after the Tafel slope have been fitted. The results show that R_p value become lower due to increasing in scan rate. While, CR value become increasing due to increase in scan rate.

Then, the Ivman analysis from data to obtain the value of R_p and corrosion rate will give some error when plotting the Tafel slope. The errors came from each of parameter value are given as Table 4.4.

Parameter	Scan rate value (mV/s)						
	15	20	25				
E _{corr}	34.20973 x 10 ⁻³	35.17919 x 10 ⁻³	43.2396 x 10 ⁻³				
I _{corr}	7.33287 x 10 ⁻⁶	16.16667 x 10 ⁻⁶	50.9371 x 10 ⁻⁶				
Ba	0.00840	0.02640	0.02589				
B _c	0.04074	0.02588	0.04233				

Table 4.4: Result of errors for constant potential different (E_{intial} : -0.5 V, E_{final} : 0.5 V)and different scan rate.

Table 4.4 shows that the result for constant voltage and different scan rate, the parameter value used for potential is constant at 1v. While, the scan rate used are 15, 20 and 25 mV/s. It can be show that The E_{corr} value is decreasing when the scan rate become higher from 15, 20 and 25 mV/s. While the value of B_a and B_c is not consistent when the scan rate become higher.



Figure 4.5: Combining Tafel graph (Different potential, constant scan rate).

Figure 4.5 shows the ideal Tafel graph before it was fitted. The ideal graph of Tafel show that same value of scan rate gives a consistent value of E_{corr} and I_{corr} value.

All three Tafel graph shows that the E_{corr} value is relatively same if the same scan rate was used. The different parameter of potential different give no effect of both I_{corr} and E_{corr} value. It can be concluded that different value of potential voltage give no change for I_{corr} and E_{corr} value.

Parameter	Potential different, V (E°, Ef)						
	(-0.5,0.5)	(-1.0,1.0)	(-1.5,1.5)				
E _{corr}	-756.71754 x 10 ⁻³	-1.01858	-848.71693 x 10 ⁻³				
I _{corr}	14.96688 x 10 ⁻⁶	220.24005 x 10 ⁻⁶	516.41432 x 10 ⁻⁶				
Ba	0.16076	0.81220	1.22233				
Bc	0.19846	0.22055	0.37523				

Table 4.5: Result of tafel parameter value for different potential and constant scan rate

15 mV/s.

The result in Table 4.5 show that the value of E_{corr} value is decreasing due to increasing of potential different. Icorr value also show same behavior as E_{corr} where the value of I_{corr} also deacreasing. While, B_a and B_c were increasing when the potential was increasing.

Table 4.6: Result of R_p and CR value (different potential, constant scan rate).

Potential Different, V (E°,Ef)	R _p (ohm)	CR (mm/y)
(-0.5,0.5)	2577	0.177731
(-1.0,1.0)	341.971	2.615
(-1.5,1.5)	241.398	6.132

The R_p and CR value where obtained from tafel graph's plotted show some changes when different potential was used. The R_p value is deacreasing when the potential is high. However, it was different for CR value where the value of CR is increasing.

Then, the Ivman analysis from data to obtain the value of R_p and corrosion rate will give some error when plotting the Tafel slope. The errors came from each of parameter value are given as Table 4.7.

Parameter	Error						
	(-0.5 V, 0.5 V)	(-1 V, 1 V)	(-1.5 v, 1.5 v)				
E _{corr}	34.20973 x 10 ⁻³	8.48249 x 10 ⁻³	53.17605 x 10 ⁻³				
Icorr	7.33287 x 10 ⁻⁶	27.81161 x 10 ⁻⁶	361.7509 x 10 ⁻⁶				
Ba	0.00840	0.08502	4.96145				
B _c	0.04074	0.01490	0.05573				

Table 4.7: Error of Tafel's parameter (different potential, constant scan rate).

The result in Table 4.7 show that the error of E_{corr} value is not consistent. The error become lower for different potential at 2 v then it increased back at different potential 3v. For error of Icorr,the error become increasing when potential different is become high. The error for B_a and B_c also become higher when the potential different increase.

4.2.3 LINEAR POLARIZATION RESISTANCE

The data obtained from potentiostat were analyzed by Ivman software to predict the value of polarization resistance, Rp and corrosion rate, CR.. By using scan rate 15, 20 and 25 mV/s and constant potential different, $E_{initial}$: -0.5 V and E_{final} : 0.5 V, the LPR graph of scan rate 15, 20 and 25 mV/s are shown in Figure 4.6 to Figure 4.8.



Potential Voltage(v) vs Current(A)

Figure 4.6: LPR graph for scan rate 15 mV/s.



Figure 4.7: LPR graph for scan rate 20 mV/s.



Figure 4.8: LPR graph for scan rate 25 mV/s.

Figure 4.8 shows the three graph of the reaction rate (corrosion current) can be expressed as being proportional to the exponential of the voltage offset from the corrosion potential for one oxidation (anodic) and one reduction (cathodic) reaction. Uncompensated resistance in the electrolyte and leads is either absent or is much smaller than the polarization resistance. The polarization resistance as measured by this technique is equal to the sum of all resistances of which the actual polarization resistance is one contributor. To estimate the rate of uniform corrosion from the polarization resistance, each reacting site across the entire electrode surface is assumed to function simultaneously as a cathode and an anode. The anodic and cathodic sub-reactions do not occur on different sites. The linear graphs shows that R_p is equal to applied voltage ($\Delta \varepsilon$) over instanteneous current between electrode. The R_p value for scan rate 15 mV/s is 830.229, for 20 mV/s is 447.751 and for 25 mV/s is 146.535. It shows that the value of R_p value is deacreasing with increasing the scan rate value. Value of B_a and B_c is assume to be 0.12.



Figure 4.9: Graph of same potential different and different scan rate

Figure 4.9 shows that the lower scan rate used for the experiment, the higher value R_p will be get. It is because the lowest scan rate will make the higher polarization of the graph. For activation polarization, the bigger applied voltage of potential different will be resulted if lower scan rate used. While, the small aplied voltage will resulted if bigger scan rate used. Sampling time used for the reaction actually will increase if small scan rate is used.

The data obtain from potensiostat were analyzed by using Ivman software with using LPR method to predict the R_p and CR value. By using scan rate 15, 20 and 25mV and constant potential different, $E_{initial}$: -0.5 V and E_{final} : 0.5 V, the parameter value and the errors are get as results as in Table 4.8.

Parameter	Scan Rate (mV/s)					
	15	Error	20	Error	25	Error
Linear	830.229	35.042	447.751	11.150	146.535	6.110
Polarization(R _p)						
Voltage Offset	-1.028	0.0116	-1.09	0.008	-0.878	0.0045
Delta V	0.418		0.520		0.375	
Ba	0.12		0.12		0.12	
Bc	0.12		0.12		0.12	
CR (mm/y)	0.373		0.677		2.07	

Table 4.8: Parameter and error value (same potential different, different scan rate)

Table 4.8 shows that R_p value is decreasing due to increasing in scan rate. The B_a and B_c are assume to be equal to 0.12. The result of errors also show that it were deacreasing if higher scan rate is used. The CR get from this experiment also show that it will become increasing if higher scan rate is used.



Figure 5.0: LPR graph for constant scan rate and different potential

The result of LPR parameter value and error for different potential and constant scan rate 15 mV/s in this experiment are shown as Table 4.9.

Parameter	Potential Different,v (E°, E _f)								
	(-0.5,0.5)	error	(-1,1)	error	(-1.5,1.5)	error			
Linear	830.229	35.042	519.742	22.491	244.895	21.390			
Polarization									
(\mathbf{R}_p)									
Voltage Offset	-1.028	0.0116	-1.032	0.014	-0.952	0.012			
Delta V	0.418		0.745		0.522				
Ba	0.12		0.12		0.12				
Bc	0.12		0.12		0.12				
CR (mm/y)	0.373		0.595		1.263				

Table 4.9: Result of LPR parameter value and error (different potential, constant scanrate 15 mV/s

From Table 4.9, it shows that all three graph is relatively no change between each other. The activation polarization shows that changes the potential different give not much effect for linearity of the graph. The errors are become lower when bigger potential is used. The value of CR is more higher when different potential applied at the electrode.

4.3 DISCUSSION

From the experiment's result, uncertainties are erroneous from deviation due to an assumption of an exact value of Tafel slope (β). So far, this slope is under discussion intensively. For Tafel slope graph, it shows a different perception of slope that bring an addition to uncertainty corrosion rate calculation of 20%. Tafel slope in LPR equation demonstrate a calculation instantaneous corrosion rate. There are two slopes which consist of anodic and cathodic slope to calculate corrosion rate.

Where βa and βc is anodic and cathodic Tafel slope, respectively, and α is coefficient of electron transfer. The coefficient of transfer electron of α is usually taken about 0.5. While cathodic and anodic Tafel slope (β_{anodic} , $\beta_{cathodic}$) is about 30 mV/decade to 100 mV/ decade, respectively. They did not give an alternative value of those constants.

Potential and current relationship regime is governed by a corrosion reaction. Then, the free corrosion potential and potential corrosion (E_{corr} and I_{corr}) point occurs at the mixed point of intersection of anodic and cathodic current. Accuracy of polarization plot is mostly influenced by scan rate and solution dynamics.

Because of unstability composition solution and dynamics electrochemical reaction, the Tafel plot results an unhopefully linearity region . There has been, sometimes, more than one possibility for Tafel slope line. One of the factors influenced Tafel plot is scan rate. Effect of different scan rate makes a different potential and current plot. These feature plots are under user control. Conducting a very slow of scan rate will cause an unstable plot. While, the fast scan will result an uncomplete electrochemical reaction process, the specimen is not allowed time to reach a stable potential

The fact that an ideal of Tafel plot is quite difficult to obtained. It has to have stable reaction kinetics and both reduction and oxidation energy barrier is identical. Such that the total of α must be one. When standard free energy is not the same, bring

the shift of Tafel slope to asymmetry plot. Tafel slope described by Fenton show the case of a one-electron transfer reaction is asymmetry.

CHAPTER 5

CONCLUSION

5.1 INTRODUCTION

This chapter will discuss about the conclusion of this research. The conclusion is made from the objective and also problem statement. The result collect show the objective is achieved.

5.2 CONCLUSION

The highest error from this experiment is from LPR tehnique which give uncertaint value of R_p and CR. Weight loss method considered the the most efficient tehnique in measuring corrrosion rate which give the value 0.3mm/y. From theory,the value of CR of Carbon Steel X52 is 0.5 mm/y.

5.3 **RECOMMENDATION**

For better result to get corrosion rate and Tafel graph, the preparation and potensiostat setup is need to be improved. The Saturated Chemical Electrode (SCE) need to be used carefully in order the error can be overcame.

REFERENCE

- ASTM G 5-94 Standard Reference Test Method for Making Potentiostatic and Potentiodynamic Polarization Measurements.
- Bard, A. J. and Faulkner, L. R. 2001. *Electrochemical Methods: Fundamentals and Applications*. New York: John Wiley and Sons, Inc.
- Denny, J. 1996. Principal and prevention of Corrosion. United Kingdom: Prentice Hall, Inc.
- Fenton, J. and Ramani, V. 2006. Fuel Cell Technology Short Course, Florida Solar Energy Center, Cocoa, February: 5.
- Fransson, M. L. 2005. Understanding Corrosion Inhibition: A Surface Science Study of Thiophene Derivatives on Iron Surfaces in Gaseous and Liquid Systems. Ph.D Dissertation, University of Princeton.
- Fritz, J. and Dolores, T. 2004. *Film Formation and CO2 corrosion in the presence of Acetic Acid.* Ph.D. Thesis. University of Ohio.
- George, K. and Nesic, S. 2004. Electrochemical Investigation and Modeling Carbon Dioxide Corrosion of Carbon Steel in The Presence of Acetic Acid. *Proceedingsof theNACE Annual Corrosion Conference*, pp 43.
- Hedges, B. and Lorraine M. V. 1999. The Role of Acetate in C02 Corrosion: The Double Whammy. *Proceedings of the NACE Annual Corrosion Conference*, pp 12-13.
- Mokhtar, I. C. 2005. *Prediction CO2 Corrosion With The Presence of Acetic Acid*. Ph.D. Thesis, UMIST.

Papavinasam, S. and Revie, R.W. 1999. Synergistic Effect of Pressure and Flow on Corrosion Rates: Studies Using High-Temperature, High-Pressure Rotating Electrode System Corrosion. *Proceedings of the NACE* Annual Corrosion Conference, pp 30.

Satpati, A.K., Phadnis, S.V and Sundaresan, R.I. 2005. Electrochemical and XPS studies and the potential scan rate dependent pitting corrosion behavior of Zircaloy-2 in 5% NaCl solution. *Corrosion Science*, 47: 1445-1458

- Streeter, I. and Richard, G. C. 2006. *Mass transport corrected Tafel analysis of voltammetric waves*. Electrochimica, Inc.
- Trethewey, K.R. and Chemberlain, J. 1995. *Corrosion for Science and Engineering*: Leichester: Longman, ltd.
- Veloz, M. A. and Gonza'lez, M. 2002. Electrochemical study of carbon steel corrosion in buffered acetic acid solutions with chlorides and H2S. Electrochimica, Inc.

GANTT CHART FOR FINAL YEAR PROJECT 2

Presentation	Do the final report	Analysis the error of results	Compare the result obtain	Result analysis	Experiment Set Up	Preparing Specimen and fabricate	WEEK
							1
							2
							3
							4
							δ
							6
							7
							8
							6
							10
							11
							12
							13
							14

GANTT CHART FYP 2

APPENDICES A

APPENDICES B

POLARIZATION BEHAVIOUR OF METAL (M) IN ACID SOLUTION



log i