Analyses Corrosion Prediction Software for CO_2 Corrosion of Carbon Steel Using Statistical Formulas

Y. P. Asmara[1], A. G. E. Sutjipto[2], J.P. Siregar, T. Kurniawan, Jamiluddin Jaafar
[1] Faculty of Mechanical Engineering, Universiti Malaysia Pahang
[2] Faculty of Science and Technology Industry, Universiti Malaysia Pahang, Pahang, Malaysia
Email: YPanca@hotmail.com

***Abstract*—The statistical formulas are capable tools to find a regression of corrosion rate effectively among combining factors. One type of statistical model which is response surface methodology (RSM) has shown a proven method in minimizing number of running. Through this technique, this research study predicting corrosion rate of carbon steel as effects of pH, CO_2 pressure and temperature. It can be used to run 3 dependent factors, 3 level experiment with only 16 number of running. The result reveals that NORSOK corrosion prediction software with second order model regression has 98 % of coefficient determination. Model prediction of Cassandra has 99.3% of coefficient determination. Second order model also has been verified with experimental data which shows a good correlation.**

***Index Terms*—CO_2 Corrosion, carbon steel, corrosion models**

I. Introduction

Predicting of corrosion behavior is an important issue in project of corrosion design to decrease a failure risk. Degree of corrosiveness is influenced by several factors that potentially complicate to predict. Corrosion reaction behaves in many mechanisms [1-4]. Multiple factors variables create difficulty to select an interest factors. Therefore, the building experiment has to able to reduce a robust data and simplify factors involved besides providingareasonably agreement between the experimentally observed and the real condition. Appropriate design experiment is also useful tool to minimize cost, time and energy.

Response surface methodology offers a simple design to process dependent factorseconomically [5-17]. Compare with full randomized design, response surface methodology is far simple [18]. This experiment design suggests that it is not necessary to randomized all factors during an experiment. Response surface is powerful technique, especially in determining stationer point which is the maximum or minimum curve located. Multi-variant regression prediction is presented in the three dimension (3D) graphic contour. So, the focus of response interest or predicted value will be easily identified.

Manuscript received July 14, 2018; revised April 1, 2019.

A. Response Surface Methodology

Response surface methodology (RSM) deals the correlation between several response variables[19]. The main idea of RSM is to set an optimal design experiment. First step is determining suspected variables that only significantly influenced response. Once a dominant variables interest found the others are left, then starting to design a central composite design. The second-degree model can be used to optimize (maximize, minimize, or attain a specific target for) a response[20].

A contour plot can make an easier way to find the responses result of two variables. To find regression coefficients is calculated by least sum square methods and using matrices manipulation to predict a statistically parameters (residual, deviation, variant analyze, coefficient determination).

In this work, two types of models regression are used to facilitate interpretation of experiment data. The model regressions are exponential and second order model that will predict corrosion rate data calculated by two predicting model programs- "NORSOK[21] and Cassandra[22]".

NORSOK [7] standard is owned by Norwegian Oil Industry Association and Federation of Norwegian Manufacturing Industries. The program covers only calculation of corrosion rates where CO_2 is the corrosive agent. It does not include the corrosivity, e.g. contamination's of O_2, H_2S etc. The model is an empirical containing CO_2 at different temperatures, pH, CO_2fugacities, wall shear stresses, and temperatures from 20 to160 ℃.

Cassandra [8] is a model as a implementation of de Waard and BP's experiences. The input includes pH, CO_2 concentration, temperature, and water contaminant. This model does not consider a scaling temperature. The user must set an assumption of scaling temperature.

II. Experimental Setup

A. Building an Experiment Design on CO_2 Corrosion

Relationship between corrosion rate and factors involved in CO_2 environment have been published intensively. Majority result stated that the corrosion rate

doi: 10.18178/ijmerr.8.3.374-379

haslinearand polynomial functions. The first one-linear function- is for corrosion rate under scaling temperature. While, the later-polynomial functions-is occurred if oxide film is formed.

Therefore, a suitable design to estimatea simple curvature model regression, in the widely range of temperature, ison an assumption that corrosion rate (response) will behaves a second-degree polynomial model.So, the first order model is definitely not suitable. Then with the aim to optimally research, design experiment response surface try to be applied. The minimum number of levels required for each factor to quantify that behavior is three. Further,by adding center points with some repetition variantswould satisfy the requirement for pure error analysis.

B. Corrosion Rate Models

The exponential model of corrosion rate equation is confirmed with Henry's reaction constant's temperature dependence as[23],

$$\log (V_{cor}) = 5.8 - 1710/T + 0.67 \log (pCO_2)$$

$$CR_t = K_t \times fCO_2^{0,62} \times (S/19)^{0,146 + 0,0324 \log (fCO2)} \times f(pH)_t$$

where

V_{cor} = corrosion rate in mm/yr
T = operating temperature in K
pCO_2 = partial pressure of CO_2 in bar

Y = response
X_k = k^{th} predictor
β_k = k^{th} population regression coefficient

The exponential first order model is also argued by Kapusta which build a corrosion rate prediction involving the role of several factors as following:

$$CR = (CR_{NAP} + C_{RS} + CR_{HSR}) \times f_f \times f_{sc} \times f_{al}$$

where C_{RNAP}, C_{RS} and C_{RHSR} represent the corrosion induced by naphthenic acids, sulfur and mercaptans, respectively. Then f_f is the flow enhancement factor, f_{sc} is a scale factor that reflects the protectiveness of iron sulfide, and f_{al} is the alloy factor, i.e., the ratio of the corrosion rate of an alloy to that of carbon steel.

Considering the effect of temperature dependence with an activation energy of general corrosion rate was reported by Jon Lee[24]. According to the Arrhenius relation below, this model corrosion rate follows an exponential behavior as:

$$\text{Ln}(C_{RT}) = C_o + C_1/T$$

The entire variance of that uncertainty is around ± 3 standard deviations. He compared with analysis of the literature data. The result has shown that the temperature dependence of general corrosion of an alloy behave a similar to a prediction model. Corrosion rate model presented by Arrhenius seems the same as what Song written. Song related the current density with the respect to the temperature as:

$$i^o = I_{reff}. Exp(E/R(1/T_{reff} - 1/T))$$

C. Second- order Model Regression

There is a curvature of general second order model which expressed as:

$$Y = \beta_0 + \sum_{i=1}^{k} \beta_i X_i + \sum_{i=1}^{k} \beta_{ii} X_i^2 + \sum_{i<j}\sum \beta_{ij} X_i X_j + \varepsilon$$

where Y = response that can fit the following linear, quadratic, or cubic regression models:

$\hat{y}_i =$ fitted response

Another way of modeling curvature is to generate additional models by using the log10 of x and/or y for linear, quadratic, and cubic models.
Model regression for second order for three dependence variable is as follows:

$$\hat{Y} = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \beta_3 X_3 + \beta_{11} X_1^2 + \beta_{22} X_2^2 + \beta_{33} X_3^2 + \beta_{12} X_1 X_2 + \beta_{13} X_1 X_3 + \beta_{23} X_2 X_3 + \varepsilon$$

Analogically, exponential model regression can be written as:

$$\hat{LnY} = \beta_0 + \beta_1 \ln X_1 + \beta_2 \ln X_2 + \beta_3 \ln X_3 + \beta_{11} \ln X_1^2 + \beta_{22} \ln X_2^2 + \beta_{33} \ln X_3^2 + \beta_{12} \ln X_1 \ln X_2 + \beta_{13} \ln X_1 \ln X_3 + \beta_{23} \ln X_2 \ln X_3 + \varepsilon$$

Which is developed from simple exponential equation regression model of first degree:

$$\hat{Y} = a * X_1^a * b * X_2^b * c * X_3^c$$

$$Ln\hat{Y} = aLnX_1 + bLnX_2 + LnX_3$$

$\hat{Y}$ = predicted value (independence factors)
β = regression constant
X = main effect of dependence factors
XX= interaction effects between dependence factors

Where constant prediction is calculated through equation

$$b = [X^T.X]^{-1}.X^TY$$

Then,

$$\hat{Y} = Xb$$

And residual is defined by

$$r = Y - \hat{Y}$$

Coefficient determination (R^2)is defined as,

$$r^2 = 1 - \frac{SSerror}{SStotal} = 1 - \frac{\sum\left(y_i - \hat{y}_i\right)^2}{\sum\left(y_i - \bar{y}_i\right)}$$

TABEL I. CORRELATION BETWEEN CODE AND UN-CODED FACTORS ON EXPONENTIAL REGRESSION

Code	pH	Total Pressure (bar)	Temperature (^{0}C)
√3	6.6	3.7	107
1	5.8	3	80
0	4.9	2.2	53
-1	4.1	1.6	35
-√3	3.6	1.3	26

TABEL II. CORRELATION BETWEEN CODE AND UN-CODED FACTORS ON SECOND ORDER MODEL REGRESSION

Code	pH	Total Pressure (bar)	Temperature (^{0}C)
√3	6.4	3.5	95.8
1	5.8	3	80
0	4.95	2.3	57
-1	4.1	1.6	35
-√3	3.5	1.1	19.3

$\bar{y}_i$ = ith observed response value

$\hat{y}_i$ = mean response

Another formula is presented on regression model as,

$$r^2 = \frac{ss_{regression}}{ss_{total}} = \frac{\sum\left(\hat{y} - \bar{y}_i\right)}{\sum\left(y_i - \bar{y}_i\right)}$$

Coefficient of determination; indicates how much variation in the response is explained by the model.

Calculation of code from the un-code factors

$$X_{code} = \frac{2(X - X_{\max})}{(X_{\max} - X_{\min})} + 1$$

For exponential model, code is calculated **from equation:**

$$X_1 = \frac{2(\ln v - \ln v_{atas})}{(\ln v_{atas} - \ln v_{bawah})} + 1$$

TABELIII. EXPERIMENT VARIANTS CODED AND RESULT

No	Temperature (^{0}C)	Total Pressure (bar)	pH	Corr. rate (Casdra/ Ln)	Corr. rate (Casdra)	Corr. rate (NRSK/ Ln)	Corr. Rate (Nrsk)
1	-1	-1	-1	9.02	9.02	7.5	7.5
2	1	-1	-1	12.78	12.78	10	10
3	-1	1	-1	14.23	14.23	11	11
4	1	1	-1	22.17	22.17	14	14
5	-1	-1	1	4.16	4.16	2.4	2.4
6	1	-1	1	8.53	8.53	1.6	1.6
7	-1	1	1	5.87	5.87	3.5	3.5
8	1	1	1	13.29	13.29	2.4	2.4
9	0	0	0	10.83	11.56	8	7.9
10	0	0	0				
11	0	0	0	Pure error			
12	0	0	0				
13	√3	0	0	14.88	13.77	2.7	2.7
14	-√3	0	0	6.77	5.78	5.1	3.6
15	0	√3	0	15.4	15.48	11	10
16	0	-√3	0	7.37	6.6	5.9	5.2
17	0	0	√3	4.8	5.72	1	1.2
18	0	0	-√3	15.82	17.2	12	13

III. RESULT AND DISCUSSION

TABLE IV. FIRST ORDER MODEL REGRESSION ANALYSIS OF VARIANCE CALCULATED BY CASSANDRA AND NORSOKCORROSION RATE PROGRAM.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	3.91843	3.91843	1.30614	36.45	0.000
Linear	3	3.91843	3.91843	1.30614	36.45	0.000
Residual Error	11	0.39422	0.39422	0.03584		
Total	14	4.31264				
R-Sq = 90.86%						

Analysis of Variance calculated by NORSOK corrosion rate program

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	3	7.95662	7.95662	2.65221	20.32	0.000
Linear	3	7.95662	7.95662	2.65221	20.32	0.000
Residual Error	11	1.43584	1.43584	0.13053		
Total	14	9.39246				
R-Sq = 84.71%						

At the first order model regression, both of Cassandra and NORSOK corrosion calculation program shows a quite unsatisfied of coefficient determination. It has 84% for NORSOK and 90.86% for Cassandra. It is because of those model regressions are only influenced by main effects factors. Linear dependence of the corrosion rate on independent factors (temperature, CO_2pressure, and pH) indicates that along the temperature applied there is no scaling effect considered. But, theoretically, at the high temperature and pH, corrosion rate must decrease. Therefore, the coefficient determination of the regression may be able to be increased by involved the quadratic effects of each factors. This conclusion suggests that the model must be developed to become a second order model regression.

A. Second Order Model Regression

TABLE V. CORROSION RATE CALCULATED BY" NORSOK" WITH SECOND ORDER MODEL REGRESSION

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	260.627	260.627	28.9585	30.85	0.001
Linear	3	223.927	223.927	74.6423	79.52	0.000
Square	3	25.930	25.930	8.6432	9.21	0.018
Interaction	3	10.770	10.770	3.5900	3.82	0.091
Residual Error	5	4.693	4.693	0.9387		
Total	14	265.320				

Obs	StdOrder	C4	Fit	SE Fit	Residual	St Resid
15	15	7.900	7.816	0.967	0.084	1.26 X

Estimated second order model Regression by NORSOK

Y= 7.81615+ 0.150218x1 + 1.27431x2 - 3.82148x3 - 1.48270X1.x1 +0.0570924x2x2 -0.115918x3.x3 + 0.0250000x1.x2 -0.925000x1.x3 - 0.700000x2.x3

R-Sq = 98.23%

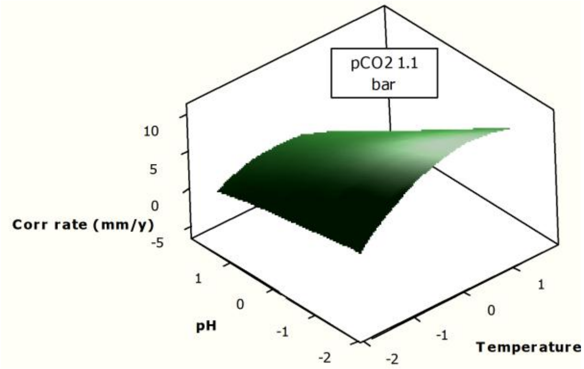

Figure 1. Surface plot calculated by NORSOK program showsdependence of corrosion rate on Temperature and CO_2 pressure at pH of 4.9

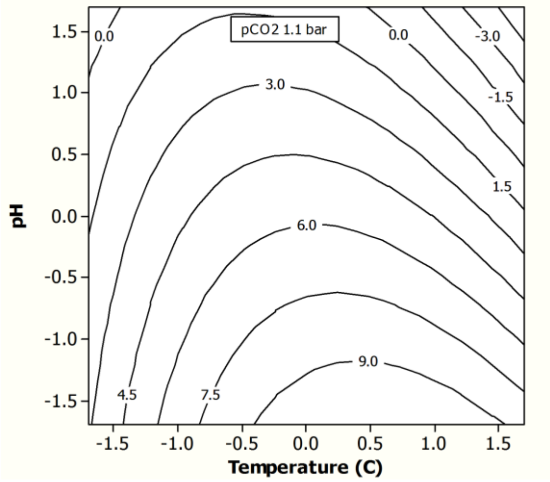

Figure 2. Contour plot calculated by NORSOK program

TABLE VI. ANALYSIS OF VARIANCE CALCULATED BY NORSOK CORROSION RATE PROGRAM FOR EXPONENTIAL MODEL REGRESSION

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	248.472	248.472	27.6080	18.06	0.003
Linear	3	214.691	214.691	71.5637	46.81	0.000
Square	3	23.011	23.011	7.6703	5.02	0.057
Interaction	3	10.770	10.770	3.5900	2.35	0.189
Residual Error	5	7.644	7.644	1.5288		
Total	14	256.116				

R-Sq = 97.02%

Figs. 1 and 2 illustrate possible behaviors of responses (corrosion rate) as functions of factor settings (temperature, CO_2 pressure, pH) which calculated by NORSOK program software. The polynomial coefficient regression analyzed based on design experiment response surface shows a 98% confidence level.This regression is better than calculation by exponential regression model (97%). In this case, selecting point of variant factors assume the value of the response increases from the low temperature exceed to scaling temperature. The setting range of temperature is appropriate to proof that scaling temperature is located between that ranges which is indicated by point of transition corrosion rate. From the contour plot on Fig. (2) is shown clearly that scaling temperature occurred at 75^0C. This scaling temperature will decrease with the increase of pH.

TABLE VII. CORROSION RATE CALCULATED BY" CASSANDRA" WITH SECOND ORDER MODEL REGRESSION

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	365.382	365.382	40.598	90.22	0.000
Linear	3	347.321	347.321	115.774	257.29	0.000
Square	3	3.264	3.264	1.088	2.42	0.182
Interaction	3	14.797	14.797	4.932	10.96	0.012
Residual Error	5	2.250	2.250	0.450		
Total	14	367.632				

Obs	StdOrder	C4	Fit	SE Fit	Residual	St Resid
9	9	13.770	14.647	0.525	-0.877	-2.10 R
15	15	11.560	11.494	0.669	0.066	1.42 X

R-Sq = 99.39%

Estimated regression second order model regression for corrosion rate by Cassandra

Y= 11.4943+ 2.69035x1 + 2.62453x2 - 3.32845x3 - 0.491541X1.x1 -0.0538244x2x2 +0.0915044x3.x3 + 0.903750x1.x2 +0.0112500x1.x3 -1.01625x2.x3

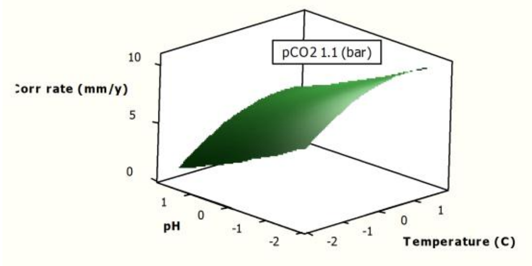

Figure 3-Surface plot calculated by CASSANDRA program at pCO_2 of 1.1 bar

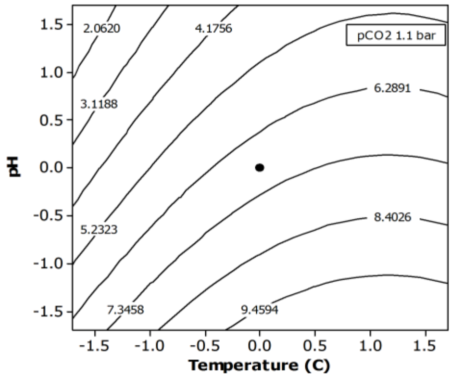

Figure 4. Contour plot calculated by CASSANDRA program at pCO_2 of 1.1 bar

TABLE VIII. ANALYSIS OF VARIANCE CALCULATED BY CASSANDRA CORROSION RATE PROGRAM FOR EXPONENTIAL MODEL REGRESSION.

Source	DF	Seq SS	Adj SS	Adj MS	F	P
Regression	9	3.31590	3.31590	0.36843	105.92	0.000
Linear	3	3.18664	3.18664	1.06221	305.37	0.000
Square	3	0.04947	0.04947	0.01649	4.74	0.063
Interaction	3	0.07978	0.07978	0.02659	7.65	0.026
Residual Error	5	0.01739	0.01739	0.00348		
Total	14	3.33329				

Obs	StdOrder	C4	Fit	SE Fit	Residual	St Resid
9	9	2.700	2.775	0.046	-0.074	-2.03 R
15	15	2.382	2.379	0.059	0.004	0.87 X

R-Sq = 99.48%

Fig. 3 and Fig. 4 is model corrosion rate behavior calculated by Cassandra software program. This regression has a coefficient determination about of 99%. Only have an uncertainty of 0.6%. And very satisfied confidence level is shown by an exponential regression coefficient (99.48%). A polynomial curve of corrosion rate in CO_2 environment at the range of temperature, pH, and CO_2 pressure reveal that corrosion rate has a transition temperature at the temperature of 80 °C.

The corrosion rate determined by software program calculation of Cassandra confirm with NORSOK program. A reduction of corrosion rate occurred on the surface due to corrosion product at a certain temperature range 70^{0}C–80^{0}C. According to the figure 1 and 3, this scaling temperature is influenced by factors set.

Parabolic polynomial dependence between the corrosion rate and temperature has been found by researchers.This is attributed to carbonate scale formation. Schmitt[4], recorded that carbonate scale will be observed grow during 48 h of CO_2 corrosion of steel grade J 55 in brine at 80^0 C under 5 bar of CO_2. He stated that oriented texture and morphology carbonate scales grown on steels depend on steel microstructure. Considering of the growth of carbide scale also was studied by by Brown [25]. He observed that scale on steel surface repair at temperature of 80^{0}C and low pH.Critical scaling tendency decrease with increasing of carbon content is explained by Hunnik[26]. He argued that at the temperature interested, degree of carbon saturated have been exceeded. The other researcher in acociated with this is Nesic[27]. Nesic proposed a model of iron carbonate (FeCO) film growth which film growth occurs by precipitation of iron carbonate saturated. Then he recorded that very protective films and low corrosion rates are predicted at high pH, temperature, CO_2 partial pressure and Fe^{2+}ion concentration.

B. Verification with Experimental Data

In the case of pH effect, response surface, Figure 1-3,calculate a linear correlation of pH to corrosion rate. The increase of pH will decrease corrosion rate. This trend result is the same as both NORSOK and Cassandra program calculation. The decrease of corrosion rate, it may relate to barrier properties of thin layer forming layer of corrosion products. This result is supported by Hoffmeister[28]observation. Even more, he found that not only uniform corrosion was retarded but also reduce initiation times of crevice corrosion.

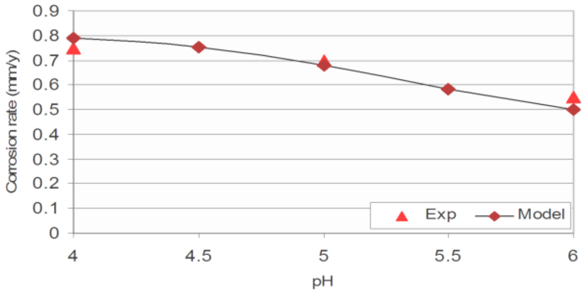

Figure 5. Corrosion rate at varying pH; a comparison model with Nesic's experimental data [27] (1 bar, 20°C, and stagnant condition).

The effect of pH on corrosion rate was studied in solutions saturated with CO_2 with the addition of HAc in the pH range from 4 to 5.5 using RSM. The results are shown in Figure 5. In Figure 5, the model prediction is compared to Nesic's experimental data [27], which had shown a good fit. As the pH was increased from 4 to 6, the corrosion rate decreased from 0.8 mm/y to 0.5 mm/y.

IV. Conclusion

Response surface methodology is capable to analyze combine effects and reducenumber of runs requiredin the experiment rather than fully randomizeddesign.This method presents a satisfied coefficient determination of regression (more than 97%). Corrosion rate calculated by NORSOK software has a best fit on second order model regression (98%).Cassandra software model regressionfor corrosion rate shows an exponential pattern, with fitting regression of 99.4%. But, the difference with second order model which is not significant. Its differences is 0.09%.In condition of elevated temperature, determination of temperature scalingwillbe easier when using second order model corrosion regression.

Acknowledgments

The authors are thankful to Universiti Malaysia Pahang for providing grant and facilities for the research with grant number RDU150372.

References

[1] R. Asma, Y. P. Asmara, and C. Mokhtar, "Study on the effect of surface finish on corrosion of carbon steel in CO2 environment," *Journal of Applied Sciences*, vol. 11, no. 11, pp. 2053-2057, 2011.

[2] Y. Asmara, et al., "Experimental investigations on corrosion model of welded 6061 aluminum exposed in NaCl solution," *International Journal of Automotive and Mechanical Engineering*, vol. 11, p. 2600, 2015.

[3] Y. P. Asmara, *The Cathodic Protection of Mild Steel and 304 Stainless Steel in Artificial Seawater Using an Impressed Current System*. 2001.

[4] Y. P. Asmara, *Efek Kecepatan Aliran Minyak terhadap Kecepatan Korosi dalam Pipa di Lingkungan Minyak dan Gas Bumi*. MEDIA TEKNIKA, 2008. **8**(1).

[5] Y. P. Asmara and M. Ismail, "Study combinations effects of HAc in H2S/CO2 corrosion," *Journal of Applied Sciences*, vol. 11, no. 10, pp. 1821-1826, 2011.

[6] Y. P. Asmara, et al. "Predicting Effects of Corrosion Erosion of High Strength Steel Pipelines Elbow on CO2-Acetic Acid (HAc) Solution," in *Proc. IOP Conference Series: Materials Science and Engineering*. 2016. IOP Publishing.

[7] Y. P. Asmara, and M. C. Ismail, *The Use of Response Surface Methodology to Predict CO2 Corrosion Model Empirically*. 2010.

[8] Y. P. Asmara, and M. C. Ismail, "Efficient design of response surface experiment for corrosion prediction in CO_2 environments," *Corrosion Engineering, Science and Technology*, 2012, vol. **47, no.** 1, pp. 10-18.

[9] Y. P. Asmara, A. Juliawati, and A. Sulaiman, "Mechanistic model of stress corrosion cracking (scc) of carbon steel in acidic solution with the presence of H2s," in *Proc. IOP Conference Series: Materials Science and Engineering*. 2013. IOP Publishing.

[10] Y. P. Asmara, et al., "Effects Pre-strain of Carbon Steel on Stress-Strain Diagram in CO_2 Environment with the Presence of H_2S," *International Journal of Material Science Innovations (IJMSI)*, vol. 2, no. 3, pp. 52-58, 2014.

[11] Y. P. Asmara, N. A. A. Razak, and Salwani, "Analysis of corrosion prediction software for detection corrosion in oil and

gas evironment containing acetic acid, co2 and h2s gases*,"* in *Proc. International Symposium on Corrosion & Materials Degradation (ISCMD 2014)*. 2014.

[12] Y. P. Asmara, et al. "Application of response surface methodology method in designing corrosion inhibitor," in *IOP Conference Series: Materials Science and Engineering*. 2017. IOP Publishing.

[13] Y. P. Asmara, et al., "Electrochemical behaviour of high stress steel (AISI 4340) in CO_2 environments with the presence of H2 gas," *Applied Mechanics and Materials*, 2015. **695**: pp. 98-101.

[14] Y. P.Asmara, et al. "Improving Efficiency of Aluminium Sacrificial Anode Using Cold Work Process. in IOP Conference Series: Materials Science and Engineering," 2016. IOP Publishing.

[15] Y. P.Asmara, et al., *"Long term corrosion experiment of steel rebar in fly ash-based geopolymer concrete in NaCl solution," International Journal of Corrosion*, 2016.

[16] Y. P. Asmara, et al. "Development of green vapour corrosion inhibitor," in *IOP Conference Series: Materials Science and Engineering,"* 2017. IOP Publishing.

[17] Y. P. Asmara, et al., "Flow assisted erosion-corrosion of high speed steel (HSS) in nanofluid coolant," *Applied Mechanics & Materials*, 2015. **695**: pp. 143-146.

[18] Y. P. Asmara, *A new approach in empirical modelling of co2 corrosion with the presence of hac and h2s*. 2010, UNIVERSTI TEKNOLOGI PETRONAS.

[19] G. Box, E., P., Draper Empirical Model Building and Response Surfaces, John Wiley and Sons, New York, 1987.

[20] Y. P. Asmara and M. Che Ismail, "A statistics approach for the prediction of CO_2 corrosion in mixed acid gases," *Corrosion and Materials*, vol. 34, no. 4, pp. 25-30, 2009.

[21] M-501, N., *Well integrity in drilling and well operations standard* Norwegian Oil and Gas Industry 2014.

[22] Cassandra, C.M.S.i.W.s., Mc Mohan. A.J., BP Report No.1993 - 220483, 1993.

[23] De Waard, C., Milliam, D.,E., Carbonic Acid Corrosion of Mild Steel, Corrosion, 31, 5, 1975, pp. 131 - 135. .

[24] K. L. J. Lee, "A Mechanistic Modeling of CO2 Corrosion of Mild Steel in the Presence of H2S," Department of Chemical Engineering, Russ College of Engineering and Technology, PhD Thesis 2004, Ohio University.

[25] B. Brown, K. Lee, Nesic., Corrosion in Multiphase Flow Containing Small Amount of H_2S, NACE Internationa, Corrosion, 3341, 2003.

[26] V. Hunnik, E. W. J., Pots, B. F. M., Hendriksen, E.L.J.A., "The formation of protective FeCO3 corrosion product layers in CO_2 corrosion," Corrosion: NACE International, Houston, 6,1996.

[27] S. Nesic, *Key Issues Related to Modelling of Internal Corrosion of Oil and Gas Pipelines, "A review"* Corrosion Science, 2007. vol. 49, no**.** 12, pp. 4308-4338.

[28] H. Hoffmeister, and G. bScheidacker, Effect of chloride contents, pH and temperature on crevice corrosion of alloy 33 as determined by remote crevice assembly (RCA), corrosion: NACE International, Houston, 04290, 2004.

Y. P. Asmara Recently, I am designed as senior lecturer in University Malaysia Pahang, Malaysia (UMP), Faculty of Mechanical Engineering. Before assigned as senior lecturer at UMP, I worked as post doctoral research at Corrosion Research Centre, Department of Mechanical Engineering,Univ. Technology Petronas, *Malaysia. At 2010 to 2012, I worked as* research associate at Department of Mechanical Engineering, University Technology Petronas, Malaysia. At 2006 to 2012, I got award as PhD scholarship from University Technology Petronas with the title thesis of empirical modelling of corrosion in CO2 environments with the presence of H_2S gas and HAc. Master by course at University Manchester Science and Technology, UMIST, UK.During master degree, it was tough eight (8) modules and 8 experimental works. There was also research project with the title of Cathodic Protection of Stainless steel in Seawater. My bachelor degree was from Mechanical Engineering Department, Institute Technology SepuluhNopember, Surabaya, Indonesia.