

## Predicting Temperature of Corrosion Scale Formation Carbon Steel in Oil and Gas Environment

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### Abstract

Formation of scales on the metal surface during corrosion process in oil and gas environment is one of the important parameter in predicting corrosion rate. The scales are formed on metal surface at specific temperature. Quality of the scales depend on service temperature, concentration of carbon-dioxide (CO<sub>2</sub>) and acetic acid (HAc) as main elements in oil and gas environments. This research aims to determine scale formation temperature on of carbon steel under different concentration of CO<sub>2</sub> and HAc using mathematics formulas. The corrosion rate for carbon steel was calculated using linear resistance polarization (LPR) test methods. Specimens were placed in a beaker contained 3.5% NaCl connected to a CO<sub>2</sub> cylinder for CO<sub>2</sub> gas bubbling. The corrosion tests were conducted at room temperature, 60 °C and 80°C in several concentration of CO<sub>2</sub> and HAc. A statistical analysis with response surface methodology (RSM) was used to process the model to predict corrosion scale temperature using second-degree model mathematics formulas. An attempt will also be made to verify the results using data literatures. As results, the predictions show in acceptable ranges (70% – 80 %) as compared to experimental data from literatures.

### Keywords

Corrosion scales temperature, Corrosion predictions models, Oil and gas environments, Carbon steel.

### Introduction

Oil and gas environment which are exposed to sour/sweet conditions, mostly in transportation pipeline, are covered with corrosion products scales such as FeCO<sub>3</sub> and FeAc when acetic acid (HAc) and Carbon-dioxide (CO<sub>2</sub>) present in the oils (Asmara, 2009; Asmara, 2011; Videm, 1994). These types and quality of corrosion products vary depend on temperature, pressure and flow rate (Nesic et al, 2007; Asmara, 2015, et al, 2010; Lee et al., 2004; Wei et al, 2006 . It can determine types of damages to the pipelines which leads to pitting corrosion, cracking and scale detachment (spalling) of the pipeline material. They will affect on corrosion rate (Asmara at al., 2011; Asmara et al., 2016; Nyborg et al., 2006). The other contaminants such as H<sub>2</sub>S, NaCl, types of pipelines materials, and inhibitors will also contribute to the

corrosion rate. Studies have demonstrated that those multi species factors can govern the corrosion process in many ways and in several mechanisms.

One of the most important parameter which determines corrosion scale is temperature. Temperature affects the conditions for formation of the protective carbonate layers and affects corrosion rate in a different manner. At temperatures lower than 60 °C, the solubility of FeCO<sub>3</sub> is high and the precipitation rate is slow; thus protective films will not form until the pH is increased more than solubility product (Asmara et al., 2013; Asmara et al., 2012). At that temperature, hydrogen evolution acts as the rate determining step. At temperatures above 100°C, there is a direct reaction between steel and water to produce dense and protective films. Carbon steel will face problems with pitting and stress corrosion cracking because carbonate film is formed rapidly at 80° C (Nesic et al., 2007).

## Methodology

### *Specimen preparation and test matrix*

The working electrodes were made of carbon steel and the chemical composition is as shown in Table 1. The cylindrical specimens were of 12 mm diameter and 10 mm long. Before immersion, the specimen surfaces were polished successively with 240, 400 and 600 grit SiC paper, rinsed with methanol and degreased using acetone. The test matrix used to carry out the experiment is presented in Table 2.

Table 1. Composition of 080a15 carbon steel used in the experiments.

Steel	C (%)	Si (%)	Mn (%)	P (%)	S (%)	Cr (%)	Ni (%)
080A15	0.14	0.175	0.799	0.01	0.03	0.06	0.065

Table 2. Experimental matrix used in the test.

Steel Type	080A15 (BS 970)
Aqueous solution	3 wt% NaCl,
Purged gas	CO <sub>2</sub>
Total pressure	Atmospheric
Temperature	25°C - 100°C
Rotation rate	Static
pH	4 - 6
Measurement techniques	Linear polarization resistance (LPR)

### *Static test set-up*

The linear polarization resistance (LPR) technique was used to measure the corrosion rate. The procedure was similar as the ASTM experimental test G 5-94 (ASTM standard).

### *Cell solutions*

The experiments were performed in stagnant condition. The total pressure was 1 bar, and the glass cell was filled with 1 liter of distilled water with 3% wt NaCl which was stirred with a magnetic stirrer. Then CO<sub>2</sub> gas was bubbled through the cell in order to saturate and de-aerates

the solution. After the solution was prepared, the pH was adjusted to reach the determined pH by using NaHCO<sub>3</sub> as a buffer solution. During the experiment, constant concentration of gases was continuously bubbled through the electrolyte in order to maintain consistent water chemistry.

## Model Regression

### *Second-order model regression*

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

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

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

$\hat{y}_i$  = fitted response

Y = response

$X_k$  =  $k^{\text{th}}$  predictor

$\beta_k$  =  $k^{\text{th}}$  population regression coefficient

### *Response surface methodology*

Response surface methodology (RSM) with central composite design (CCD) is used to optimize process conditions (Asmara., et al, 2019). It is used to determine the influence of factors as mentioned in the Table 2. Through RSM and applying second order model regression, temperature scale is obtained.

## Results and Discussion

### *Scaling temperature*

Based on the literature reviews (Hunnik., et al, 1996; wei, 2002; Parakala, 2005; Yuhua 2002; Vera, 2006; George, 2004) it is known that effect of temperature increases corrosion rate until the temperature reaches a maximum value called scaling temperature. Beyond this temperature, the corrosion rate will decrease or becomes constant. Factors affecting the scaling temperature are pH and HAc concentration. The scaling temperature as effects of pH predicted by the RSM models are presented in Figure 1.

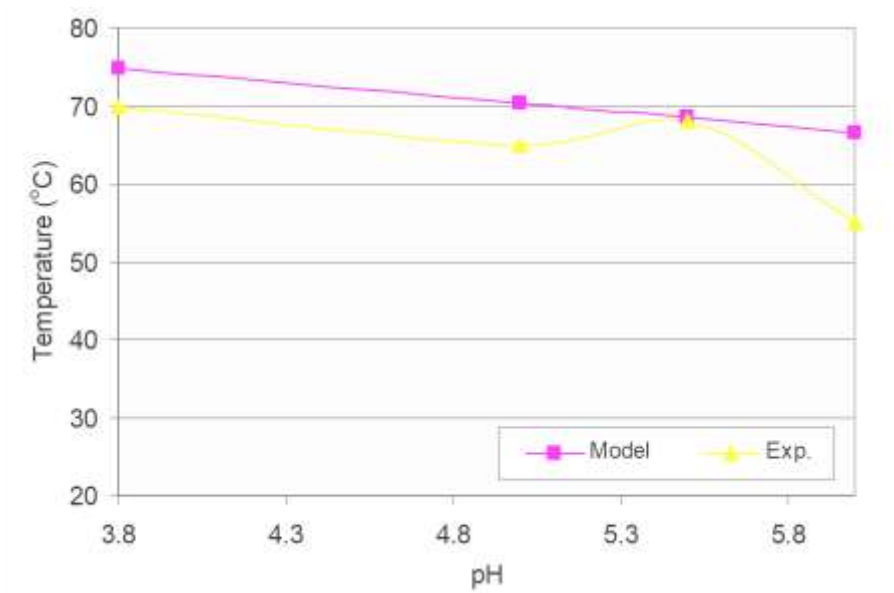


Figure 1. Effects of pH on scaling temperature as calculated by RSM at conditions: stagnant, blank solutions, total pressure 1 bar, and 3% NaCl CO<sub>2</sub> saturated solution.

From Figure 1, it can be seen that higher pH tend to decrease scaling temperature. This observation is supported by several researchers, who related this phenomena to film formation where higher pH tend to favor film precipitation.

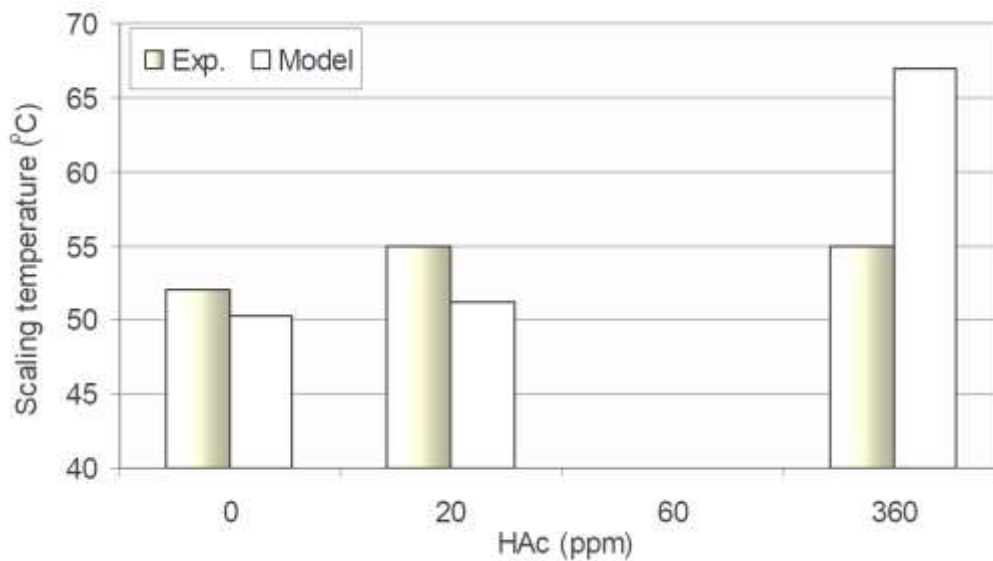


Figure 2. Effects of HAc on scaling temperature as calculated by RSM at conditions: stagnant, pH 6, total pressure 1 bar, and 3% NaCl CO<sub>2</sub> saturated solution.

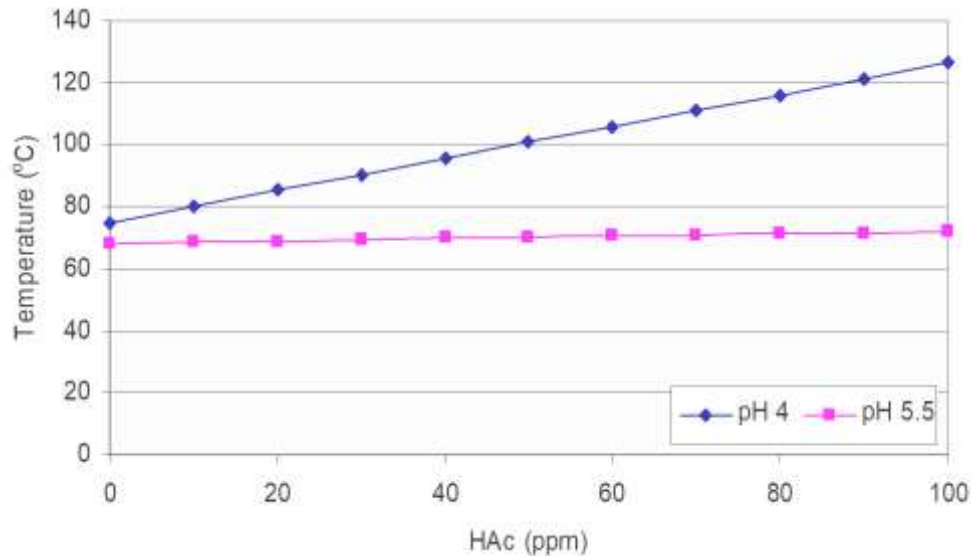


Figure 3. Effects of HAc on scaling temperature as calculated by RSM at conditions: stagnant, total pressure 1 bar, and 3% NaCl CO<sub>2</sub> saturated solution.

Scaling temperature is also influenced by HAc concentration. As shown in Figure 2 and Figure 3, higher HAc concentration will increase scaling temperature. The findings are also supported by (Ismail, 2005). A comparison between calculations from RSM and experimental data is presented in Figure 2. (George, 2004) explained that the presence of HAc can interrupt the film formation and increase scaling temperature. Surface analysis investigation indicated that HAc concentration has decreased the thickness of the film.

## Conclusions

### Mechanism corrosion rate in CO<sub>2</sub>/HAc system

- The introduction of 100 ppm of HAc to the CO<sub>2</sub> gaseous mixture causes the corrosion rate to increase sharply in the temperature range 60–70°C.
- HAc is the dominant factor that governs the reaction process in CO<sub>2</sub> system. The behavior of cathodic reaction consists of chemical reaction and diffusion process.
- Based on mathematics model, the scaling temperature will increase as HAc concentration increases.
- Scaling temperature decreased when pH increased.
- The results have shown that second-order polynomial model can be used to predict CO<sub>2</sub>/HAc corrosion pattern adequately.
- This study has proven that central composite experimental design can be applied to predict CO<sub>2</sub> corrosion process with reasonable planning and execution. Thus, the statistical analysis and evaluations of data could be proved analytically.
- Although these models reach reasonable results, the precision can be improved by considering more parameter conditions.

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## References

- Asmara, Y.P. and M. Ismail, Study combinations effects of HAc in H<sub>2</sub>S/CO<sub>2</sub> corrosion. *Journal Applied Sciences*, 2011. 11(10): p. 1821-1826.
- Asmara, Y.P. and M. Che Ismail, A Statistics Approach for the Prediction of CO<sub>2</sub> Corrosion in Mixed Acid Gases. *Corrosion and materials*, 2009. 34(4): p. 25-30.
- Videm, K., The Effects of Some Enviromental Variabales on The Aqueous CO<sub>2</sub> Corrosion of Carbon Steel, The Institute of Material, No. 13, 1994.
- Nesic, S., Key issues related to modelling of internal corrosion of oil and gas pipelines "A review" *Corrosion Science*, 2007. 49(12): p. 4308-4338.
- Lee, K.L.J., A Mechanistic Modeling of CO<sub>2</sub> Corrosion of Mild Steel in the Presence of H<sub>2</sub>S, Department of Chemical Engineering, Russ College of Engineering and Technology, PhD Thesis 2004, Ohio University.
- Wei Sun, S.N., Kinetics of Iron Sulfide and Mixed Iron Sulfide/Carbonate Scale Precipitation in CO<sub>2</sub>/H<sub>2</sub>S, PhD Thesis, Department of Chemical Engineering, Russ College of Engineering and Technology, Ohio University, 2006.
- Asmara, Y.P., et al., Electrochemical Behaviour of High Stress Steel (AISI 4340) in CO<sub>2</sub> Environments with the Presence of H<sub>2</sub> Gas. *Applied Mechanics and Materials*, 2015. 695: p. 98-101.
- Asma, R., Y.P. Asmara, and C. Mokhtar, Study on the effect of surface finish on corrosion of carbon steel in CO<sub>2</sub> environment. *Journal of Applied Sciences*, 2011. 11(11): p. 2053-2057.
- Asmara, Y.P., et al. Predicting Effects of Corrosion Erosion of High Strength Steel Pipelines Elbow on CO<sub>2</sub>-Acetic Acid (HAc) Solution. in *IOP Conference Series: Materials Science and Engineering*. 2016. IOP Publishing.
- Nyborg, R., Field Data Collection Evaluation and Use for Corrosivity Prediction and Validation of Models Part II: Evaluation of Field Data and Comparison of Prediction Models, *Corrosion: NACE International*, Houston, 6118, 2006.
- Asmara, Y.P., A. Juliawati, and A. Sulaiman. Mechanistic model of stress corrosion cracking (scc) of carbon steel in acidic solution with the presence of H<sub>2</sub>s. in *IOP Conference Series: Materials Science and Engineering*. 2013. IOP Publishing.
- Asmara, Y.P. and M.C. Ismail, Efficient design of response surface experiment for corrosion prediction in CO<sub>2</sub> environments. *Corrosion Engineering, Science and Technology*, 2012. 47(1): p. 10-18.
- Asmara, Y.P. et al, Analyses Corrosion Prediction Software for CO<sub>2</sub> Corrosion of Carbon Steel Using Statistical Formulas, *IJMERR*, 374, 8.
- Asmara Y.P., Tedi Kurniawan, Corrosion prediction for corrosion rate of carbon steel in oil and gas environment: A review, *Indonesian Journal of Science and Technology*, 3, (1) pp.64-74.
- van Hunnik, E.W.J., Pots, B.F.M., Hendriksen, E.L.J.A., The Formation of Protective FeCO<sub>3</sub> Corrosion Product Layers in CO<sub>2</sub> Corrosion, *Corrosion: NACE International*, Houston, 6,1996.
- wei, W., H., CO<sub>2</sub> Corrosion Mechanistic Modeling in Horizontal Slug Flow. Department of Chemical Engineering, Russ College of Engineering and Technology, PhD thesis: Ohio University, 2002.
- Parakala, S.R., EIS Investigation of Carbon Dioxide and Hydrogen Sulfide Corrosion Under Film Forming Conditions, Department of Chemical Engineering, Russ College of Engineering and Technology, Master Thesis, Ohio University. 2005.
- Yuhua Sun, T.H., CO<sub>2</sub> Corrosion in Wet Gas Pipelines at Elevated Temperature, *Corrosion: NACE International*, Houston, 2281, 2002.

- Vera, J.R., Oil Characteristics Water/Oil Wetting and Flow Influence on The Metal Loss, Part 1: Effect of Oil and Flow on CO<sub>2</sub>/H<sub>2</sub>S Corrosion, Corrosion NACE International, Houston, 6113, 2006.
- Ismail, C., Mokhtar, Prediction CO<sub>2</sub> corrosion with The Presence of Acetic Acid, PhD Thesis, UMIST, Manchester, 2005.
- George, K., S.N., Electrochemical Investigation and Modeling of Carbon Dioxide Corrosion of Carbon Steel in The Presence of Acetic Acid, Corrosion: NACE International, Houston, 4379, 2004.

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