

Corrosion Modeling: Comparison, Interpretation & Limitation

Corrosion modeling is a vital tool in the pre-Front End Engineering Design (pre-FEED), FEED, and operational stages of the life of pipeline and equipment systems. Corrosion and materials engineers often rely on corrosion prediction models to select appropriate materials for construction, incorporate sufficient corrosion allowance into a design, and evaluate chemical corrosion inhibitor requirements or recommend other corrosion mitigation methods. Often, it is found that life cycle costs of using carbon steel with chemical corrosion inhibition are more attractive for systems containing long, large-diameter pipelines, as compared with costs of using an alternative corrosion resistant alloy (CRA) material. Cost analysis is vital for topsides systems, as phase equilibrium and production rates can change over the life of the field, e.g. increasing water cut. It is important to account for these changes when modeling, trying various scenarios to optimize the correct material choice and corrosion mitigation strategy for the entire life of the field. It is also essential to use the proper corrosion model for a given set of conditions to obtain useful results. Corrosion modeling is a key tool in finding the most cost-effective balance.

The various corrosion modeling programs have ranges of environmental conditions in which each is most applicable. To enable better comparison of the corrosion rates predicted by different models under nearly identical conditions, corrosion rates for a sample set of conditions are provided using three publically available corrosion models. Some are more conservative (tend to reliably over-estimate corrosion rates) than others. Comparisons of the predictions are discussed herein.

Temperature, Pressure, & Environmental Composition

Foremost, it is imperative to understand the applicable range of environmental conditions for each model so that the proper model is chosen. Table 1 highlights the applicable ranges of temperature and pressure for each model used in this comparison.

In the event that the environment being modeled is outside a model's limits, the predicted corrosion rates, if obtainable, may not be of any tangible use. Most models are focused toward CO₂ corrosion prediction and are based on the De Waard model. However, each model incorporates De Waard's findings in different ways. Model A is an empirical model, applying DeWaard's principles to fit copious experimental data. Model A only applies to CO₂ corrosion (no H₂S). Model B allows the input of H₂S content but only for pH calculations. Model B is an empirical tool which allows the input of H₂S content, but only for the purposes of pH calculations – no H₂S scaling effects are accounted for. Oil wetting effects are also not considered in Model B. Model C does account for some influence of H₂S on corrosion and scale formation in its corrosion modeling predictions. Model C is a mechanistic model that includes effects of multiphase flow, precipitation of corrosion product films and oil wetting in its predictions.

Figure 1 shows the temperature sensitivity of the studied models. The predicted corrosion rates differ depending on the model. As the graph indicates, corrosion rate plateaus for Model A as temperature increases, but continues to increase with temperature for Models B and C. The plateau occurs because of the effects of scale formation accounted for by Model A, helping illustrate that predicted corrosion rates are highly dependent on each Model's treatment of parameters. Scale deposition effects on corrosion rate predictions will be discussed further in a subsequent section.

Fugacity

The fugacity of a gas component of any system is affected by the total pressure of the system and the quantity of gas present. Fugacity is the corrected partial pressure of a chemically reactive gas and is equivalent to partial pressure under ideal conditions. CO₂ fugacity has been shown to affect CO₂ corrosion rate. In most models, a fugacity value is ascertained and used in corrosion rate predictions through calculations or tables. Most models have input limits on either the quantity of CO₂ or the fugacity value. For example, in Model B the limit for CO₂ is 5 mol% when calculating fugacity values, while Model A allows a general range of CO₂ fugacity from 0.1 bar to 10 bar (the allowed ranges of mol% is dependent on the total pressure). So Model A operates over a much wider range of CO₂ quantity, provided the calculated fugacity value is within the specified range. Additionally, the methods of accounting for CO₂ fugacity in corrosion rate calculations vary from model to model.

Model	Temperature		Pressure	
	Min	Max	Min	Max
A	41°F 5°C	302°F 150°C	14.5 psi 1 bar	14,503 psi 1,000 bar
B	68°F 20°C	284°F 140°C	0 psi 0 bar	2,900 psi 200 bar
C	34°F 1°C	248°F 120°C	14.5 psi 1 bar	10,152 psi 700 bar

Model	H ₂ S	CO ₂
A	No	Yes
B	Yes ¹	Yes
C	Yes	Yes

¹ For use in pH calculations only; no scaling effects accounted for.

Table 1: The applicable T and P ranges for three widely available corrosion models.

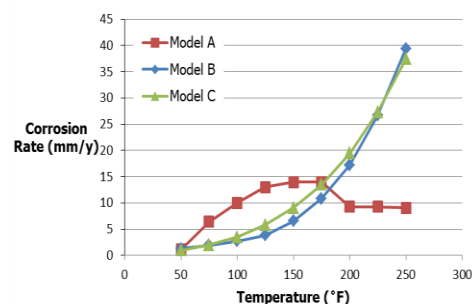


Figure 1: Corrosion Rate Comparison as a function of temperature under the following defined conditions: pH of 4.5, 1 mol% CO₂, 0% H₂S, and P=200 bar.

Corrosion Modeling: Comparison, Interpretation & Limitation

Model A has specific equations that are each used in a discrete CO₂ fugacity range while Model B uses a general equation in which equation coefficients change based on temperature and pressure inputs. A slight pressure increase can significantly change the calculated fugacity, and therefore the corrosion rate, for the three models (Figure 2). Of the three models compared, Model A is considered the most conservative, while all are considered realistic in the range shown.

Scale Deposition

In the field, scale deposits can form semi-protective layers and can thus reduce the corrosion rate. Some models do not account for possible presence of protective scales. CO₂-precipitated iron carbonate (FeCO₃) scales are taken into account in Models A and B. Model C only takes into account iron sulfide scales, which are only precipitated in the presence of H₂S. The extent of scale formation and protection in Model A is dependent on multiple factors, but the degree of protectiveness is automatically assumed. In Model B, the effect of protective films can be included or excluded intentionally by choosing the scaling temperature, thus permitting the user's judgment on the presence of scales. Model C allows the user to choose either a porous or a protective corrosion product layer. At moderate temperatures, Model A is considered to be the most conservative, even though its treatment of scaling effects is based on empirical data. As temperature changes, scale exhibits varying degrees of protectiveness, which is not accounted for in Model B. Other proprietary corrosion modeling programs exist that institute scale correction factors or use a continuous function to account for scale growth. Figure 1 highlights how corrosion rate calculated by Model A plateaus at the scaling temperature while Model C's predicted rate continues to increase under identical conditions. The scaling temperature is the maximum temperature at which the model will continue to calculate corrosion rate, above which the corrosion rate plateaus. This plateau signifies a scaling limit, where the rate of scale precipitation is predicted to overcome the corrosion rate, and thus significant corrosion mitigation is expected. Model B and C produce no plateau, indicating no scale control factor at these temperatures. The Model B rate would plateau if the manually inputted scaling temperature was decreased.

It is good practice to obtain a more detailed assessment of scaling impact on predicted corrosion rates by using an appropriate thermodynamic modeling program to model scale deposition.

Flow Regime

There are two main ways in which flow may affect CO₂ corrosion. Turbulent flow can lead to erosion corrosion or flow-accelerated corrosion (FAC). These two mechanisms are dictated by flow regime and the inherent stress that flowing fluid creates on the pipe wall. FAC is when fast flowing water removes the semi-protective oxide layer and continues to remove any other precipitating oxide, leading to

metal loss. Erosion corrosion involves impingement of particles through mechanical wear on the scale and/or oxide layer.

Flow regime is often incorporated into corrosion models by using the shear stress of the fluid on a steel surface as a modeling parameter. Models may allow the manual input of a shear stress value, or may instead calculate it from other inputs. Model A and Model B allow the user to calculate or input the shear stress.

The effect of multiphase flow on CO₂ corrosion is complicated by the different flow patterns that exist, the most common being stratified, slug, and annular-mist (annular dispersed) flow. Different flow patterns affect the wetting of the steel surface. Stable water wetting, stable oil wetting, and intermittent wetting can occur, all of which greatly affect corrosion rate. Model A and Model B assume 100% water wetting if any water is present in the system, but were not intended for use with annular-mist flow regimes. Model C does take the effect of water and oil present.

pH

pH has a strong influence on corrosion rate, and can directly affect it by influencing the rate of dissolution of iron into solution. One important indirect effect of pH is its influence on the formation of scale films. High pH results in the decreased solubility of iron carbonate, thus leading to an increased precipitation rate and higher scaling tendency. However, at high pH calcium carbonate scale can form, which can spall off, creating regions of high-rate localized corrosion. Figure 3 shows how, under nearly identical input conditions, different models predict distinctly different corrosion rates. Model A is quite sensitive to variation in pH and Model C has strong pH dependence due to large effects of H⁺ mass transport limitation, predicting very low corrosion rates when pH is above 5. In comparison, pH appears to have little effect on corrosion rates predicted using Model B. ^{Ref 1}

Conclusion

There are significant model-dependent variations between predicted corrosion rates by different models. Particular parameters have a greater influence on corrosion rates, depending on the model's treatment of the parameter. This can lead to overly conservative results, in the case of Model A, or predictions showing nearly no change, as in Model B. When choosing between models, it is imperative that the model user understands the nuances and limitations of the model so that the appropriate model can be chosen, and so model predictions can be correctly interpreted in the context of the system being modeled.

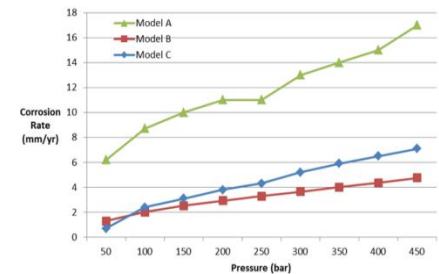


Figure 2: Corrosion Rate Comparison as a function of pressure under the following defined conditions: pH of 4.5, 1 mol% CO₂, and T = 40°C.

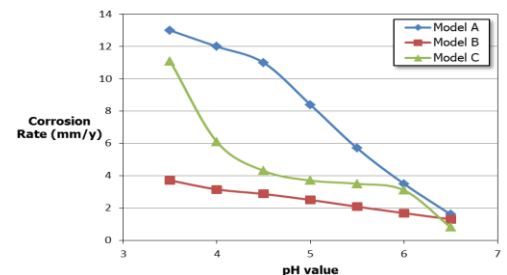


Figure 3: Corrosion Rate Comparison as a function of pH value with T=40 C°, 1 mol% CO₂, and P=200 bar for different corrosion models.



Upstream engineering for offshore oil and gas specializing in:

- Materials & Corrosion
- Flow Assurance
- Water Injection
- Chemical Systems
- Commissioning & Startup
- Subsea Engineering
- Offshore Risk Management
- Operations Readiness

GATEKEEPERS are published for the benefit of our friends and clients. If you have any questions about this article, please contact us at info@gateinc.com or 281.398.5781

References

1. Rolf Nyborg, Overview of CO₂ Corrosion Models for Wells and Pipelines, NACE 2002, Paper No. 02233.

