CO_2 Corrosion Prediction: Considering Validation

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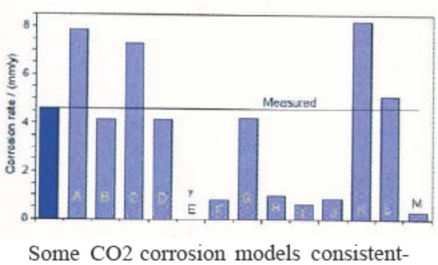
Carbon dioxide (CO2) corrosion modeling software is used by asset owners, contractors and consultants in the oil and gas industry to predict the CO2 corrosion rate at both the design and operation phases of pipelines and well tubing. Prediction results from a dozen CO, corrosion models are known to vary wildly" This article discusses the need for CO2 corrosion model validation and introduces the CO2 corrosion model validation matrix and index score system for an objective and effective validation of a CO2 corrosion model's performance.

Corrosion Model Validation

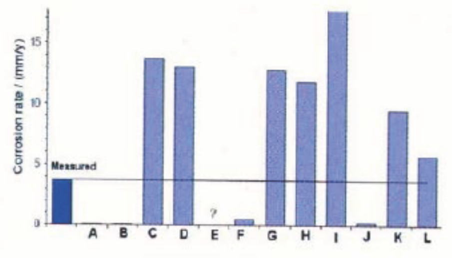
CO2 corrosion is a recognized integrity threat worldwide. CO2 corrosion model-ing has been used at both the design and operation phases of oil and gas pipelines for the prediction of internal corrosion growth rates. Since the classic carbon dioxide corrosion model published by C. DeWaard and D.E. Milliams in 1970s[1], over a dozen CO2 corrosion models have been developed over the past 40 years. An excellent overview of the different CO2 corrosion models is given in reference[2].

A considerable gap exists between CO2 corrosion model predictions and the reality[2-4]. Some CO2 model developers claim that their model can "accurately" predict this and "accurately" predict that, but when it comes to the corrosion rate prediction, it simply fails and it fails badly.

Figures 1 and 2 show comparisons of the measured corrosion growth rate and the corrosion growth rates predicted from 13 CO2 corrosion prediction models under two specific field conditions[3]. Some CO2 corrosion models consistently underestimate the CO2 corrosion rate under most operating conditions by a factor of over 10 in some cases (Models "F" and "J").



Some CO2 corrosion models consistently overestimate the CO2 corrosion rate



(Models "C" and "K"). Other models simply fail to give reasonable predictions when the operating conditions change (Models "B," "D" and "G" in Figure 1).

When a model failed to predict the corrosion rate, it failed. Explaining the failure to predict by saying the model is sensitive to pH, sensitive to oil wetting, sensitive to shear stress so on and so forth is completely irrelevant to the end users. It is nothing but the final corrosion rate predicted by a CO2 corrosion model that matters to the end users.

A model's ability to "accurately" predict pH, the effects of oxygen, NaCl, bicarbonate, H2S, HAc, scaling, oil wetting, fluid velocity, and any other factors has absolutely no use if the model consistently fails to make a reasonable prediction of the actual corrosion rate.

Figure 1 shows that four out of the 13 CO2 corrosion-prediction models produced reasonable corrosion growth rates, while the majority of the CO2 prediction mod-els simply failed to produce meaningful results. Under another specific field condi-tion (Figure 2), all models failed to produce reasonable corrosion rates.

Contractors or consultants who have been using a single CO2 corrosion model-ing software for all clients and under all operating conditions may not realize the considerable, sometimes shocking uncer-tainties in the predicted corrosion growth rates (by a factor of over 10). Facility owners and users of CO2 corrosion model software should protect their interest by validating the CO2 corrosion model soft-ware independently.

Without proper validation, facility own-ers and users of CO2 corrosion-model-ing programs have no way of knowing the accuracy of the predicted corrosion growth rates. The blind trust in a sin-gle CO2 corrosion model without proper validation and the subsequent use of the modeled results in the design will either expose the assets to increased integrity risk (in case of Models "F" and "J") or lead to overdesign with the unnecessary use of corrosion-resistant alloys (CRAs) or additional inhibitor dosage (in case of models "C" and "K").

Commercial CO2 model software developers typically do not provide the users with any validation details. Validation of modeled results against lab or field data is often difficult as quality lab or field data under the prevailing operating conditions used in the prediction software are not readily available. This is particularly true at the design stage where the input parameters are often simulated or projected.

Validation of modeled results against corrosion-monitoring data in the field may not be applicable as that data is based on "spot" measurement at a specific location, and under some uncertain local operating conditions. Also, the modeled results represent the "worst-case" scenario in the whole system (not spot measurement) under the specific operating conditions.

The only practical way to ensure that the modeled results are reasonably reliable is to validate the CO2 modeling software itself by utilizing the user's or any third-party's well-defined quality lab and field data before starting the modeling project. It is critical to the user or any third-party quality data, not the model developer's data for the validation process.

Validating Corrosion Models

An objective and effective validation process must cover a wide range of parameter values in a systematic way. Non-performing CO2 corrosion models (such as Models "F", "J", "C", "K") over a wide range of operating conditions will be positively identified and the errors of prediction are objectively quantified.

The following CO2 corrosion model validation matrix (CO2MoVM) and CO2 corrosion model validation index score (CO2MoVIS) systems are proposed for the objective, comprehensive and systematic validation of any CO2 corrosion-modeling software.

The CO2 corrosion model validation matrix (CO2MoVM) consists of eight cat-

Table 1 CO2 Corrosion Model Validation Matrix and Index Score System

Input parameter range	Low Input Range		Medium Input Range		High Input Range	
Input parameter category	**L1**	**L2**	**M1**	**M2**	**H1**	**H2**
Partial pressure of CO2, pCO2	PE (pCO2,L1)	PE (pCO2,L2)	PE (pCO2,M1)	PE (pCO2,M2)	PE (pCO2,H1)	PE (pCO2,H2)
Temperature, Temp	PE (Temp, L1)	PE (Temp, L2)	PE (Temp, M1)	PE (Temp, M2)	PE (Temp, H1)	PE (Temp, H2)
pH	PE (pH, L1)	PE (pH, L2)	PE (pH, M1)	PE (pH, M2)	PE (pH, H1)	PE (pH, H2)
Liquid velocity, V_L	PE (VL, L1)	PE (VL, L2)	PE (VL, M1)	PE (VL, M2)	PE (VL, H1)	PE (VL, H2)
Partial pressure of H2S, pH2S	PE (pH2S, L1)	PE (pH2S, L2)	PE (pH2S, M1)	PE (pH2S, M2)	PE (pH2S, H1)	PE (pH2S, H2)
Organic acids (HAc+Ac), HAc	PE (HAc, L1)	PE (HAc, L2)	PE (HAc, M1)	PE (HAc, M2)	PE (HAc, H1)	PE (HAc, H2)
Bicarbonate, HCO3-	PE (HCO3-, L1)	PE (HCO3-, L2)	PE (HCO3-, M1)	PE (HCO3-, M2)	PE (HCO3-, H1)	PE (HCO3-, H2)
Chlorides, CL	PE (CL, L1)	PE (CL, L2)	PE (CL, M1)	PE (CL, M2)	PE (CL, H1)	PE (CL, H2)
AVG of Percent Error	PE (AVG, L1)	PE (AVG, L2)	PE (AVG, M1)	PE (AVG, M2)	PE (AVG, H1)	PE (AVG, H2)
Model Validation Index Score, MoVIS	**PE (AVG, L) = MoVIS-L score** Minimum of 10 dada sets in the L range are required to compute the MoVIS-L score		**PE (AVG, M) = MoVIS-M score** Minimum of 10 dada sets in the M range are required to compute the MoVIS-M score		**PE (AVG, H) = MoVIS-H score** Minimum of 10 dada sets in the H range are required to compute the MoVIS-H score	
Model Validation Index Score, MoVIS	PE (AVG, L+M+H) = **MoVIS** score					
PE = absolute value of percent error = |[(model predicted CorrRate)-(measured CorrRate)]|/(measured CorrRate)						
MoVIS-L score: The MoVIS-L score shows the CO2 model's performance at the lower end of the input parameters.						
MoVIS-M score: The MoVIS-M score shows the CO2 model's performance in the medium range of the input parameters.						
MoVIS-H score: The MoVIS-H score shows the CO2 model's performance at the higher end of the the input parameters.						
MoVIS score: The MoVIS score shows the CO2 model's overall performance across a wide range of input parameters.						

Table 2 Recommended Parameter Range for CO2 Corrosion Model Validation Matrix

Input parameter range	Low Input Range		Medium Input Range		High Input Range	
Input parameter case category	**L1**	**L2**	**M1**	**M2**	**H1**	**H2**
Partial pressure of CO2, bar	0.05	0.10	1.0	3.0	10.0	20.0
Temperature, oC	20.0	40	50	60	80	120
pH	3.0	3.5	4.0	4.5	5.0	6.0
Liquid velocity, m/s	0.1	0.5	1.0	3.0	10.0	15.0
Partial pressure of H2S, bar	2.5×10^{-5}	2×10^{-4}	1.5	3.0	3.5	4.0
Organic acids (HAc+Ac), ppm	10	50	100	500	1,000	2,000
Bicarbonates (HCO3-), ppm	50	100	200	500	1,000	2,000
Chlorides, ppm	100	200	1,000	5,000	20,000	100,000
AVG of Percent Error	PE (AVG, L1)	PE (AVG, L2)	PE (AVG, M1)	PE (AVG, M2)	PE (AVG, H1)	PE (AVG, H2)
Model Validation Index Score, MoVIS	**PE (AVG, L) = MoVIS-L score** Minimum of 10 dada sets in the L range are required to compute the MoVIS-L score		**PE (AVG, M) = MoVIS-M score** Minimum of 10 dada sets in the M range are required to compute the MoVIS-M score		**PE (AVG, H) = MoVIS-H score** Minimum of 10 dada sets in the H range are required to compute the MoVIS-H score	
Model Validation Index Score, MoVIS	PE (AVG, L+M+H) = **MoVIS** score					

egories of input parameters in three different input value ranges (low, medium and high), with a total of 48 data sets in the matrix. The absolute value of error percent, PE, in each data set is used to compute the average score, defined as the CO_2 corrosion model validation index score (MoVIS), in three input parameter value ranges (low, medium, high).

The MoVIS-L, MoVIS-M and MoVIS-H scores are direct indications of a CO_2 corrosion model's prediction accuracy in the low, medium and high input parameter value ranges, respectively. The overall MoVIS score is the average of the MoVIS-L, MoVIS-M and MoVIS-H scores, representing the absolute error percentage averaged over the eight input parameter categories in three ranges of input parameter values. The overall MoVIS score is a direct, objective and comprehensive measure of a CO_2 corrosion model's prediction accuracy.

After validating the CO_2 corrosion model software, facility owners and users of the CO_2 corrosion model software will know the accuracy or the uncertainty in the predicted results which will lead to better engineering and financial decisions when it comes to corrosion allowance, material selection, chemical treatment, CO_2 removal, glycol injection, pH stabilization and other methods for CO_2 corrosion mitigation.

Table 2 shows the recommended parameter value range to be used in the CO_2 Corrosion Model Validation Matrix. It is important to note all data sets used in the matrix must be high quality. CO_2 corrosion modeling follows the "garbage in, garbage out" rule. If a high-quality data set is not available in some boxes in the matrix, leave the boxes blank and exclude them in the computation of the MoVIS score. Low-quality data should never be used in the validation matrix.

High-quality data should meet the following criteria:

- The lab or field data must be from a reliable and reputable source and must be verifiable with a clear and detailed description of the source, history and the background information relating to the data.
- The lab or field data must be complete and have detailed information on the operating/test conditions and the test/measurement procedures/techniques used to obtain the data. Incomplete data should not be used in the validation matrix.
- The lab or field data from – and/or used by – the CO_2 corrosion model developer should not be used in the validation matrix.

Conclusion

It is always easier and better to validate the CO_2 corrosion modeling software before beginning a modeling project than trying to validate the modeled results afterward. A CO_2 corrosion prediction model may be a useful tool at the design and operating phases of the oil and gas pipeline, but it must be used with caution. ***P&GJ***

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