

From the desk of G. A. Aaker, Jr., PE.

The following **SAMPLE CALCULATION** may be used as a guideline to predict the corrosion rate from the effects of CO₂

1. Design Conditions:

Operating Condition = 245 psi (16.33 Bars),
Mol % CO₂ = 4.0%,
Partial Pressure CO₂ = 9.8 psi (.6533 Bars),
Temperature = 120 ° F (48 ° C)

2. Corrosion Effects:

The corrosion of carbon steel in a wet CO₂ environment can lead to iron carbonate as a reaction product. Although recent work suggests that an iron carbide matrix is first produced on the surface of a corroding steel surface, a carbonate scale, which will protect the underlying metal, can often be formed. The formation and protectiveness of such a scale depends on a number of factors such as the solubility of iron carbonate (which will vary with pH and the presence of other salts), the rate of reaction of the underlying steel and the surface quality (roughness/cleanliness). In addition, the scale persistency will be sensitive to turbulence and may grow to such a thickness that it cracks and spalls. Current practice is to not rely on such carbonate scale to give continuous protection over the full length of a hydrocarbon flow line or export line. Particularly in regions of high flow or at weld seams, scale breakdown can lead to a rapid rate of localized corrosion (Mesa Attack). Although a carbonate scale may protect the majority of a line, the corrosion rate used for design calculations must be based on the de Waard and Milliams equation. However, at temperatures of 60°C or more the scale is considered stable and protective enough to allow modification of the de Waard and Milliams equation by a multiplying factor,

$$F(s): V = F(s) v(dWM)$$

where V is the adjusted corrosion rate, F(s) is the factor for scaling and v(dWM) is the corrosion rate calculated from the original de Waard and Milliams equation.

$$\begin{aligned} \text{Log } F(s) &= (2500/(T+273)) - 7.5 \\ \text{Log } F(s) &= (2500/(48^{\circ}\text{C}+273)) - 7.5 \\ \text{Log } F(s) &= (2500/321) - 7.5 \\ \text{Log } F(s) &= 7.788 - 7.50 \\ \text{Log } F(s) &= 0.2882 \\ F(s) &= 1.941 \end{aligned}$$

Since the is temperature is less than 60° C use 1.0.

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If the correction for high temperature scaling is made, then no allowance should be made for pH correction. The pH correction factor is for bare metal surface and it is currently unclear what effect pH will have on the corrosion rate of a surface that is protected by a high temperature scale. The original de Waard and Milliams work was carried out at low partial pressures of CO₂ (< 1 bar). The fugacity of a gas species is effectively the activity of a gas species and for ideal gases or gases at low pressures this is equal to the partial pressure. At higher pressures, because of non-ideality, the fugacity or activity of CO₂ is less than its partial pressure and this should be used in the calculation of corrosion rates. It is possible to calculate the CO₂ fugacity (f CO₂) and use it in the de Waard and Milliams equation corrected for partial pressure:

$$f \text{ CO}_2 = (a)(pp\text{CO}_2)$$

Where f CO₂ is the CO₂ fugacity, (a) is the fugacity coefficient and ppCO₂ is the partial pressure of CO₂ For operating pressure of 245 psi

$$\begin{aligned} pp\text{CO}_2 &= \text{Pressure}(\% \text{ CO}_2) \\ pp\text{CO}_2 &= 245 \text{ psi} (4.0\%)(.01) \\ pp\text{CO}_2 &= 9.8 \text{ psi or } 0.6533 \text{ Bars} \\ \text{Log}(a) &= P \text{ total } (0.0031 - 1.4/(T + 273)) \\ \text{Log}(a) &= (245/15)\text{Bars}(0.0031 - 1.4/(68^\circ\text{C} + 273)) \\ \text{Log}(a) &= (16.33\text{Bars})(0.0031 - 1.4/321) \\ \text{Log}(a) &= (16.33\text{Bars})(0.0031 - .0044) \\ \text{Log}(a) &= (16.33\text{Bars})(-0.0013) \\ \text{Log}(a) &= -0.0212 \\ (a) &= .9523 \end{aligned}$$

then, the calculated corrected partial pressure is:

$$\begin{aligned} f \text{ CO}_2 &= (a)(pp\text{CO}_2) \\ f \text{ CO}_2 &= (0.9523)(0.6533 \text{ Bars}) \\ f \text{ CO}_2 &= 0.6221 \\ \text{the corrosion rate } v(\text{dWM}) &\text{ is given by:} \\ \text{Log}(v) &= 5.8 - 1710/(t + 273) + 0.67 \\ \text{Log}(f \text{ CO}_2) \text{ Log}(v) &= 5.8 - 1710/(48 + 273) + 0.67\text{Log}(0.6221) \\ \text{Log}(v) &= 5.8 - 1710/(321) + 0.67(-.2061) \\ \text{Log}(v) &= 5.8 - 5.32 + - 0.1381 \\ \text{Log}(v) &= 0.3419 \end{aligned}$$

(v) = 2.19 mm and the adjusted corrosion rate V is:

$$V = F(s) v(\text{dWM})$$

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$$V = (1.0) (2.19 \text{ mm}) V$$
$$V = 2.19 \text{ mm per year}$$

The use of inhibitors can be 90% effective, therefore, with inhibitors, $V = 0.219$ mm per year. For 20 Years:

$$V = 0.219 \text{ mm (20 yrs)}$$
$$V = 4.3 \text{ mm} = 0.17244 \text{ inches}$$

The above prediction is recognized as being very conservative and usually is modified

$$V = 0.177 \text{ inches} \times 0.60 = 0.120 \text{ inches}$$

Required minimum corrosion allowance for 20 years is 0.102 inches

3. Velocity Effects

It is known that in mixed phase conditions without the presence of solids that a slug flow condition readily damages any scale formed. As a result, where scale damage has occurred carbon steel corrosion rates would be at least equal to those predicted if no iron carbonate scale is formed. When scale is damaged pitting corrosion will take place. For systems, which are primarily liquid phase, and without solids, superficial flow velocities exceeding approximately 2.7 meters per second cause scale damage and corrosion similar to the slug flow condition. If solids are present, any protective scale is readily removed, and corrosion rates will be at least as great as predicted if no iron carbonate scale is formed.