# Corrosion Modeling of Sweet Flowlines Part 1: Techniques

$CO_2$ corrosion modeling is a common practice to evaluate carbon steel flowlines and piping, both with and without inhibition, to ensure they achieve their intended design life. Modeling is also used to help determine if a corrosion resistant alloy should be used and can also be utilized to determine corrosion allowance and inhibition requirements.

## Corrosion Modeling

Corrosion modeling is meant to provide a more accurate estimate of corrosion rates to better indicate whether carbon steel or a corrosion resistant alloy should be used in a given application. Its use can be reasonably extended to evaluate corrosion allowance and corrosion inhibition requirements if required, but these are modeled values and some amount of flexibility must be assumed in the results. Corrosion modeling can also provide a good check if a standard practice, that does not include corrosion modeling, is used to determine the corrosion allowance and inhibition requirements. This ensures that any standard practice used is still valid and aids with adjustments to the standard strategy, if required.

Modeling is often preferred to corrosion testing because it can be performed in less time and at substantially less cost, but this is commonly accompanied with a resultant loss of accuracy. Corrosion testing should be performed if there is a significant doubt regarding the accuracy of the corrosion rates modeled or if there is a strong desire to validate the acceptable use of carbon steel in what may be viewed as marginal conditions.

There are a significant number of corrosion models available, many of which are proprietary or commercial. They all place a different emphasis on the various inputs and how the corrosion rates are calculated. However, they all rely on pressure, temperature and $CO_2$ concentration at a minimum. How conservative a model is can vary from one set of conditions to another and also depends on what additional inputs the corrosion model incorporates. This is generally not a concern because corrosion models tend to be conservative and do not completely reflect operating conditions.

## Corrosion Models & Organic Acids

There are other factors that can affect corrosion modeling, but one of the most significant is organic acids. These include acetic and formic acids. These will have an effect on the pH if a sufficient quantity is present, and can subsequently affect the corrosion rate. Organic acids may also lead to top of the line corrosion issues in wet gas systems. Not all corrosion models include organic acids, and in those that do, the effect varies significantly.

The simplest method for taking organic acids into account in corrosion modeling is to adjust the pH or bicarbonate concentration. This can be achieved by at least two methods. The first requires the in-situ pH to be known and an effective bicarbonate concentration can be solved for by iteration. This method can be more challenging, but is generally more indicative of the actual conditions, since many corrosion models solve for the in-situ pH using $CO_2$ partial pressure and temperature alone. The second is to consider some fraction of the organic acid concentration neutralizing an equivalent amount of the bicarbonate concentration. This is simpler, but comes at the sacrifice of some accuracy. Both methods will provide results that are within experimental error and are expected to provide reasonable results in all but the most extreme cases.

## Corrosion Allowance

The corrosion allowance provides a small amount of material that can corrode over a given time without impacting the integrity of the system. Nearly every carbon steel pipe used in the oil and gas industry has some corrosion allowance incorporated into the wall thickness. The smallest corrosion allowance often observed is 1.5 mm (0.0625 inch), and the largest approaching 9 mm (0.375 inch), with 3 mm (0.125 inch) being the most common and readily available.

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**Corrosion Modeling**

Used to Provide:

- A more reasonable estimate of corrosion rates to better indicate whether **carbon steel** or a **corrosion resistant alloy** should be used.
- Can be reasonably extended to evaluate **corrosion allowance** and **corrosion inhibition** requirements.
- A **good check** if corrosion modeling has not been used to determine corrosion allowance and inhibition requirements.



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**Factors that Effect Inhibitor Efficiency**
- Fluid Cleanliness
- Flowing Regime
- Erosive Velocities
- Other Chemicals
- Historical Experience

**Factors that Effect Inhibitor Availability**
- Number of Pumps
- Alarms
- Pump Switching
- Monitoring
- Number of Tanks



## Corrosion Inhibition

Even a little $CO_2$ can cause a significant amount of corrosion if given enough time, sufficiently so that any corrosion allowance can be exhausted before the design life is achieved. Corrosion inhibitors are commonly added to produced fluids to overcome this and ensure the system achieves the intended design life. There are two factors that control how effective a corrosion inhibitor is in a carbon steel flowline. The first is the ability of the inhibitor to reduce the corrosion rate, or efficiency, and the second is the availability of the inhibitor to reduce the corrosion rate.

## Corrosion Inhibitor Efficiency

Inhibitor concentration and dose rate are often considered the primary factors when considering inhibitor efficiency. However, other factors are present such as actual flowing conditions, the purity of the fluids, erosive velocities, etc. Historic experience can also be a benefit. Concentration and dose rate can be estimated initially, but are expected to change over time as the field matures and conditions change.

Flowing conditions, specifically the velocity and flow regime, have a dramatic effect on the inhibitor's efficiency as these can affect residence times and ability for the inhibitor to become sufficiently atomized. The presence of other species can also have a significant impact. When inhibitors are tested, they are tested in clean conditions where the fluids have no contaminants such as salts, corrosion products, or other chemicals.

Historic experience can be used to initially estimate initial inhibition requirements and what is possible prior to physically determining an inhibitor's capability. This experience should take into account the fluids being inhibited, project location, generic usage requirements (dose rate, residence times, compatibility issues, etc.). However, just basing the selection of an inhibitor on general historic performance may not be sufficient and an inhibitor qualification program should be undertaken to ensure the inhibitors identified perform as expected and are compatible with all fluids being produced and injected.

In addition to pre-determining the initial dosage that is confirmed by performing field trials, inhibitor qualification can also provide a benefit by having residence time evaluated for potential issues prior to commissioning. Although there is an upfront expense to accomplish this, these benefits can be significant over a project's life.

## Corrosion Inhibitor Availability

The availability of an inhibitor must be considered early in the design phase of a project if a high availability need is anticipated. This includes general operating guidance, as well as the design of the system. Experience has shown that well designed systems are highly redundant and can ensure inhibitor is available almost full time, with interruptions only due to unforeseen events. These systems do successfully inhibit fields with high corrosion rates. Several of the primary factors that are included into ensuring high inhibitor availabilities are listed in the table to the left. If done properly, the availability in a given system can exceed 98% uptime and delivery.

## Summary

Sweet corrosion of flowlines is a common issue. Corrosion modeling provides a snapshot of how aggressive the conditions in a given system are and is an indication whether a CRA is required or if the use of carbon steel with corrosion inhibition is feasible.

Carbon steel with a corrosion allowance and corrosion inhibition is the preferred selection, but its successful use often depends on the effective qualification of the inhibitor and the design and operation of the delivery system in terms of ensuring that inhibitor is available to prevent corrosion and so enable the flowline to safely and adequately meet its intended design life.