Top of Line Corrosion

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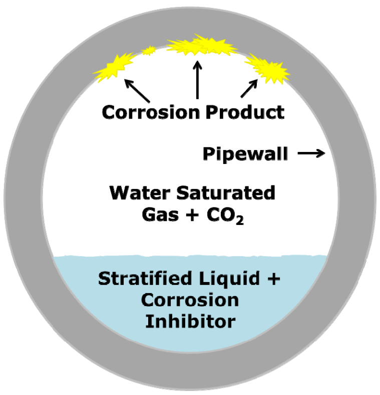

Figure 1: A typical TOL Corrosion in the field

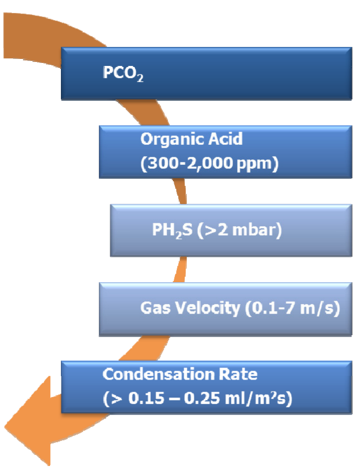

Figure 2: Key parameters and the critical range for TOL corrosion concern.

Top of Line (TOL) corrosion occurs in multiphase wet gas systems when water vapor contained in the gas phase condenses on the internal upper pipe walls. This happens due to the heat exchange occurring between the pipe and colder surroundings (river water, seawater or cold air) if the pipe is not thermally insulated or buried at a reasonable depth. The condensed liquid then becomes enriched by the corrosive species naturally present in the gas stream and assumes a low pH because it does not contain any buffering species such as bicarbonate or iron. The predominant concern is carbon dioxide (CO_2), which reacts with water to form carbonic acid (H_2CO_3), although hydrogen sulfide (H_2S) can also present significant challenges. As TOL corrosion occurs in wet gas lines operated in stratified flow, the corrosion inhibitor or other corrosion protection chemicals such as mono -ethylene glycol (MEG) injected into the system remain at the bottom of the line and are not able to protect the top of the line.

TOL Corrosion Management

All initiatives are oriented towards four major priorities:

- Understanding the TOL corrosion mechanism.
- Development of new techniques, tools and procedures for controlling TOL corrosion for existing lines.
- Development of new tools for the prediction and control of TOL corrosion, and for the design of lines for ongoing and future projects.
- Development and testing of new monitoring and inspection tools to guarantee the *in-situ* integrity of existing lines.

TOL Corrosion Mechanism

Stratified flow regimes in a wet gas system is a prerequisite for TOL corrosion susceptibility. The aggressive condensed water which contains various corrosive species, such as CO_2, H_2S, and acetic acid (HAc), forms on the cooler metal surface at the top of the line and the sides, and attacks the metal wall. Several TOL corrosion models have been developed based on the hypothesis that the TOL corrosion rate is dependent on the water condensation rate and the amount of iron which can be dissolved in the condensing water.

Key Parameters Influencing TOL Corrosion

The main parameters influencing TOL corrosion are the temperature of the fluid, the CO_2 and H_2S partial pressures, the concentration of organic acids, the gas velocity, and the condensation rate, which is also temperature driven.

- Effects of CO_2
- Effects of H_2S
- Effects of Organic Acids
- Effects of Gas Velocity
- Effects of Condensation Rate

Effects of CO_2

The partial pressure of CO_2 has a significant influence on the TOL corrosion rate as it is primarily responsible for controlling the TOL corrosion rate in sweet systems.

Effects of H_2S

TOL corrosion rates in sour environments are mainly dependent on iron sulfide scale characteristics, which are predominantly a function of temperature and H_2S concentration. In this situation, condensation rate is a secondary parameter. TOL corrosion rate tends to increase at H_2S partial pressures above 2 mbar and at increasing water condensation rate.

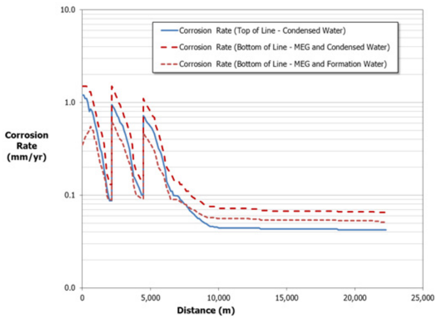

Figure 3: Corrosion Rate Profile for a field including Top of Line-Condensed Water, Bottom of Line -MEG and Condensed Water, MEG and Formation Water

Effects of Organic Acids & Produced Water Composition

Corrosion experiments have noted that increasing organic acid concentrations increase TOL corrosion rates. The organic acid concentrations of severe TOL corrosion is in the range of 300 to 2,000 ppm. Organic acids affect corrosion rate in 3 ways:

1. Increasing the cathodic reaction rate by acting as a source of protons.
2. Inhibiting the anodic dissolution reaction, usually due to a film-forming effect.
3. Changing the solubility and protectiveness of the corrosion product films.

Although produced water composition does not directly impact the TOL conditions beyond the partitioning of organic acids to the gas phase, a substantial indirect effect also occurs as a result of the overall buffering effect of the brine (for instance if it contains high levels of bicarbonate). This is because the gas phase exists in equilibrium with the water in the base of the line, so the gas phase pH and the inherent corrosivity of the system is generally lower where produced waters have a higher pH.

Effects of Gas Velocity

The gas velocity has a direct effect on the condensation rate, which in turn can affect the TOL corrosion rate. This is due to the mass transfer limitation for condensation present in the gas phase. The critical gas velocity for TOL corrosion concern is in the range of 0.1-7 m/s, but the liquid velocity should also be considered.

Effects of Condensation Rate

At low condensation rates, a protective film of iron carbonate appears at the surface of the pipe exposed to TOL corrosion, which lowers the corrosion rate. At high condensation rates, saturation cannot be reached, and the corrosion rate can be in the order of several millimeters per year (mm/yr). The critical condensation rates for TOL corrosion in wet multiphase gas lines are between 0.15 and 0.25 ml/m^{2}s. The corrosion rate is governed by the rate of the corrosive reaction and the rate of condensation.

Control of TOL Corrosion

Several actions can be taken to control TOL corrosion in the existing pipeline and also prevent it in the design of future pipelines:

- Applying an increased corrosion allowance for carbon steel lines.
- Applying local heat insulation on the most corrosive areas.
- Applying water-soluble, filming-type corrosion inhibitor with short contact time efficiency through batch injection.
- Employing corrosion resistant alloys (CRA) in those areas where water condensation occurs at a significant rate.
- Providing internally clad carbon steel at the upstream end of the system where temperatures and condensation rates are highest.
- Sending a spray pig through the line to distribute corrosion inhibitor from the bulk liquid phase on to the top portion of the line.
- Neutralizing organic acids by MDEA to reduce the TOL corrosion rate have been confirmed by preliminary tests in the condensing loop.

Conclusion

TOL corrosion is specific to hot multiphase wet gas lines operated in the stratified flow when subjected to external cooling. The CO_2 and H_2S partial pressure, the quantity of organic acids dissolved in the condensed water, and the water condensation rate are the main parameters that influencing the corrosion rate. Tools, techniques and chemicals in the forms of local heat insulation, batch corrosion inhibitor and routine pigging programs, and internally clad carbon steel are now available for prevention and control of the TOL corrosion.

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