

**The impact of the nature of the condensation process on the Top of the Line Corrosion**

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Top of the Line Corrosion, TLC, is a corrosion process that may occur during gas or liquid-gas stratified transportation in horizontal or slightly inclined pipelines. This type of corrosion phenomena happens when vapor condenses due to a change in temperature between the gas flowing inside of the pipe and the pipe-wall. Depending on the temperature gradient the condensation rate can vary; this parameter, as well as the total pressure and gas velocity, is believed to affect the nature of the condensation process and this determines the severity of the metal dissolution and the characteristics of the attack. The TLC phenomena has not being studied in extend due to the difficulties to have an experimental set up that reflects field conditions. For that reason its prediction is also an un-solved issue. On the other hand, TLC is a process difficult to mitigate using traditional methods such as corrosion inhibitors, because it is impossible for the inhibitor to get in touch with the top of the line. Volatile inhibitors use not to be considered as a solution due to cost-effective arguments and environmental-healthy reasons.

A study of TLC was conducted on a 4" internal diameter flow loop at the following conditions: 70°C, 8 bars of carbon dioxide and a condensation rate of 0.25 ml/m<sup>2</sup>/s and 80°C, 1.5 bars of carbon dioxide and a condensation rate of 1 ml/m<sup>2</sup>/s. Carbon steel samples placed on top and bottom of an outside cooled test section were used to determine the corrosion rate by the weight loss technique and to analyze the corrosion product morphology, distribution and composition at the scanning electron microscope, SEM. Some samples were mounted in a cold cured low viscosity epoxy to do cross section analysis with the objective of evaluating the presence of localized attack as well as the thickness and density of the corrosion layers. Bottom samples were evaluated for comparison.

Fig. 1 shows the aspect of a top sample after testing. SEM inspection of top samples revealed that, at the experimental conditions tested, iron carbonate crystals were formed in certain zones of the sample while in other areas no crystalline corrosion products could be found, see Fig. 2 and 3

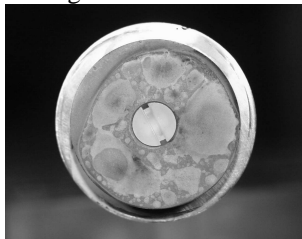


Fig. 1 General view of a top sample after testing.

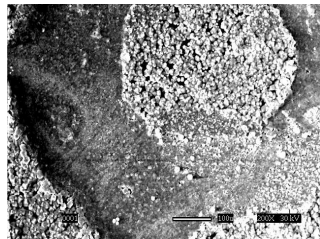


Fig. 2 SEM image of the corrosion products on a top sample.

The nature of the condensation process in the top of the line under the tested conditions explain the non-uniform distribution of the iron carbonate crystals and it could also explain the non-uniform attack of the metal surface as it can be noticed on samples after the removal

of the layer, Fig. 4. The residence time of droplets of condensed liquid on the metal surface is high enough to generate conditions for iron carbonate precipitation. Such small volume of liquid in contact with the metal surface can be quickly acidified by the carbonic acid coming from the CO<sub>2</sub> dissolution. This acid environment promotes the iron dissolution and consequently the pH increases, so that supersaturation conditions can be reached and iron carbonate crystals can be formed in some areas of the sample. The existence of partially protected zones and active areas may induce the initiation of localized attack as can be appreciated in Fig. 5 and 6.

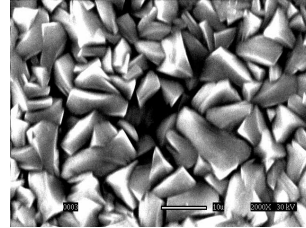


Fig. 3 Iron carbonate crystals observed in some areas of the top sample

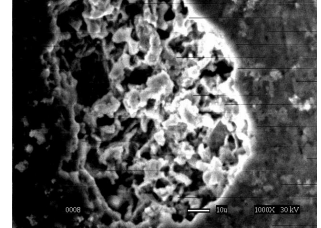


Fig. 4 Detail of an area of the coupon after corrosion products removal

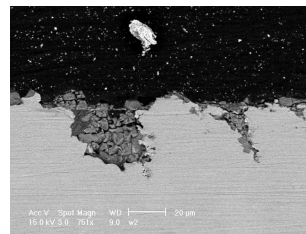


Fig. 5 Cross section of a top sample showing possible localized attack initiation

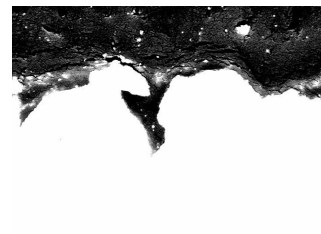


Fig. 6 Cross section of a sample showing possible localized attack initiation

Differences in composition can be inferred from backscatter images at the SEM as it can be noticed by comparing Fig. 7 and 8, which correspond to a top view on a sample after the removal of the corrosion products. It is believed that the metal dissolution on the areas surrounding droplets of condensed liquid is similar to the attack observed in the bottom samples where no iron carbonate protective layers are formed. The iron rich phase of the carbon steel (ferrite) is dissolved leaving the carbon rich phase (cementite) intact, see Fig. 9 and 10. Analytical surface techniques are being applied to conclude on this aspect of the study.

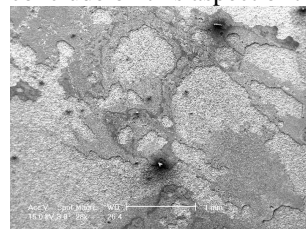


Fig. 7 Secondary electron image of a top sample after layer removal

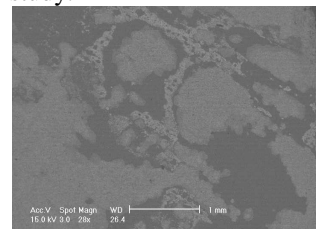


Fig. 8 Backscatter image of a top sample after layer removal

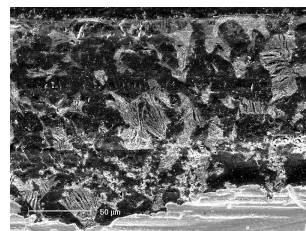


Fig. 9 Cross section of a bottom sample

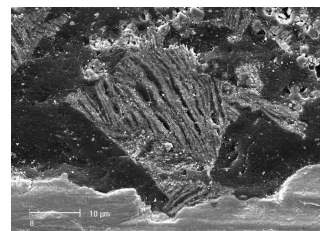


Fig. 10 Detail of Fig. 9