ABSTRACT

Inhibited erosion-corrosion of low carbon steel material (UNS G10180) was investigated in a CO₂ saturated oil-brine-sand flow. Experimental data for erosion, corrosion, and erosion-corrosion (E/C) were collected using a 3-cell erosion-corrosion flow loop that allows all three components to be measured simultaneously. Erosion, corrosion, and erosion-corrosion as well as inhibited corrosion and inhibited erosion-corrosion are measured at 40% water cut. Comparing 40% and 100% water cut data: the addition of oil was found to lower both erosion and corrosion rates for the conditions considered. The presence of sand particles has been shown to reduce the performance of corrosion inhibitor and increase metal loss rate due to corrosion. For the conditions considered in this paper, the presence of sand in systems where iron carbide precipitation was taking place increased inhibitor effectiveness and decreased metal loss due to corrosion. Experimental results indicate that the interaction between oil and imidazoline-based inhibitor lead to the formation of iron carbide precipitates on the steel surface that reduced the inhibitor effectiveness.
INTRODUCTION

Low carbon steel is a widely used material for many industrial applications across many sectors. In particular, the oil and gas industry uses this material at nearly every stage of extraction, transportation, and refining. These applications include pipelines, process equipment involved in extraction, production equipment, processing systems and transportation. The adoption of this material is primarily due to low cost, availability and weldability when compared to other engineering materials and alloys. However, low-carbon steel has low resistance to corrosion.

CO₂ corrosion is one of the most common damage mechanisms that occur in oil and gas production. Controlling and preventing CO₂ corrosion is critical to reducing metal loss to prevent the need to constantly replace deteriorating equipment. If corrosion is successfully controlled, the overall cost of production can be reduced.

Generally speaking, corrosion is a very complex process combining electrochemistry, transport processes, and material science. CO₂ corrosion is affected by a variety of environmental factors such as temperature, pH, species concentration, CO₂ partial pressure, material, and dissolved oxygen in the system just to identify a few critical parameters. The corrosion process can be more complicated if erosion is also taking place along with CO₂ corrosion. The combination of erosion and corrosion is usually described as erosion-corrosion.

Erosion-corrosion results from the interaction between electrochemical (corrosion) and mechanical (erosion) processes. Many studies emphasize that the complexity of erosion-corrosion arises due to synergism between erosion and corrosion. Such synergistic processes can result in higher metal loss than the sum of the independent erosion and corrosion mechanisms. The removal of protective iron carbonate scale formed on the steel surface by sand erosion is a simple example of a synergistic effect that can take place during the erosion-corrosion process.

A common method of mitigating erosion-corrosion is the use of chemical inhibitors. Performance of corrosion inhibitors can be significantly affected by sand erosion. Therefore, accurate prediction of chemical inhibitor effectiveness when sand is being produced is particularly important. Accurate modeling of this behavior is critical when the wells are deep, or off-shore, because coupon testing is impractical and replacement costs are high. Researchers have investigated the performance of corrosion inhibitors under sand production for total brine solution, in which it was reported that sand erosion decreases inhibitor efficiency. This decrease in inhibitor performance was attributed to the reduction in surface coverage of the physically adsorbed inhibitor layer on steel surfaces. However, the inhibitor performance has not been studied for oil-brine mixtures. In this paper results are presented for inhibitor performance in flows containing brine, oil, and sand.

Phenomenological Modeling of Inhibitor Performance

The interaction of the inhibitor with the metal surface is generally explained by chemical-physical adsorption of the inhibitor to a metal surface. The adsorbed inhibitor layer retards the electrochemical reaction at the metal surface. The inhibitor adsorption depends on the chemical composition of the inhibitor, the operating temperature, and the electrochemical potential at the metal/solution interface.

Different inhibitor adsorption phenomenological models have been developed for characterizing the mechanism of corrosion inhibition such as Flory-Huggins, Frumkin, Temkin, Langmuir, Freundlich, Bockris-Swinkels, Hill-de Boer, Parsons, Damaskin-Parsons, and Kastening-Holleck models. Such models have the same general form given by equation (1)
where \(G(\theta,n)\) is a configurational factor, \(C_{inh}\) is the inhibitor concentration, \(\theta\) is the fraction of surface coverage by inhibitor, \(f\) represents the interaction between adsorbed inhibitor molecules, and \(n\) is the ratio of the inhibitor surface coverage to that of water.

Based on a recent study by Hassani et al., the Frumkin isotherm was found the most representative model for predicting inhibitor effectiveness for systems with oil/water/sand mixtures. As such, the Frumkin isotherm was chosen as the phenomenological model in this work. The Frumkin isotherm can be used for surface coverage prediction when a mutual interaction of the inhibitor molecules is important. In this work the Frumkin isotherm model in the following form was chosen

\[
\frac{K_a}{d} C_{inh} = G(\theta,n)e^{-f\theta} \quad (1)
\]

In Equation (2), \(K_{aid}\) is the adsorption/desorption constant, \(f\) is an interaction parameter, \(\theta\) is the surface coverage of the inhibitor, and \(C_{inh}\) is the concentration of the inhibitor. In a mechanistic interpretation, \(f\) can either be a negative or positive value depending on the degree of intermolecular interaction between inhibitor molecules that are absorbed on a metal surface. A negative value for \(f\) is used when the adsorbed molecules attract each other, and a positive value is used when the molecules repel each other. The surface coverage, \(\theta\), is defined as

\[
\theta = 1 - \frac{CR_{\theta}}{CR_{\theta=0}} \quad (2)
\]

where \(CR_{\theta}\) is the measured inhibited corrosion rate and \(CR_{\theta=0}\) is the uninhibited corrosion rate.

The purpose of this work was to investigate the impact of sand erosion on the effectiveness of an imidazoline based inhibitor in oil-brine sand flows using the above equations.

**EXPERIMENTAL PROCEDURE**

In previous work, a 3-cell erosion-corrosion flow loop with a direct impingement test cell was developed and validated. This system enabled the simultaneous measurement of erosion, corrosion and erosion-corrosion (E/C) in a single test. This flow loop can handle single or two phase flow. Experiments in this paper were conducted in two phase oil-brine \(CO_2\) saturated flow that impinges the carbon steel targets installed in series of the three test cell at a desired flow velocity. A schematic of the flow loop is shown in Figure 1. The loop is made of (UNS S31603) stainless steel, so it can tolerate the high temperatures and corrosivity of the test solution. The flow loop can operate at pressures up to 150 psig (1.13 MPa), temperatures up to 200 °F (93 °C) and a flow velocity of 32.6 ft/s (9.9 m/s). Approximately 6 gallons (37.9 L) of oil and 2 gallons (7.6 L) of brine solution were used per test and the total capacity of the storage tank is 20 gallons (75.7 L). The loop has a sand feeder located at the top of the tank and an inhibitor application valve located in the bypass section of the loop. The major components of the loop are the 3-cell test section, sand feeder, tank, inhibitor injection site, and circulation pump.

The three cell test section consists of three plugged tee test cells in series that can measure erosion, corrosion, and erosion-corrosion in a single test. An expanded view of the three test cells is shown in Figure 2. Erosion-corrosion is measured in the first test cell using a low carbon steel (UNS G10180) weight loss (WL) probe. Erosion is measured in the second test cell using a stainless steel (UNS S31603) probe and corrosion is measured using a low carbon steel (UNS G10180) linear polarization resistance (LPR) probe or WL probe in the third test cell. The diameter of each probe is 1.25 inches and each probe is located at about 0.5 inches in front of the nozzle exit. Details for the design and
preparation of LPR and WL probes are described elsewhere. The impingement nozzle from which the test solution gets into the test cell is aligned with the center of the probe and has an inner diameter of 0.265 inches (0.6731 cm).

Figure 1: Schematic of 3-cell E/C flow loop

Figure 2: Expanded view of the 3-cell E/C test section
Test Procedure

Before starting any experiment, the flow loop was cleaned and flushed to eliminate residual oil, inhibitor, and sand. Details of the cleaning method are discussed elsewhere. The test solution was prepared outside of the loop by adding 18% wt Sodium Chloride (NaCl) and 200 ppm Sodium Bicarbonate (NaHCO₃) to 2 gallons (7.6 Liters) of distilled water. For a limited set of experiments, the water volume was increased to 3.5 gallons (13.2 Liters). Before introducing the solution into the tank, it was mixed to be homogenous. 6 gallons (37.9 Liters) of mineral oil was then added to the tank to get two phase oil-brine mixture. The system was then exposed to vacuum pressure to de-aerate and deoxygenate the system and the test solution for at least two hours. The oxygen content in the solution was maintained at a concentration less than 10 ppb during a test. The test solution was then pressurized with 20 psig CO₂ gas and circulated through the system using a diaphragm pump (Wanner Engineering D-10X Hydra-Cell). The pump has a maximum flow capacity of 7.8 GPM. During the circulation process, the test solution only flows through the bypass to allow for specimen isolation. The solution was circulated for at least 6 hours to reach the desirable temperature and pH. Experiments in this paper were conducted at a pH of 4.8 and a temperature of 135°F. Accurate temperature control of the loop was provided by two band heaters and a temperature controller, which is mounted to the exterior of the stainless steel tank. The pH of the test solution was monitored before and after the test in a bypass section between the tank and the pump, which is called the pH section, using a temperature-compensated pH probe. The pH probe was calibrated before each measurement. High salt concentrations can influence the apparent pH measured using common electrode-based systems. Thus, all measurements were corrected using the calibration curve determined by Hassani. The pH was adjusted by adding either hydrochloric acid or sodium hydroxide. Referring to Figure 1, during the test, the brine solution flows through partially closed bottom of the tank valve (depending on the desired water cut value), the oil flows through the partially closed middle of the tank valve (depending on the desired water cut value), and oil-brine mixture passes through the pump and then exits and impacts the 3-cell test section before returning to the tank. Water cut was monitored periodically and adjusted as needed during the test.

Sand was introduced into the system through the sand feeder located at the top of the tank shown in Figure 1. The sand feeder was de-aerated and pressurized with CO₂ gas, which should be higher than the system pressure, to ensure that the sand was introduced into the system. Sand concentration was monitored throughout the test, which was measured at the discharge of the pump, and additional sand was added as needed throughout the sand feeder. Measuring sand concentration in oil-brine mixture is described elsewhere. The sand circulated from the tank, through the pump, impacted the three probes in the test section, and then returned to the tank.

The inhibitor used in this study is a water-soluble, oil-dispersible, imidazoline-based inhibitor. The inhibitor was premixed with brine/oil mixture before starting the test, so that it was mixed using the action of the flow. The inhibitor was injected by a syringe through the inhibitor valve at the bypass section after being placed under vacuum. The inhibitor concentration was calculated based on the total amount of brine solution in the flow loop.

Iron concentrations were monitored at the beginning, middle, and end of tests. Concentrations were determined using a colorimetric method (VACUettes Iron R-6001B†).

† Trade name.
RESULTS

In order to study the behavior of imidazoline inhibitor and construct a model for the inhibitor effectiveness in oil-brine sand flow, erosion, corrosion, erosion-corrosion, inhibited corrosion and inhibited erosion-corrosion experiments have been conducted. As described above, these experiments were monitored using LPR and WL methods. In this section, experimental results are presented for: (i) the effect of oil on CO\textsubscript{2} corrosion; (ii) erosion rates in an oil-brine flow with low sand concentration; (iii) erosion-corrosion in oil-brine flow with low sand concentration; (iv) the effect of imidazoline based inhibitor on CO\textsubscript{2} corrosion in oil-brine flow with no sand; and (v) effect of low sand concentration on condition (iv). The flow loop and test conditions are described in the Experimental Procedure Section and summarized in Table 1. Results for each condition are presented in the following 5 sections.

Table 1:
Summary of tests and test conditions conducted in this study

<table>
<thead>
<tr>
<th>Test</th>
<th>Test Conditions</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Temperature (°F)</td>
</tr>
<tr>
<td>Corrosion</td>
<td>135</td>
</tr>
<tr>
<td>Erosion</td>
<td>135</td>
</tr>
<tr>
<td>Erosion-Corrosion</td>
<td>135</td>
</tr>
<tr>
<td>Inhibited Corrosion</td>
<td>135</td>
</tr>
<tr>
<td>Inhibited Erosion-Corrosion</td>
<td>135</td>
</tr>
</tbody>
</table>

(i) Influence of Oil on CO\textsubscript{2} Corrosion Behavior

Many studies indicate that the presence of oil can influence the CO\textsubscript{2} corrosion rate of low carbon steel materials\textsuperscript{14-16}. In this research, the oil-water ratio was fixed at 40% water for all oil based experiments. Baseline corrosion rates for 40% water cut were established by carrying out pure corrosion tests. These experiments were repeated at least three times to insure repeatability of the results. Figure 4 shows an example of LPR-monitored corrosion rates for 40% water-cut and for 100% water cut. The LPR corrosion rate for 100% water was initially 200 mpy and then increased until it reached a steady state corrosion rate of approximately 480 mpy. No protective iron carbonate (FeCO\textsubscript{3}) scale was found at the end of the pure corrosion test. An image of the specimen surface at the end of the test is shown as an inset in Figure 4. The trend was reversed for the 40% water with the corrosion rate beginning at 400 mpy and then decreasing to a steady state value of approximately 100 mpy in 10 hours. A protective iron carbonate scale was observed on the surface of the test specimen, shown as an inset in Figure 4. The formation of this scale was assumed to be the source of the decreased steady state corrosion rate.
This behavior was repeatable and was confirmed with weight loss measurements. Table 2 shows the average corrosion rates as determined by LPR and WL for three replicates of the pure corrosion test. The measured corrosion rates are in good agreement for both techniques.

Table 2:
Summary of low carbon steel corrosion rate test results obtained from the 3 test cells for 40% water cut

<table>
<thead>
<tr>
<th>Cell 1 (weight loss)</th>
<th>Cell 2 (weight loss)</th>
<th>Cell 3 (LPR)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corrosion Rate, mpy (n=3)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>164 ± 33</td>
<td>156 ± 6</td>
<td>159 ± 11</td>
</tr>
</tbody>
</table>

To confirm that the surface product observed in the 40% water cut tests was actually iron carbonate, XRD analysis was performed. A representative XRD analysis for the corrosion product is shown in Figure 5. While the baseline conditions of temperature, pH and flow, would tend to indicate that this is not in the scale forming region, the iron concentrations rapidly increased during these tests. This rapid increase is likely the cause of the scale formation in the presented results. Other candidate mechanisms are currently under investigation. However, by increasing the water volume in the system while maintaining a constant 40% water cut in the test section, the iron concentration can be reduced below the supersaturation level, and no scale forms. See Table 3 showing measured iron concentrations.

Table 3:
Measured iron concentration for two different water volume

<table>
<thead>
<tr>
<th>Water Volume (Gallons)</th>
<th>Iron Concentration (ppm)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3.5</td>
<td>70</td>
</tr>
<tr>
<td>2</td>
<td>170</td>
</tr>
</tbody>
</table>
(ii) Erosion Rates in Oil-Brine-Sand Flow

Pure erosion tests were carried out for 40% water cut with 0.3 wt% sand with the objective of evaluating the influence of oil on the erosion rate. A stainless steel WL probe was used in this test, since both low carbon steel and stainless steel materials were determined to have similar erosion behavior in a previous study. Erosion results for 40% and 100% water cut are shown in Table 4, both test had the same total concentration of sand. The stainless steel test specimen material exhibited decrease in erosion rate with 40% water cut compared to 100% water cut system. This decrease was expected, since the 40% water cut system has a higher viscosity than 100% water cut system.

Table 4:

<table>
<thead>
<tr>
<th>Water Cut</th>
<th>100%</th>
<th>40%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Erosion Rate, mpy (n=3)</td>
<td>126 ± 15</td>
<td>43 ± 7</td>
</tr>
</tbody>
</table>

(iii) Erosion-Corrosion in Oil-Brine Flow with Low Sand Concentration

Three erosion-corrosion tests were conducted with 40% water cut and 0.3 wt% sand to study the combined effect of mechanical erosion and chemical/electrochemical CO$_2$ corrosion. Using the three-cell test system, which was validated in previous work and the corrosion and erosion results did not vary in a statistically significant manner among the test cells. The metal loss due to mechanical erosion was measured using a stainless weight loss (WL) probe. The metal loss due to corrosion was measured with a low carbon steel material LPR probe and the total metal loss due the combined effect of erosion and corrosion was measured with a low carbon steel WL probe. Representative LPR data collected from an erosion-corrosion test was compared to LPR data for a corrosion test with no sand as shown in Figure 6. As was observed in the pure corrosion tests described above (Figure 4), the 40% water cut system with no sand results in the formation of iron carbonate scale. However, when sand is introduced into the system, the scale is eroded and removed, reducing the protective effect of the scale. The corrosion rate is nearly two times higher when compared to the pure corrosion system. An image of both the pure corrosion test specimen and the erosion-corrosion test specimen are shown
as insets in Figure 6. These images clearly show the presence of scale in pure corrosion and the removal of that scale with the addition of sand.

Figure 6: LPR data comparing pure corrosion system with no sand and erosion-corrosion system with 0.3 wt% sand concentration

Figure 7: Summary of metal loss rates in the 3-test cells obtained from three erosion-corrosion tests at 40% water cut and 0.3 wt% sand concentration

Figure 7 shows a comparison of the measured metal loss rates measured during the uninhibited erosion-corrosion tests described above. For these tests, the metal loss rates measured by LPR and WL are statistically equivalent. This equivalency indicates that the scale formation rate is higher than...
the erosion rate, which prevents erosion from removing the scale and then contributing to the total metal loss as measured by WL techniques. Because of the interaction of scale and sand, the corrosion rate measured in Figure 7 with LPR is influenced by both the scale formation and erosion processes.

(iv) Inhibited Corrosion in Oil-Brine Flow with no Sand

Inhibited corrosion tests in oil-brine flows were carried out using LPR. Two inhibitor concentrations, 100 ppm and 200 ppm, were studied in these tests. Figure 8 shows the LPR results obtained for the inhibited corrosion tests along with the LPR results for an uninhibited corrosion test. The addition of 100 ppm inhibitor resulted in an average LPR corrosion rate similar to the uninhibited system. However, the time required for the corrosion rate of the uninhibited system to reach steady state was considerably longer. This is due to the time required to form the protective scale in the uninhibited tests. The addition of 100 ppm or 200 ppm inhibitor eliminated the scale, so the corrosion rate reductions were due to the action of the added inhibitor. This behavior is not totally unexpected as there have been some previous reports of imidazoline-based inhibitors retarding the formation of iron carbonate scale. Chokshi et al.\textsuperscript{17} suggested mechanisms include a decrease in concentration of Fe\textsuperscript{2+} at the surface of the steel and/or specific scale inhibition properties of the corrosion inhibitor molecule\textsuperscript{17}. Although iron carbonate scale was not found on the specimen surface after corrosion tests with the inhibitor, a layer of iron carbide was observed covering the specimen surface. Previous studies based on XRD analysis show that iron carbonate scale (FeCO\textsubscript{3}) is tough and hard corrosion product while iron carbide (Fe\textsubscript{3}C) precipitates are fluffy and can easily be wiped off the surface, and that is what was observed in this research. Figure 9 shows an example of the iron carbide layer formed on the specimen surface after corrosion tests with 200 ppm inhibitor concentration.

Figure 8: LPR corrosion test results for 40% water cut and inhibitor concentrations of 0, 100 ppm and 200 ppm.
(v) Effect of Sand on Inhibited Corrosion in Oil-Brine Flow

Inhibited erosion-corrosion tests were conducted to investigate the influence of sand on the performance of imidazoline inhibitor in reducing CO₂ corrosion. In these tests, 200 ppm inhibitor concentration was investigated. Figure 10 compares LPR corrosion rates for an inhibited corrosion test in the absence of sand and LPR corrosion rates in the presence of 0.3 wt% sand. The LPR traces represent only the corrosion component of inhibited erosion-corrosion. As expected from the results described above, the inhibited corrosion tests with no sand resulted in the precipitation of iron carbide on the specimen surface, giving an average LPR corrosion rate of 95 mpy. With the addition of both inhibitor and sand, no corrosion product was observed on the test coupon at the end of the test, but has yet to be confirmed with XRD. The total metal loss rate for the inhibited erosion-corrosion test was lower than that of the comparable inhibited corrosion test (36 mpy vs. 95 mpy). This is likely due to improved inhibitor adhesion to the steel surface exposed by the action of the sand when compared to inhibitor adhesion to a carbide or carbonate scale.

Previous studies on inhibited erosion, corrosion, and erosion-corrosion performed by E/CRC 8 with 100% water cut and the same environmental conditions, did not produce iron carbonate scale (FeCO₃) or iron carbide (Fe₃C) precipitates. This was true regardless of the concentration of the inhibitor. For the 100% water cut case, the presence of sand decreased the inhibitor efficiency by reducing the surface coverage of the inhibitor molecules. As a result, higher inhibitor concentration was required to achieve the same surface coverage obtained in the absence of sand. 8, 18 For the 40% water cut system studied here, inhibitor performance was improved by the addition of sand into the system. This improvement was likely due to the immediate removal of iron carbide by the action of the sand. Previous research has shown that the presence of corrosion product can reduce the ability of the inhibitor to reach the metal surface. Corrosion products effectively reduce the local concentration of inhibitor near the steel surface. 17

Figure 11 shows the metal loss rates measured during three replicates of the inhibited erosion-corrosion test described above. Unlike the case of uninhibited erosion-corrosion shown in Figure 7, the metal loss rates measured from the LPR and the stainless steel WL probe add to the same metal loss rate as measured using a low carbon steel WL probe. This implies that the synergistic effect between erosion and corrosion for inhibited system is negligible. Inhibited erosion-corrosion tests showed that imidazoline inhibitor with a concentration of 200 ppm reduces the metal loss rate of erosion-corrosion by nearly 5 times when compared to a system without inhibitor. The LPR traces for this comparison are shown in Figure 12.
Figure 10: LPR data comparing inhibited corrosion with no sand and corrosion component of inhibited erosion-corrosion with 0.3 wt%, sand concentration for 40% water cut and 200 ppm inhibitor concentration.

Figure 11: Summary of metal loss rates in the 3-test cells obtained from three inhibited erosion-corrosion tests for 40% water cut, 0.3 wt% sand, and 200 ppm inhibitor concentration.
In addition to the study at 200 ppm described above, several single tests were run for 25, 50 and 100 ppm inhibitor concentrations. Results from these tests, combined with the results obtained for 200 ppm inhibitor concentration, were used to construct a phenomenological model based on Frumkin isotherm for predicting the inhibitor effectiveness for such environmental conditions. The Frumkin isotherm fits to inhibited erosion-corrosion experimental results collected in this research are shown in Figure 13. Data for 100% water cut collected by Hassani and co-workers\(^8\) are also included in Figure 13.

The surface coverage represented by the vertical axis in Figure 13 was calculated using equation 3. A surface coverage value of zero equates to high corrosion and increasing surface coverage correlates to lower corrosion rates. The two adjustable parameters in Equation (2) were determined by using least squares fitting routine with each data set. As can be seen from Figure 13, the 40% water cut system indicates greater surface coverage at 25 and at 50 ppm inhibitor concentration when compared to similar data at 100% water cut. However, the inhibitor performance nearly the same as the 100% water cut system at higher inhibitor concentrations.

Table 5:
Frumkin isotherm fit parameters for 40% and 100% water cut values.

<table>
<thead>
<tr>
<th>Water Cut</th>
<th>Erosion Rate (mpy)</th>
<th>(K_{ad})</th>
<th>(f)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100%</td>
<td>120</td>
<td>0.0215</td>
<td>2.0458</td>
</tr>
<tr>
<td>40%</td>
<td>45</td>
<td>0.03965</td>
<td>2.0458</td>
</tr>
</tbody>
</table>

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CONCLUSIONS

The main goal of this investigation was to experimentally characterize the inhibitor effectiveness for 40% water cut systems. This objective required studying the effect of oil on erosion, corrosion and erosion-corrosion. Based on data from LPR and weight loss methods, the addition of oil precipitated a decrease in corrosion rate. This decrease in corrosion rate was attributed to the formation of a protective iron carbonate scale. The scale formation was promoted in this test by an rapid increase in the iron concentration in the test solution. The addition of oil to this system also reduced the pure erosion rate by a factor of 3 when compared to the value measured for 100% water cut. This reduction was likely due to the increase in fluid viscosity upon the addition of oil. For erosion-corrosion tests, the addition of oil increased the metal loss rates by a factor of two due to the removal of the protective scale by the action of the sand. Addition of an imidazoline inhibitor for 40% water cut system prevented the formation of protective iron carbonate scale and promoted the formation of iron carbide (Fe₃C) on steel surface. Low rates of metal loss observed in inhibited erosion-corrosion tests indicated that an imidazoline-based inhibitor studied in this work reduces the corrosion rate relative to uninhibited corrosion. was effective in reducing and controlling erosion-corrosion in such environmental conditions. Iron carbide precipitates were removed by sand erosion, and both the corrosion component of inhibited erosion-corrosion and the total metal loss of inhibited erosion-corrosion were lower than inhibited corrosion without sand. The presence of 0.3 wt% sand concentration increased the inhibitor effectiveness, due to the elimination of corrosion products present on the metal surface. The removal of these products likely promoted proper inhibitor surface adsorption, which improved inhibitor performance. The addition of imidazoline based inhibitor also inhibited the formation of a scale.

ACKNOWLEDGEMENTS

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Figure 13: Frumkin isotherm fit to inhibited erosion-corrosion experimental data for 40 % and 100% water cuts at 0.3 % wt sand concentration.
authors would also like to recognize Petrobras for providing financial support to Erosion-Corrosion Inhibition projects.

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