A study of corrosion inhibition of steel AISI-SAE 1020 in CO₂-brine using surfactant Tween 80

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Abstract. Surfactant inhibitors also called active surface agents are molecules composed of a polar hydrophilic group and a non-polar hydrophobic group, with characteristics of adsorption on metal surfaces, high efficiency of inhibiting, low price, low toxicity and easy production. In this work, the corrosion inhibition was study by CO₂ steel AISI-SAE 1020 with the addition of 0.01M Tween 80 surfactant to a brine solution (3% NaCl). Electrochemical Impedance Spectroscopy and potentiodynamic polarization testing investigated the phenomenon. The results revealed that the surfactant studied acts as an excellent corrosion inhibitor and inhibition efficiency (E%) increases with increasing fluid velocity. The morphology of the steel surface after exposure to the solution of 3% NaCl with and without surfactant indicates the inhibition phenomenon is due to the adsorption of the surfactant molecules, which insulate the surface of the corrosive medium and reduces the attack surficial.

1. Introduction
Naturally, the Carbon dioxide (CO₂) is finding in oil and gas wells. When it combined with water, a corrosive environment is generated due to the production of reducible species as hydrogen ions and carbonic acid, which cause electrochemical reactions with the metal. Mild steels, materials commonly used in the oil industry, are susceptible to CO₂ corrosion, which represents the biggest problem in oil components and structures. In order to counteract these disadvantages, they have been used modification methods aggressive means, such as injection of corrosion inhibitors. Surfactant inhibitors also called active surface agents are molecules composed of a polar hydrophilic group and a non-polar hydrophobic group, with characteristics of adsorption on metal surfaces, high efficiency of inhibiting, low price, low toxicity and easy production [1-3]. Some researchers [4-7] have reduced steel corrosion in acidic solutions by use of surfactants.

Nonionic Tween type surfactants are esters of polyoxyethylene sorbitan (anhydride sorbitol or hexitol), partially esterified with higher fatty acids, which due to its neutrality, it is not produce counter-ions, thus can be used as excellent corrosion inhibitors. Salah et al. [8] evaluated the inhibition of corrosion of magnesium in hydrochloric acid through the addition of the Tween 80 surfactant, they have found that it inhibits corrosion by physical adsorption on the surface of magnesium, and its ability to inhibit depends on the concentration of the surfactant. However, the efficiency of the inhibitor not only depends on its concentration but also of the structure of the molecule, as concluded in the work done by Abdallah et al. [9]. In this work it was determined that the corrosion inhibition efficiency increases with increasing length of the hydrocarbon chain and the presence of a double bond in the chemical structure. The effect of temperature on the efficiency of the inhibitor has also been studied by Guannan and Xianghong [10] who evaluated the inhibitory action of the Tween-20
nonionic surfactant in corrosion of cold rolled steel in sulfuric acid medium 0.5-7.0M; they have indicated that the corrosion decreases with increasing temperature. However, despite the widespread use on an industrial level and the excellent characteristics of tween surfactant as corrosion inhibitor and demulsifiers of water in oil [11], very little documentation is finding about the anticorrosive properties of this compound. Therefore, in this study investigated the effect of surfactant Tween 80 in inhibiting corrosion of steel AISI-SAE 1020, at different temperatures and speeds, using the rotating cylinder electrode.

Understanding the process of corrosion that occurs at the interface of a metal surface in contact with a medium containing dissolved CO₂, inhibitor and under various parameters such as temperature, speed, presence of corrosion products (FeCO₃) on the metal surface is great importance to ensure the integrity of the transportation pipelines.

2. Experimental development

2.1. Equip and preparation of solutions

To evaluate the corrosion of the AISI-SAE 1020 steel, electrochemical tests were performed using an EG & G PARC Model 636 rotary cylinder electrode (ECR), consisting of a rotary unit driven by a motor with rotation ranges between 0 and 9999rpm. The device was coupled to a glass cell with 5 openings, allowing the entry of CO₂, temperature gauge and three electrodes (Figure 1).

A platinum wire was select as counter electrode. A reference electrode of Ag/AgCl, this was connected to the solution by a salt bridge of KCl. Cylindrical samples were used as working electrodes, the material selected was AISI SAE 1020 steel, due to its similarity with the steels used in the oil industry. The dimensions of working electrodes were 11.88mm and 11.13mm in diameter and high respectively. The steel composition is present in Table 1. Before performing each test, the test pieces were surface treated according to standard ASTM G1.

![Figure 1. Experimental setup used.](image)

| Table 1. Chemical composition of tested steel (wt%). |
|--------------------------------------------------|
|          |          |
| C        | 0.024    |
| Mn       | 0.448    |
| P        | 0.0184   |
| S        | 0.0121   |
| Si       | 0.0017   |
| Cr       | 0.0057   |
| Mo       | 0.0039   |
| Ni       | 0.0318   |
| Nb       | <0.0005  |
| V        | <0.0003  |
| Ti       | 0.0009   |
| Cu       | 0.0268   |
| Fe       | Balance  |

2.2. Equip and preparation of solutions

Impedance spectroscopy test and potentiodynamic polarization were performed. An AC voltage of 10mV was use in the first case, with initial and final frequencies of 100,000Hz and 0.1Hz respectively. On the potentiodynamic polarization test were used potentials between -250mV to 250mV with respect to corrosion potential, scan rate of 2mV/min in anodic direction. The Potentiodynamic polarization curves allowed determination of electrochemical characteristics of steel, such as the corrosion potential (Ecorr) and corrosion current density (Icorr).
2.3. Analysis of the layers formed
Once testing is complete, the specimens were rinsed with distilled water and then dried with air jet for morphological analysis of the layers formed on the steel. The observations were made using a scanning electron microscope with secondary electron signal. The semi-quantitative chemical analysis of energy dispersive X-ray (EDS) was performed with a Philips spectrophotometer.

3. Results and discussion

3.1. Electrochemical tests
Figures 2(a) and 2(b) show the Nyquist diagrams to speeds of 2500rpm and 5500rpm respectively. There is an almost semicircular aspect, indicating that the charge transfer process mainly controls the corrosion of the steel. Deviations from perfect circular shape are relating to the frequency dispersion of interfacial impedance, possibly by the inhomogeneity of the electrode surface or interfacial phenomena [12]. It is evident that the addition of Tween 80 leads to larger semicircles; they are shift towards higher values on the real axis showing that the inhibitor significantly increases the resistance of the solution and to the polarization of the medium with CO₂. In mediums with inhibitor, the tendency to the formation of an inductive loop at low frequencies has been attributed to adsorption of surfactant molecules on the metal surface.

Figure 2. Nyquist diagrams for systems without inhibitor and with presence of 0.01M of this. (a) 2500rpm, (b) 5500rpm.
The potentiodynamic curves (Figures 3(a) and 3(b)) show that the presence of surfactant displaces the anodic and cathodic areas to densities lower currents, indicating that Tween 80 inhibitor interferes in reactions of oxidation-reduction, due to that retards anodic dissolution and hydrogen generation, by adsorption of surfactant molecules on the steel surface.

On systems without inhibitor the change at 5500rpm 2500rpm, increases the supply of oxidizing agents in the Helmholtz double layer, resulting in an increase of the current density with the speed.

**Figure 3.** Polarization diagrams for systems without inhibitor and with presence of 0.01M of this. (a) 2500rpm, (b) 5500rpm.
3.2. Inhibition efficiency
Using equation 1 the inhibition efficiency was determined, which is shown in Figure 4. values of 73.13%, 89.67%, 96.63% and 92.55% for medium with 2500rpm and 40°C, 2500rpm and 70°C, obtaining, 5500rpm and 40°C, 5500 rpm and 70°C, showing that under the experimental conditions the addition of surfactant allows the corrosion rate (Vcorr) values are reduced considerably.

\[ E(\%) = \frac{V_{corr} - V_{corr}^*}{V_{corr}} \times 100 \] (1)

The Figure 4 indicates that the inhibition efficiency increases with the increase in fluid velocity given the greater transfer of inhibitor molecules to the metal-solution interface. The lesser inhibitory capacity is acquired when the medium have 2500rpm and 40°C, this is attributed to the influence of temperature in the solubility of the surfactant in the brine, due that the agitation generates a better distribution of molecules in the medium, leading to a high homogeneity of the inhibitor film on the steel surface.

![Figure 4](image)

**Figure 4.** Polarization diagrams for systems without inhibitor and with presence of 0.01M of this. (a) 2500rpm, (b) 5500rpm.

3.3. Analysis of the layers formed
Images of Scanning Electron Microscopy (SEM), reveal the steel surface after being exposed to the solution in presence and absence of inhibitor, with temperature and speed of 70°C and 5500rpm respectively. The Figure 5(a) shows the micrograph of the specimen after immersion in the solution without inhibitor, it can be seen that the surface is strongly affected due to attack by species such as \( \text{HCO}_3^- \) and \( \text{H}^+ \), leading to the formation of layers of iron carbonate not protective and presence of high roughness. Figure 5(b) shows that the metallic surface immersed in solutions with inhibitor is in better conditions, exhibiting smoother surfaces compared to the surface without inhibitor. Thus, it is concluded that the inhibitor tween 80 has a strong tendency to adsorb on the metal surface, protecting it of the corrosive medium.
3.4. Inhibition mechanism

According to the surface analysis and electrochemical experiments, it is suggested that the mechanism of corrosion inhibition in medium CO₂-brine occurs by adsorption of the functional groups of the surfactant molecules on the surface of 1020 steel, according to Malik et al. [13], this phenomenon can be expressed according to the following equation:

\[
\text{Surfactant (sol.) + nH}_2\text{O (ads.)} \rightarrow \text{Surfactant (ads.) + nH}_2\text{O (sol.)}
\]  

Where \( n \) is the number of water molecules removed from the metal surface per molecule adsorbed surfactant.
It is considered that at a concentration of 0.01M, which is higher than the critical micelle concentration (CMC), the metal surface is covered with a monolayer of surfactant molecules and the additional molecules combine to form micelles or multiple layers, such as indicates [13].

4. Conclusions

Evaluation of inhibition of the steel 1020 corrosion by using surfactant Tween 80 shows that:

At a concentration of 0.01M Tween 80 to temperatures and speeds of 40°C, 70°C and 2500 and 5500rpm, was showed the rate of corrosion of steel is decreased significantly, due to the adsorption of the surfactant molecules on the metal surface. Increased solution resistance and polarization is obtained when the medium is in the presence of surfactant. High inhibition efficiencies are achievable above 70% and this increases with increasing speed. Suggesting that the Tween 80 is an excellent corrosion inhibitor in media with CO2.

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