Effect of contents oil temperature and flow rate in the electrochemical corrosion of the AISI-SAE1020-steel

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Abstract. Primary causes of corrosion in components and equipment used in the petroleum industry are due to the density differences present in the multiphase system Water/Hydrocarbon/CO₂ as well as the presence of weak particles of carbonic acid. The present research is focus on the study of the corrosion rate of the steel AISI-SAE 1020 under a saturated CO₂ multiphase system. The effects of fluid speed, temperature and oil content on the steel corrosion were carried out in an electrode of rotator cylinder and also using electrochemical impedance spectroscopy, and potentiodynamic polarization measurements. The results show that the effect of oil content in the rate of steel corrosion is inversely proportional with the speed of the rotor. Our observations indicate that increasing the rotor speed in systems containing 60% oil or higher produce a simultaneous increase in the degradation rate of materials. Similarly, temperatures higher than 60°C generate layers of siderite that reduce the electrochemical effect.

1. Introduction
Since the beginning of the exploitation of oil, the oil industry has had to confront joint production of water and oil that causes formation of unwanted emulsions. Water and oil penetrate the bottom of the well as two separate phases, which due to the rise in the tube, pumping, push gas and expansion relief valves, are subjected to different stresses that result stirring and shearing, causing the dispersion of these phases. Actually, two-thirds of world oil production was obtained in the form of emulsion, which may present as oil-in-water (o/w) or water-in-oil (w/o).

It has been known that the formation of emulsions or multiphase flows are the main cause of corrosion in the oil industry, due to the density difference between the phases; in addition, the transportation stream increases the impact of corrosively [1]. Despite this, this phenomenon is not well defined. The electrochemical study and corrosion in the presence of different phases is relatively a new theme, which began to emerge less than a decade. Efforts to understand the electrochemical of emulsions still fail to clarify the phenomena and mechanisms of corrosion. Some researchers believe that the aqueous phase, which may include components that accelerate the corrosion process, such as dissolved salts, CO₂, H₂S, acetic acid and other acids, is the main cause of corrosion in these systems. Y. Gonzales et al. evaluated the behaviour of a carbon steel in a solution of oil and water to 3% NaCl, saturated with CO₂ [2], finding that the addition of oil results in better corrosion resistance that the system only with brine. K Efird [3] et al., they studied the effect of the percentage of salt water in the crude, demonstrating that the corrosion rate increases with the content of this. Additionally, some authors indicate that the proportion of hydrocarbon affects the development of corrosion in the metal, increasing the degradation rate with the amount of oil in the system, favours adsorptive processes [1] [4]. Echeverria suggests that the exposed part of metallic substrate in contact with systems water/oil...
seems to present small anodic and cathode areas, where the metal-aqueous medium interface is the anodic and cathodic that correspond to a metal-oleic medium interface, generating a behaviour less resistive [5].

To contribute to the understanding and clarification of the mechanisms and corrosion phenomena in multiphase systems with the presence of CO₂ that represents 28% of corrosion failures in the oil industry in this investigation, it was used a rotating cylinder electrode that shows the effect of the temperature, oil content and the fluid velocity in the corrosion of steel AISI-SAE 1020, in systems oil/water/CO₂. It is very important to understand the corrosion process that occurs at the interface of a metal surface in contact with a multiphase medium containing dissolved CO₂ and under various parameters such as temperature, relative water-hydrocarbon and presence of corrosion products (FeCO₃) on the surface metal to ensure the integrity of the transportation pipelines.

2. Experimental development
Experiments to evaluate the electrochemical corrosion of steel AISI-SAE 1020 were performed using a rotating cylinder electrode (ECR) brand EG & G PARC Model 636, consisting of a rotating unit driven by a motor that is fit to the retainer of the specimen, with ranges of rotational speeds between 0 to 9999rpm. The device was attached to a glass cell, composed of 5 slots, allowing the entry of CO₂, temperature gauge and three electrodes (Figure 1).

A platinum wire was selected as counter electrode and reference electrode as an Ag/AgCl, which was connect to the solution by a salt bridge of KCl. The working electrode consisted of a specimen of AISI-SAE 1020 steel with dimensions of 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.

The selected medium consisted of a mixture (o/w) deionized water to 3% NaCl, mineral oil (0.86g/cm³) as a substitute for crude, in proportions of 0%, 20%, 40% and 60% by weight. In each experimental test, the mineral oil was added after the steel was immersed in the NaCl solution deaerated with N₂ and saturated with CO₂ for half an hour, to avoid any interference of the oil phase in contact with the surface of the working electrode. The working electrode was always located at the same distance from the interface area. The evaluation of the corrosion phenomenon was evaluate at temperatures of 20°C, 60°C and 75°C and speeds of 2500 and 5500rpm.

Resistance tests were performed with polarization potential with sweeps between -250mV and +250mV respect to the corrosion potential. Frequency sweeps used with electrochemical impedance technique were between 100,000 and 0.001Hz, with an applied potential of 10mV AC. For the

Table 1. Chemical composition of tested steel (wt.%).

| Element | C   | Mn  | P   | S   | Si  | Cr  | Mo  | Ni  | Nb  |
|---------|-----|-----|-----|-----|-----|-----|-----|-----|-----|
| C       | 0.024 | 0.448 | 0.0184 | 0.0121 | 0.0017 | 0.0057 | 0.0039 | 0.0318 | <0.0005 |
| Mn      | 0.0268 |
| 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 |

Figure 1. Experimental setup used.
analysis of the formed layers were obtain images of the steel surface by the technique of Scanning Electron Microscopy (SEM).

3. Results and discussion

3.1. Effect of oil content
Figures 2(a) and 2(b) show the polarization curves and Nyquist plots for 1020 steel in systems with oil content of 0%, 20%, 40% and 60% at 20ºC and 2500-rpm speed. According to Figure 2 and the determined values of the Tafel slopes, it shows that the oil content has little influence on the anodic reaction. This concludes that the phenomenon significantly is dominated by reducing species (cathodic area). The displacement of the cathode area to the right indicates higher current densities corrosion with increasing the amount of oil, so that higher degradation rates of steel in the biphasic, mixture was obtain up to 40%, above which the corrosion rate decreases considerably. This behaviour is similar to the one found in [4] showed that the cathodic current density for emulsions with ratios of 20% to 40% oil tends to be slightly higher than the solution free of oil, while for emulsions content between 45 and 70% by weight, the electrochemical activity decreases.

![Figure 2](image-url)
Nyquist plots showed the existence of semicircles with radii larger for systems with 0% and 60% oil, indicating values polarization resistance highest. In the presence of relations oil between 0 and 40%, a capacitive semicircle in the region of high and medium frequencies, characterizes the active state of the interface when exposed to a saturated solution of CO₂ [6] and inductive loop at low frequencies [7,8]. This is attributed to the surface roughness of the material, formation of corrosion products on the metal surface. In addition, for the ratio of 40/60 observes a diffusion phenomenon, represented by a poorly defined semicircle large diameter, which can be associate by the decreased concentration at the surface of an intermediate species adsorbed [9].

In Figure 3(a), the polarization curve of 1020 steel in emulsions with oil contents of 0%, 20%, 40% and 60% at 20°C and 5500rpm is present. It is note that for w/o 60/40 and 60/40 the curves shift to more positive potentials, indicating that tends to protect the metal. This behaviour is attributing to the formation of unstable emulsions, which produces more distribution of oil in the solution and increase deposition capacity of an organic film in the metal surface, corresponding to the oil phase. This film changes the wettability of steel and has a direct effect on corrosion [10].

![Figure 3](image-url)

**Figure 3.** Curves of 1020 steel in emulsion with different concentrations of oil (a) Polarization. (b) Nyquist. 20°C, 5500rpm.
Nyquist diagrams for the system at 5500rpm (Figure 3(b)) show two time constants, a capacitive semicircle in the region of high and medium frequencies, which could be a result of charge transfer and ion migration. A second capacitive arc can be attributed to a dissolution process from the possible layer of oil on the steel surface.

3.2. Speed effect
Figure 4(a) shows the effect of the corrosion rate as a function of the rotation speed. Due to the increased in the supply of oxidizing agents in metal-electrolyte interface generated by the fluid velocity, occurs a simultaneous increase in the rate of degradation of the material with the speed, except for the system with 60% oil. The free oil mixture produces the greatest effect on the corrosion rate. This is attributed to the low conductivity of the oil phase due it difficult ion mobility, in the absence of this, the displacement of oxidizing species into the metal surface tends to develop faster. The decrease in corrosion rate of 40/60 emulsions is attributed to the formation of water in oil emulsion, where the oil phase is continuous and has higher resistivity.

Figure 4(a) shows too that at 5550rpm there is a proportional relationship between the oil content and the corrosion rate. Higher percentages of oil produce lower corrosion rates. An opposite behaviour is observe at low speeds and with systems up a maximum of 40% oil. The phenomenon is attribute to unstable emulsions formed to 5500rpm. They improving the distribution of oil in the solution and increase the likelihood of formation of organic films (corresponding to the oil phase) on steel, this film changes the wettability and has a direct effect on corrosion.

![Figure 4.](image)

(a) Effect of rotation speed on the corrosion rate for the AISI-SAE 1020 steel, NaCl 3% CO₂, 20°C, and different ratios of oil. (b) Effect of relationship of the temperature on the rate of corrosion.

3.3. Effect of temperature
The temperature affects the kinetics of corrosion, the concentration of CO₂ dissolved and diffusion of species to the metal surface. To evaluate this phenomenon in the corrosion rate of carbon steel, a system with rotational speed of 5500rpm, which generated emulsions, was select. A percentage of 40% oil and temperatures of 20°C, 40°C, 60°C and 70°C was use.

Figure 4(b) shows the values obtained of corrosion rate for this case. To temperatures below 60°C, the increase of this variable leads to decrease in the polarization resistance. This behaviour can be attributo the temperature that increases the probability of occurrence of cathodic reactions what can take control the corrosion processes. However, decreasing the rate of degradation from 60°C must be for the formation of a film with protective features, in this case, siderite (FeCO₃). Under laboratory conditions, the minimum temperatures required for the formation and growth FeCO₃ layer (with protective characteristic) on the metal surface ranging between 50°C and 70°C. Schmitt G. [11] mentions that at low temperatures (<60°C) the solubility of the FeCO₃ is high and no protective layers
are generated, while for high temperatures (≥60°C) solubility decreases and increases the rate of precipitation of the film of carbonate on the steel surface, thus reducing corrosion. A. B. Forero [12] showed that for the API 5L X70 steel, immersed in a solution of 1% NaCl saturated with CO₂, the temperature causes an increase in the corrosion rate up to 60°C, above of this temperature begins to decrease. They attributed this behaviour to the formation of layers more stable.

3.4. Analysis of the layers formed

Figure 5 shows the films formed on the steel to temperatures studied. According to the results of SEM and EDS (Energy Dispersive Microanalysis) it corresponds to the layer formed siderite (FeCO₃) primary, which increases in size depending on the temperature.

![Figure 5. Layers formed. (a) 20°C, (b) 40°C, (c) 60°C and (d) 70°C.](image)

For the temperature of 20°C, it shows that the steel is practically devoid of FeCO₃, this temperature is not high enough to generate and build the growth of crystals, due the carbonates are not easily former or dissolved in the moving fluid. At 40°C there is more amount of iron carbonate, the corrosion rate increases significantly (Figure 4(b)), this is attribute to that the carbonate crystals are porous and act as anodic sites in the corrosion process. The images of 60°C and 70°C show greater homogeneity of the formed layers, which reduce the corrosion rate at these temperatures.

4. Conclusions

Evaluation of the effect of oil content in steel degradation demonstrates the existence of an inverse relationship between the corrosion rate and the amount of oily phase to 5500rpm speed. At low speeds, the opposite behaviour was observed.

Increasing the speed of rotation favours the process of reducing the corrosive species, increasing susceptibility of the material in the environment studied, except for medium containing 60% oil. Free oil mixture produces the greatest effect on the corrosion rate of steel with the speed variation.
At 60°C and 70°C was observed forming protective layers, which managed to reduce the corrosive phenomenon.

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