Effect of Environmental Media on the Electrochemical Behavior of API X70 Pipeline Steel

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Abstract. This work investigates the corrosion behavior of X70 steel in different environments: sea sand, desert sand, mud and sea water. The principle of extracting solutions from these media consisted of mixing a soil material with distilled water, the mixture was agitated using an automatic agitator, which resulted in the extraction of solution. Potentiodynamic polarization and electrochemical impedance tests are used to characterize the samples in both media. The results show that the pipeline steel X70 has an excellent corrosion resistance in the sea sand solution, resulting in a low corrosion current density compared to other media. The impedance diagrams for both media are characterized by two capacitive loops, the first loop is attributed to charge transfer processes and the second loop is related to diffusion phenomena. The observation of corroded surfaces shows that the corrosion mechanism in different media is by pitting.

1. Introduction

Pipeline transportation remains the most economical way of transporting oil or natural gas through large land distances \cite{1, 2}. The pipeline is a system of high-pressure conduits that can withstand up to 100 bars. It is used to transport fluid materials through pipelines that generally form a network \cite{3, 4}. These pipelines are often subjected to numerous physical and chemical stresses which they must withstand in order to be able to perform satisfactorily all the functions for which they were designed during their entire life cycle. Corrosion is the most important factor that causes damage to pipelines. Hydrocarbon transmission pipelines are often buried. Under these conditions, they are exposed to internal and external corrosion, leading to significant metal losses that reduce their service life. Corrosion-related pipe failures are the most common cause of shutdowns, leading to significant gas loss and serious damage \cite{5-9}. In this work, we focus on the effect of different soils on the degradation of an X70 steel pipeline.

2. Experimental

2.1. Materials

The study material is X70 steel taken from an oil transport pipe. The chemical composition of the material is shown in Table 1.
Table 1. Chemical composition of X70 steel (% wt.).

|   | C   | Si  | Mn  | P    | S    | Cr   | Ni   | Al   | Cu   | Nb   | V   |
|---|-----|-----|-----|------|------|------|------|------|------|------|-----|
|   | 0.08| 0.32| 1.52| 0.002| 0.006| 0.03 | 0.01 | 0.03 | 0.01 | 0.05 | 0.06|

The metallographic study was carried out using a Nikon type optical microscope. The sample was polished on SiC abrasive papers of different grain sizes and then etched with 4% Nital.

2.2. Solutions Preparation
The concept involves mixing a soil material with distilled water (figure 1), the mixture is stirred using an automatic agitator. The purpose of this method is to dissolve the material (sand or sludge) in distilled water to extract a solution. In this study, four media were used: desert sand, sea sand and mud.

![Figure 1. Solution extraction from different soils.](image_url)

2.3. Electrochemical techniques
The electrochemical tests were carried out after one hour’s immersion at 27°C, using a Metrohm Autolab potentiostat-galvanostat connected to a Pyrex glass electrochemical cell with three electrodes: a working electrode (X70 steel), a saturated calomel reference electrode (SCE), and a platinum electrode. The working electrode was polished with various abrasive papers, then washed and degreased with distilled water and acetone. The polarization curves were plotted in a range of potentials (-1000 to 0) mV/SCE at a speed of 1mV/s. For the electrochemical impedance measurements, the frequency scanning was carried out in the frequency range of 100 kHz to 10 mHz, with a signal amplitude of 10mV.

3. Results
3.1. Microstructure
The micrograph of X70 steel (Figure 2) in its raw state reveals, a two-phase structure composed of two main constituents: ferrite and perlite. This is the characteristic microstructure of ferritic-pearlitic steel [10].
3.2. Electrochemical measurements

The polarization curves (Figure 3) of the X70 steel in the different solutions sea sand, desert sand, mud, and seawater after 1 hour of immersion are shown in figure 3. The corrosion potential (Ecorr), the corrosion current densities (Icorr), the corrosion kinetic parameters (βa, βc from the extrapolation of the anodic and cathodic slopes of Tafel) are presented in table 2.

We can observe that the corrosion behavior of X70 steel can vary from one environment to another. In the sea sand solution, the steel exhibits the noblest corrosion potential -505mV/SCE and a low corrosion current density 10.4 µA.cm⁻². In the other media, we notice the presence of passivation bearing in the anodic range. The passivation observed in the anodic branch is induced by the presence of iron oxides resulting from the corrosion mechanism of the studied steel in the aggressive solution [11-13]. From the results in Table 2, the X70 steel exhibits high anodic and cathodic corrosion current densities in all three media: desert sand, mud and sea water.

Figure 2. Metallographic structure of X70 steel.

Figure 3. Potentiodynamic polarization curves of API 5 L X70 steel in different solutions at 27°C.
Nyquist diagrams of the X70 steel obtained at equilibrium potential after one-hour immersion at 27°C in solutions: sea sand, desert sand, mud and seawater are given in figure 4. The diagrams are constituted of two capacitive loops, the first one is attributed to the charge transfer at high frequencies [14], and the second one is caused by the dissolution of the film formed on the metallic surface of the steel [15]. The diameter of each loop is related to the charge transfer resistance at the metal/solution interface.

| Solution                | $\text{E}_{\text{corr}}$ (mV/SCE) | $\text{I}_{\text{corr}}$ (µA/cm$^2$) | $\beta_c$ (mV dec$^{-1}$) | $\beta_a$ (mV dec$^{-1}$) |
|-------------------------|----------------------------------|-----------------------------------|--------------------------|--------------------------|
| Sea sand solution       | -505                             | 10.4                               | 1014                     | 596                      |
| Desert sand solution    | -640                             | 11.4                               | 149                      | 200                      |
| Mud solution            | -675                             | 86.7                               | 5019                     | 1524                     |
| Sea water               | -773                             | 62.6                               | 165                      | 261                      |

Table 2. Electrochemical parameters deduced from the polarization curves of X70 steel in different solutions at 27°C.

The modeling of the metal / electrolyte interface was carried out using an equivalent electrical circuit in figure 5. The values of the various parameters deduced from the parametric adjustment are grouped in Table 3. From these results, it is noted that the sea sand solution presents the highest resistance $1371\Omega \cdot \text{cm}^2$.

![Figure 4](image1.png)\hspace{6cm}![Figure 5](image2.png)

**Figure 4.** Electrochemical impedance diagrams of X70 steel in different solutions at 27°C.

**Figure 5.** Equivalent electrical circuit.
Table 3. Electrochemical parameters deduced from impedance diagrams of X70 steel in different solutions at 27°C.

| Solution          | $R_s$ ($\Omega$.cm$^2$) | $R_1$ ($\Omega$.cm$^2$) | $Q_1$ (µF.cm$^{-2}$) | $n_1$ | $R_2$ ($\Omega$.cm$^2$) | $Q_2$ (µF.cm$^{-2}$) | $n_1$ |
|-------------------|-------------------------|-------------------------|----------------------|------|-------------------------|----------------------|------|
| Sea sand solution | 9.92                    | 596                     | 1.14                 | 1.02 | 1371                    | 8.27                 | 0.902 |
| Desert sand solution | 6.1                     | 66.6                    | 6.43                 | 0.89 | 279                     | 54.8                 | 0.691 |
| Mud solution      | 9.07                    | 353                     | 2.7                  | 0.893| 691                     | 1.14                 | 0.601 |
| Sea water         | 2                       | 41.9                    | 6.04                 | 0.927| 155                     | 66.6                 | 0.575 |

The surfaces of the immersed samples were examined using an optical microscope (Figure 6). The presence of corrosion pits of different sizes was noted in the different microstructures. Therefore, the mode of corrosion in all four media is a pitting corrosion.

![Optical micrographs](image_url)

**Figure 6.** Optical micrographs of the corroded surfaces in different media (a) sea sand solution, (b) desert sand solution, (c) mud solution (d) seawater.

4. Conclusion

On the basis of the obtained results we can draw the following conclusions:

- The X70 steel presents a ferritic-pearlitic type structure.
- The nature of the soil has a great influence on the corrosion resistance of X70 steel. The best corrosion behavior is obtained in the sea sand solution where the corrosion potential and the corrosion density are respectively: -505 mV/ECS and 10.4 µA/cm$^2$ at 27 °C.
- Electrochemical impedance tests indicate that the Nyquist spectra have two capacitive loops. The first loop is attributed to the charge transfer while the second is related to the corrosion process.
- Observation by optical microscopy shows that the corrosion mode consists in pitting corrosion.
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