



## GRAVIMETRIC AND ELECTROCHEMICAL INVESTIGATION OF THE IMPACT OF VARIOUS FACTORS ON XC48 CARBON STEEL CORROSION IN DIFFERENT ENVIRONMENTS

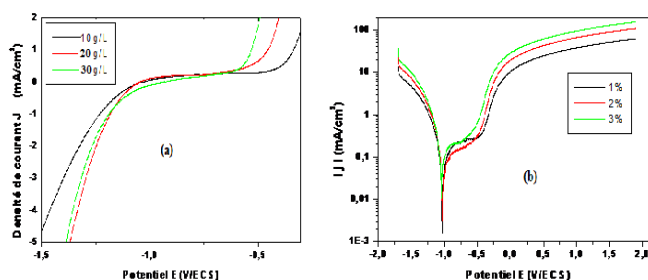
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Our main motivation in this study was to review the effects of acid concentration and solution temperature on the corrosion behavior of XC48 carbon steel in acidic and saline environments. We conducted both gravimetric and electrochemical analyses to evaluate the extent of corrosion. The gravimetric study revealed interesting findings regarding the influence of acid concentration on the corrosion rate. Initially, as the acid concentration increased, the corrosion rate showed an upward trend, reaching a peak at approximately 6M (44.1%) of sulfuric acid. However, at higher concentrations, such as 10.3M (65.15%) the corrosion rate decreased to a lower value at different immersion times. A similar trend was observed with phosphoric acid, where the maximum corrosion rate occurred at around 10M (66.6%), but decreased at 14.5M (84.68%) over different immersion times. Notably, in the case of hydrochloric acid, the corrosion rate exhibited a logarithmic behavior at higher concentrations (6M, 7M, 10M), which can be attributed to the formation of passive layers. The decrease in corrosion rate at higher concentrations indicates the protective effect of these passive layers. During the electrochemical analysis, we investigated the effect of temperature and NaCl concentration on the corrosion rate. Our results indicated that the corrosion rate increased with an elevation in temperature and NaCl concentration. The maximum corrosion rate was observed within the range of 3 to 4% of NaCl. Overall, this study provides valuable insights into the corrosion behavior of XC48 carbon steel in acidic and saline environments. The gravimetric analysis highlighted the influence of acid concentration on corrosion rate, including the formation of passive layers at high concentrations. The electrochemical study demonstrated the impact of temperature and NaCl concentration on corrosion rate, with higher values observed at elevated temperatures and increased NaCl concentrations. These findings contribute to a better understanding of the corrosion mechanisms and can aid in the development of effective corrosion prevention strategies for carbon steel in similar environments



### INTRODUCTION

Corrosion is a significant challenge in various industries, particularly in environments where

metals are exposed to acids and saline solutions. Understanding the corrosion behavior of materials under such conditions is crucial for ensuring the durability and reliability of structures and

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equipment. In this study, we focus on investigating the effects of acid concentration and solution temperature on the corrosion behavior of XC48 carbon steel in acidic and saline environments.

The use of steel as a construction material is worldwide in all economic activities: building, civil engineering, transport, communication, chemical and petroleum industries...etc. Besides mechanical properties, the competitive cost of steel is an important factor that inspires its extensive use, to the detriment of other metals. The relatively easy corrosion of steel materials when subjected to aggressive environments leads generally in their substitution if not well protected. It therefore frequently happens that steel infrastructures suffer losses of their initial mechanical properties, which can have catastrophic consequences if necessary precautions are not undertaken. The effects of corrosion extend beyond steel and include all metals, polymers, and ceramics, as well as every sector of the economy, from the integrated circuit to the reinforced concrete bridge. For instance, it is predicted that corrosion destroys about a quarter of the annual steel production. If there was no protection against corrosion by various means, these losses might be higher.<sup>1</sup>

Acids have a wide range of applications in industry. Acidic aqueous solutions, on the other hand, are generally aggressive media for metals and alloys. Acid concentration plays a significant role in the corrosion process. As the acid concentration increases, it affects the reactivity of the corrosive medium, which subsequently influences the corrosion rate. The concentration-dependent corrosion behavior of XC48 carbon steel in acidic environments has not been extensively studied, particularly in relation to different acid types such as sulfuric acid, phosphoric acid, and hydrochloric acid. In addition to acid concentration, solution temperature is another crucial factor affecting corrosion behavior. Elevated temperatures can accelerate the corrosion rate due to increased reactivity and enhanced mass transfer processes at the metal-solution interface. The combined effect of acid concentration and temperature on the corrosion behavior of XC48 carbon steel in saline environments remains an important area of investigation. The study of corrosion kinetics by gravimetric or electrochemical means has been the objective of several works.<sup>2</sup>

The gravimetric method has a drawback of causing damage to the unaffected steel when

removing the corrosion layer. On the other hand, the electrochemical technique provides a means to analyze intensity/potential curves, offering valuable insights into the behavior of a metal immersed in a specific solution. It is worth emphasizing that the shape of these curves and the associated potentials are highly sensitive to various factors, including the surface condition, structural state, concentration, and temperature of the medium.

Therefore, the objective of this study is to investigate the influence of acid concentration and solution temperature on the corrosion behavior of XC48 carbon steel in acidic and saline environments. We will conduct both gravimetric and electrochemical analyses to evaluate the corrosion rate and understand the underlying mechanisms. The findings of this research will contribute to a deeper understanding of the corrosion processes involved and aid in the development of strategies to mitigate corrosion in acidic and saline environments, thereby improving the reliability and lifespan of XC48 carbon steel in practical applications.

## RESULTS AND DISCUSSION

### 1. Gravimetric method

This method consists of exposing samples to a corrosive medium for a definite time and measuring the difference in mass of the samples before and after each test.

#### *1.1. Effect of corrosive medium concentration and immersion time*

In order to acquire more information on the behavior of steel when it is immersed in various solutions of acids, we proceeded to the calculations of the mass losses and the corrosion rates at different concentrations, during different time intervals. To appraise the investigation and bring it closer to industrial environments, we studied the behavior of the steel coupon with respect to more concentrated solutions for time intervals not exceeding 5 hours. All the results obtained are shown in the following Tables 1 and 2.<sup>3</sup>

Table 1

Effect of  $\text{H}_2\text{SO}_4$  concentration and immersion time on XC48 steel corrosion

Concentration ( $\text{mol}\cdot\text{L}^{-1}$ )	Immersion time (h)	$W_0$ ( $\text{mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ )	$\Delta m/S$ ( $\text{mg}\cdot\text{cm}^{-2}$ )
1M	1	2.2592	2.2592
	3	2.2819	6.8457
	5	2.1639	10.8198
2M	1	4.7770	4.7770
	3	4.8814	14.6442
	5	4.6654	23.3273
6M	1	11.3960	11.3960
	3	11.3960	34.1880
	5	11.3125	56.5718
10.3M	1	1.3249	1.3249
10,3M	3	1.3791	4.1374
	5	1.3166	6.5833

Table 2

Effect of  $\text{H}_3\text{PO}_4$  acid concentration and immersion time on corrosion of XC48 steel

Concentration ( $\text{mol}\cdot\text{L}^{-1}$ )	Immersion time (h)	$W_0$ ( $\text{mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ )	$\Delta m/S$ ( $\text{mg}\cdot\text{cm}^{-2}$ )
1M	1	2.0823	2.0823
	3	1.9598	5.8794
	5	2.1000	10.4932
2M	1	2.1736	2.1736
	3	2.3635	7.0907
	5	2.3790	11.8950
5M	1	4.8415	4.8415
	3	4.8859	14.6578
	5	4.7988	23.9942
10M	1	6.4374	6.4374
10M	3	6.3104	18.9313
	5	6.3558	31.7790
14.5M	1	4.3823	4.3823
	3	4.7543	14.2631
	5	4.4912	22.4563

Figures 1a and 1b show the variation in the corrosion rate as a function of the concentration of the corrosive medium and the immersion time. From this

representation, it can be seen that there is an increase in the rate of dissolution as a function of time and that the corrosive attack increases with the acid concentration.

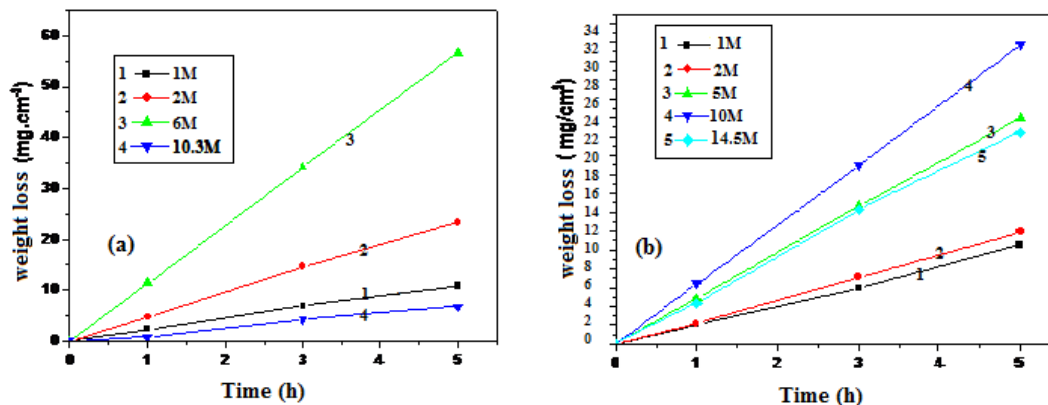


Fig.1 – Impact of immersion time and concentration of sulfuric acid (a) and phosphoric acid (b) on the corrosion rate of steel XC48,  $\Delta m/S = W_0 \cdot t$ .

We thus plot the “variation in mass – time” curve which is converted into corroded thickness as a function of time.

From the previous tables and curves, it can be seen that the corrosion rate increases at the beginning with the increasing acid concentration, and takes a maximum at approximately 6M (44.1%) for sulfuric acid. and a very low value at 10.3M (65.15%) at any time of immersion, while in the case of phosphoric acid the maximum corrosion rate was recorded at approximately 10M (66.6%), but at 14.5M (84.68%) the speed has dropped, also over all immersion time. It was found that in the case of hydrochloric acid, the shape of the curve becomes logarithmic at high concentrations (6M, 7M, 10M). The decrease in corrosion rate at high concentrations is explained by the passive layers formation.<sup>4</sup>

### 1.2. Effect of temperature on the corrosion of XC48 carbon steel

Generally, the rise in temperature accelerates the corrosion phenomena, since it decreases the stability domains of metals and speeds up the reactions and transport kinetics. The extent of its influence differs, however, depending on the corrosive environment. In order to assess the impact of the temperature on the evolution of the corrosion rate, we carried out a series of measurements as presented in Table 3.

Table 3

Variation of the corrosion rate  $W$  ( $\text{mg}\cdot\text{cm}^{-2}\cdot\text{h}^{-1}$ ) vs. temperature for 3 hours in  $\text{H}_2\text{SO}_4$  (0.5 M) and  $\text{H}_3\text{PO}_4$  (0.5 M)

T(k)	W ( $\text{mg}/\text{cm}^2\cdot\text{h}$ )	
	$\text{H}_2\text{SO}_4$	$\text{H}_3\text{PO}_4$
298	2.002	0.7381
308	5.0	1.7
318	11.0	3.95

The relationship between the direct or indirect reaction rates with temperature and activation energy is given:<sup>5-8</sup>

$$v_i = kC_i = k_0 C_i e^{\frac{-G_i}{RT}} \quad (3.1)$$

were  $v$  – the speed of the direct or indirect reaction;  $k$  – rate constant;  $k_0$  – const;  $C_i$  – the concentration of the reactant or product;  $G_i$  – the activation energy which is the minimum energy that the molecules must possess for the reaction to occur, in J/mol;  $R$  – the universal gas constant, in J/(mol·deg).

In addition, from the Arrhenius equation we can write:

$$W = ke^{\frac{-E_a}{RT}} \Rightarrow \ln W = \ln k - \frac{E_a}{RT} \quad (3.2)$$

where  $G_i$  in equation (3.1) is equal to  $E_a$  in equation (3.2).

The plot of  $\ln W = f(1000/T)$  gives a straight line whose slope ( $-E_a/R$ ) allows to calculate the activation energy ( $E_a$ ) which represents the energy barrier that must be crossed by an inhibitor to be adsorbed onto the plate surface.

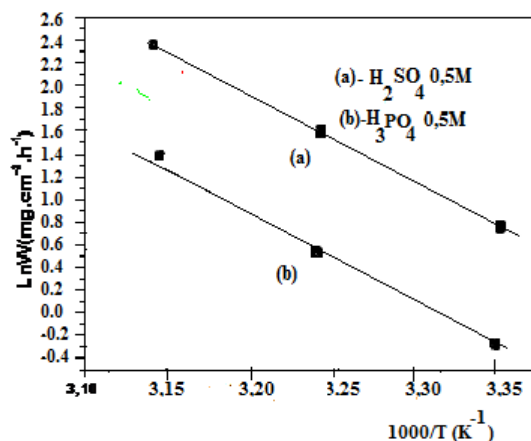


Fig. 2 – Arrhenius lines of the dissolution of XC48 steel in 0.5M  $\text{H}_2\text{SO}_4$  (a) and in 0.5 M  $\text{H}_3\text{PO}_4$  (b) at different temperatures (25–35–45°C).

Table 4

The activation energy values, calculated from the Arrhenius lines

Acids	$\text{H}_3\text{PO}_4$	$\text{H}_2\text{SO}_4$
$E_a$ ( $\text{kJmol}^{-1}$ )	65.50	66.20

## 2. Electrochemical study

### 2.1. Effect of temperature on the corrosion of XC48 carbon steel in an acid environment

The polarization curves in Fig. 3 and Fig. 4 show that the corrosion rate of XC48 steel increases with increasing temperature. This dependence is very clear, especially, in the vicinity of the corrosion potential. Figure 4a of the overall curve, plotted as a function of temperature, also shows the disappearance of the stability and passivation with increasing temperature. Almost the same interpretations are observed in the case of corrosion of XC48 steel in sulfuric acid (Fig. 4b) especially with regard to the effect of temperature on the increase in the corrosion rate.

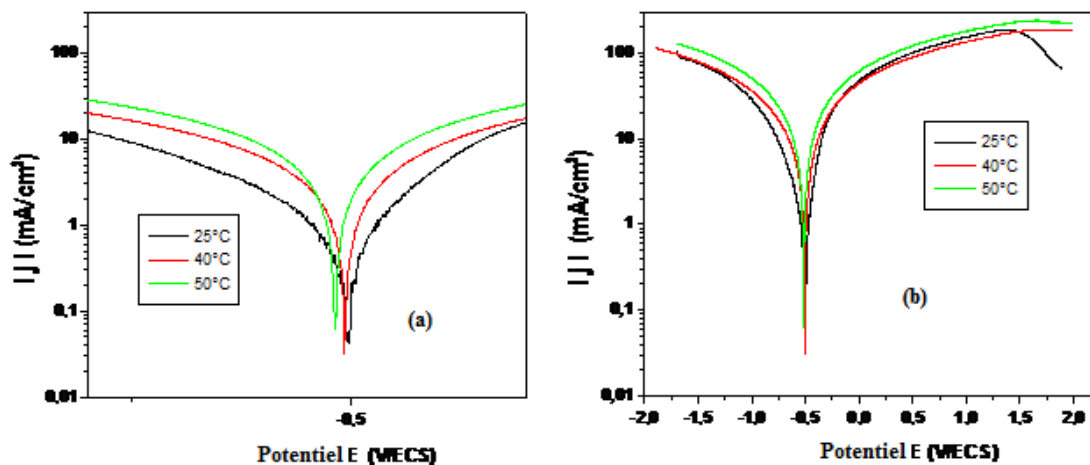


Fig. 3 – Polarization curves of XC48 steel in  $\text{H}_3\text{PO}_4$  (0.5 M) acid near the corrosion potential (a) and global (b),  $V = 10 \text{ mV}\cdot\text{s}^{-1}$ .

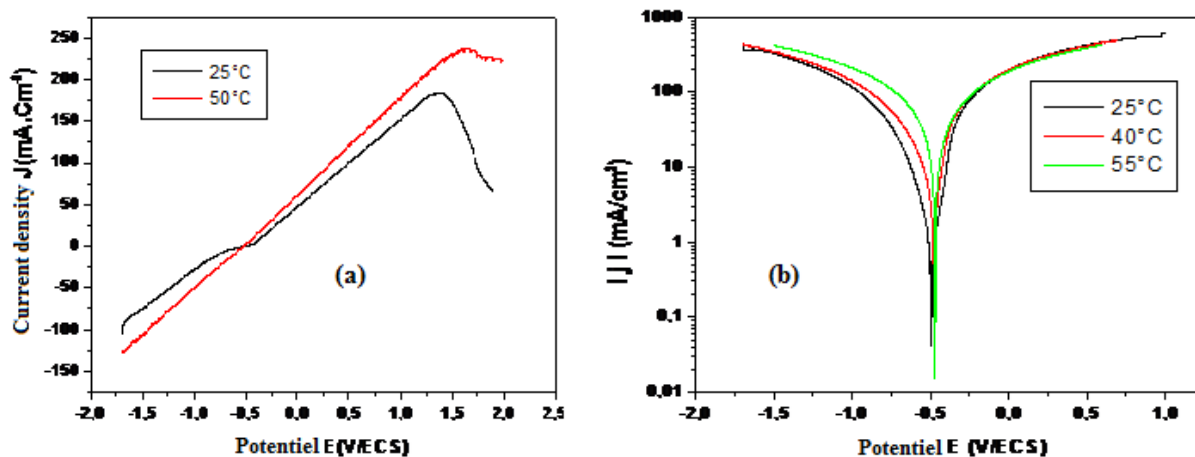


Fig 4 – Global polarization curves of XC48 steel in 0.5 M  $\text{H}_3\text{PO}_4$  acid (a) and in 0.5 M  $\text{H}_2\text{SO}_4$  acid (b) plotted as a function of different temperatures,  $V = 10 \text{ mV}\cdot\text{s}^{-1}$ .

From the temperature effect observed on the behavior of steel, the Arrhenius steel dissolution lines in different acids were plotted, and the activation

energy in each medium was calculated. From the results obtained, it can be concluded that the limit stage of the reaction is the charge transfer stage.

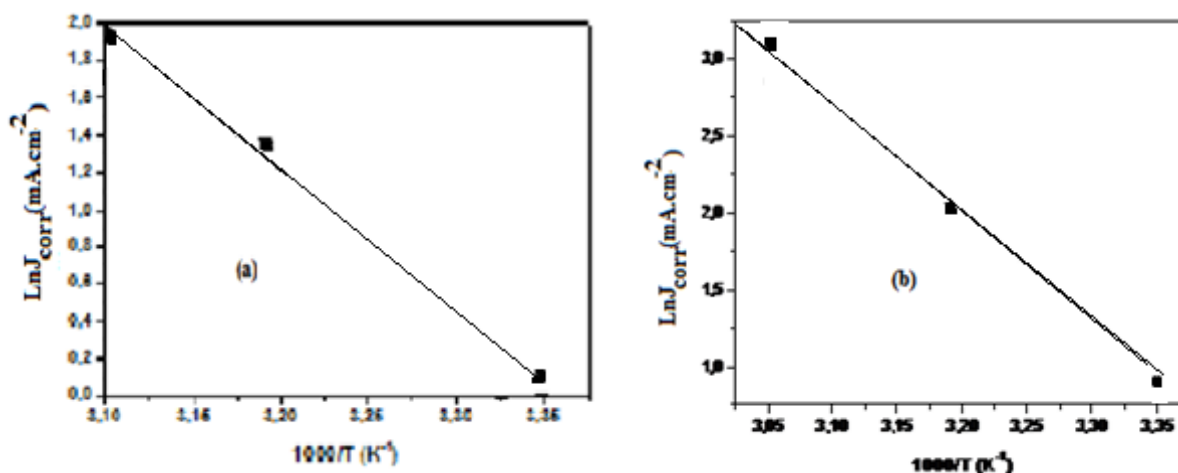


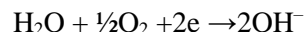
Fig. 5 – Arrhenius lines of the dissolution of XC48 steel in 0.5 M  $\text{H}_3\text{PO}_4$  at different temperatures (25–40–50°C) (a) with  $E_a \approx 63.23 \text{ kJmol}^{-1}$  and in 0.5 M  $\text{H}_2\text{SO}_4$  at different temperatures (25–40–55°C) (b) with  $E_a \approx 65.17 \text{ kJmol}^{-1}$ .

### 2.2. Effect of NaCl salt concentration on corrosion of XC48 steel

The shape of the polarization curves, Fig. 6, shows that the increase in the concentration of NaCl leads to an increase in the corrosion rate of the steel. However this increase does not last for a longtime, because at a certain concentration the downward trend in velocity begins to take place. The corrosion speed reaches its maximum value at a concentration of NaCl equal to approximately 3% (the concentration of sea water) and after that its value drops.

As the concentration of salt increases, the solubility of oxygen in water gradually decreases, which explains the decrease in the rate of corrosion at high NaCl concentrations. The early increase in the corrosion rate depends on the change in the protective properties of the diffusion barrier of the rust layer, formed on the corroded steel. In distilled water, which has a low electrical conductivity, the anodic and cathodic parts must be arranged (distributed) close to each other. Therefore, the OH<sup>-</sup> ions formed at the cathode are always close to

the Fe<sup>2+</sup> ions formed at the anode as shown in the equation:



Therefore a layer of Fe(OH)<sub>2</sub> is formed, and strongly adheres to the surface of the steel, creating a barrier against the diffusion of oxygen. On the other hand and thanks to the high electroconductivity of NaCl solution, the anodic and cathodic parts can be fixed one far from the other. In this case, the NaOH formed on the cathode does not intervene in a reaction with FeCl<sub>2</sub> formed at the anode. These compounds diffuse into solution and react with each other giving Fe(OH)<sub>2</sub> away from the steel surface. Obviously, the hydroxide formed does not create a protective layer barrier on the steel. This is why in a dilute NaCl solution, the steel corrodes quickly, since a lot of oxygen reaches the cathodic sites. With the increase of the NaCl content (more than 3%), the decrease in oxygen solubility becomes a decisive factor with respect to any change in the barrier of the layer (the barrier of the formed layer which is erected against the diffusion of oxygen), which leads to a decrease in the corrosion rate.<sup>4</sup>

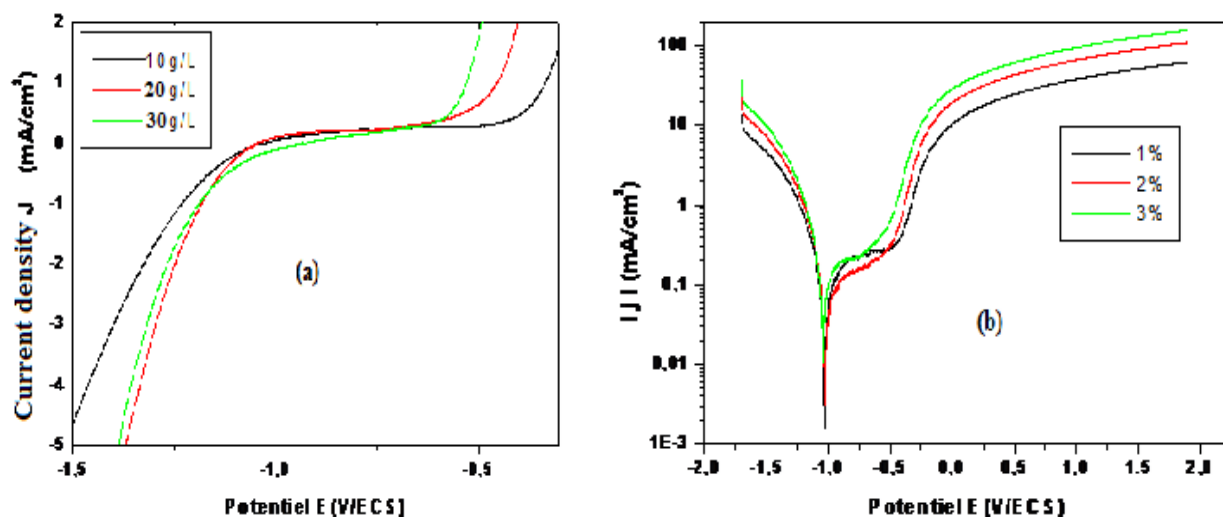


Fig. 6 – Influence of NaCl concentration on corrosion of XC48 carbon steel in 3% NaCl,  $V = 10\text{mV/S}$ .

### 2.3. Effect of temperature on the corrosion of XC48 steel in a saline medium (NaCl)

Most chemical and electrochemical reactions become faster as the temperature increases<sup>9</sup>. In this study, we suggested to study the impact of temperature on the behavior of carbon steel in 3%

NaCl. The shape of the polarization curves in Fig. 7 show that the increase in temperature leads to an increase in the corrosion rate and a reduction in the extent of the stability plateaus. The break of the protective film is faster at high temperature, which means the negative effect of temperature on the corrosion of metals.<sup>10</sup>

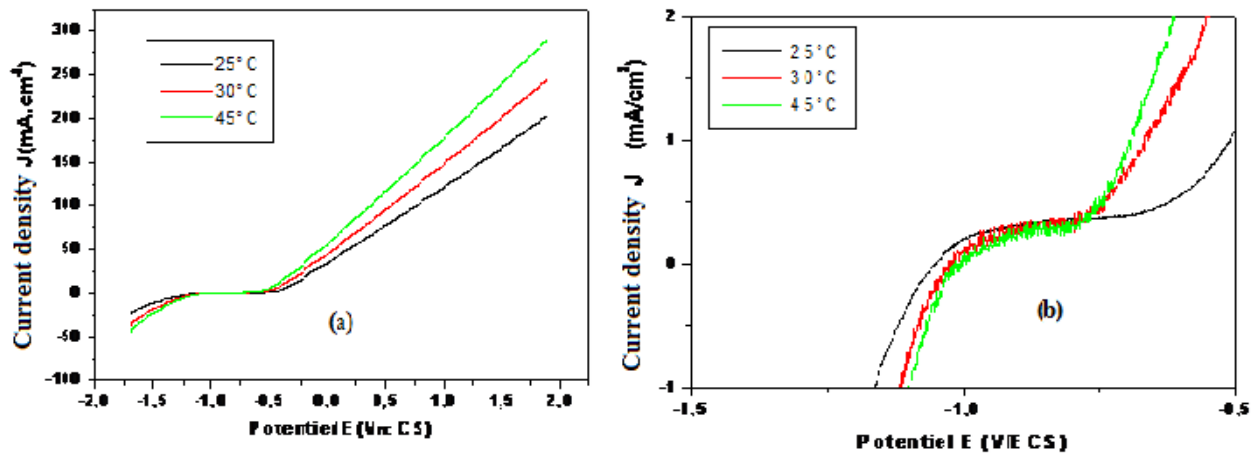


Fig. 7 – Effect of temperature on the corrosion of XC48 carbon steel in 3% NaCl,  $V = 10$  mV/S.

#### 2.4. Effect of pH on corrosion of XC48 carbon steel

In aerated water (containing oxygen), and depending on the pH, there are three dissolution zones:

- Zone of intense dissolution with hydrogen as a depolarizer, where there is the rapid decrease in the corrosion rate with increasing pH up to 4;
- Zone with a constant corrosion rate, pH from 4 to 9;
- Zone with minimum corrosion rate,  $\text{pH} > 9$ , but in the strongly basic medium, the corrosion rate increases again. The pH was varied by the addition of HCl or NaOH.

In the pH range of 4 to 10, only the diffusion rate of oxygen towards the steel surface, this defines the rate of corrosion. The main barrier ( $\text{Fe}^{2+}$  oxide layer), constantly renews itself during the corrosion process regardless of the pH values. In the acid medium ( $\text{pH} < 4$ ), the iron oxide layer will disappear, the pH value will drop on the surface of the steel, and the metal will be in direct contact with the aqueous medium. In this case the increase in the reaction rate depends both on the high rate of release of hydrogen and on the presence of oxygen as a depolarizer. The increase in the basicity of the medium ( $\text{pH} > 10$ ) leads to the increase of the pH on the steel surface. In this case, the corrosion rate decreases, since the steel becomes more and more passive in the presence of bases and dissolved oxygen.

The potential of the steel in the solution of  $\text{pH} = 10$  belongs to the active zone and reaches, in a 1N NaOH solution, a value where the steel becomes passive. When the basicity is considerably increased, for example up to 16N of an NaOH

solution (43%), the passivity ceases (the passivation layer is destroyed) and the potential suddenly moves towards the active domain.<sup>3,4</sup>

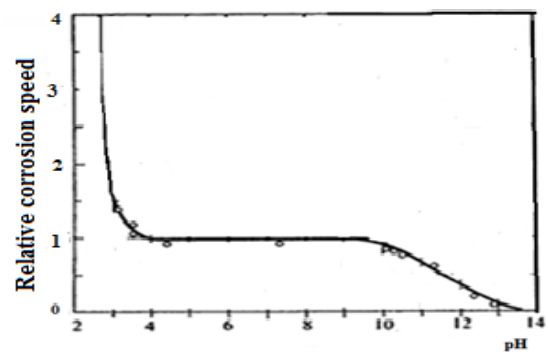


Fig. 8 – Variation of relative corrosion rate of steel with respect to pH.

Many recent studies have deeply studied the corrosion behavior of various steel types under different aggressive environments including acidic and alkaline media by varying working parameters such as temperature, immersion time, pH, acid concentration etc. in this context, Zhang *et al.* (2021) investigated the Effect of immersion corrosion time on electrochemical corrosion behavior and the corrosion mechanism of EH47 ship steel. The results showed that the open circuit potential of EH47 decreases and then increases with an increase in total immersion time, with the minimum value obtained at 28 days. With an increase in immersion time, the corrosion current density ( $I_{\text{corr}}$ ) of EH47 steel first decreases and then increases, with the minimum at about 28 days.<sup>5</sup> Mobin *et al.* reported the effect of temperature (*i.e.* 30, 40, 50, and 60°C) and immersion time extending from 1 to 7 days on mild steel corrosion in 5% HCl solution in the presence of L-valine and



different additives – salts, both inorganic (potassium iodide, KI) and organic (sodium benzoate, SB), and non-ionic sugar based surfactant (N-decyl-N'-glucosylethylenediamine, SS). They found that The corrosion rate of mild steel decreased with the presence of additives, and the extent of effect followed the sequence of  $KI < SB < SS$ . Lowest values of corrosion rates in the case of SS also reflected a smooth and better morphological surface.<sup>6</sup> Moreover, Emran (2013) studied the Effects of concentration and temperature on the corrosion properties of the Fe–Ni–Mn alloy in HCl solutions. The findings revealed a direct relationship between the corrosion rate and the concentration of HCl solutions, whereby the rate increased as the concentration increased. The researchers employed the ZSim Demo program to fit the experimental data from electrochemical impedance spectroscopy (EIS) to an equivalent circuit model. Through this analysis, appropriate equivalent circuit models were identified. Notably, the results obtained from both impedance and polarization measurements displayed a strong consistency, affirming their agreement in characterizing the corrosion behavior.<sup>7</sup> Baig *et al.* (2017) investigated the Effect of Immersion Time and Temperature on Corrosion Behaviour of Nanocrystalline Al-Fe-Cr Alloy. The results demonstrated that the developed alloy exhibited excellent resistance to uniform corrosion across all temperatures. Furthermore, it was observed that an increase in immersion time led to a shift in the corrosion potential ( $E_{corr}$ ) towards a more negative value. This shift resulted in a decrease in the corrosion current ( $j_{corr}$ ) and subsequently enhanced the corrosion resistance ( $R_p$ ) of the alloy. Therefore, prolonged immersion time positively influenced the alloy's ability to withstand corrosion.<sup>8</sup> In addition the effect of temperature on the corrosion rate of iron-carbon alloys was studied and it was found that when the temperature increases by 10 °C, the dissolution of the iron-carbon alloy accelerates by an average of 2.3 times. The values of the activation energy of the corrosion process for the investigated iron-carbon alloys are determined, which indicate that the corrosion processes in a solution of sulfuric acid proceed by an electrochemical mechanism. It is established that when the carbon content in the alloy increases, the energy of corrosion activation increases, which means that the beginning of corrosion processes on the surface of iron-carbon

alloys occurs later.<sup>9</sup> The corrosion behavior of E690 steel in 3.5 wt.% NaCl solution at temperatures from 20°C to 60°C was investigated using electrochemical test. The findings indicated that the corrosion rate of E690 steel increased as the temperature rose. The corrosion layers formed on the surface of the steel primarily consisted of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub>,  $\alpha$ -FeOOH, and  $\gamma$ -FeOOH. As the temperature increased, the proportion of  $\alpha$ -FeOOH in the corrosion layers increased, whereas the proportions of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> and  $\gamma$ -FeOOH decreased. In other words, elevated temperatures promoted the formation of  $\alpha$ -FeOOH in the corrosion layers while reducing the presence of  $\alpha$ -Fe<sub>2</sub>O<sub>3</sub> and  $\gamma$ -FeOOH.<sup>10</sup> Moreover, the corrosion behavior of carbon steel under alternating current (AC) was explored in electrolyte solutions with five different pH values, from near-neutral to alkaline, through weight loss measurements, potential monitoring techniques, potentiodynamic polarization tests, electrochemical impedance spectroscopy (EIS) tests, and surface examination. The findings revealed that as the pH value of the solution increased towards the alkaline end, the corrosion rate of the carbon steel decreased. Conversely, the corrosion rate increased with higher AC current density. At a highly alkaline pH, such as 12, the carbon steel surfaces underwent passivation, and as the pH increased, the passive region expanded. However, it is important to note that the passive film suffered from mechanical breakdown when the AC current density reached a critical level.<sup>11</sup>

## EXPERIMENTAL

### 1. Preparation of steel samples for corrosion measurements:

All the experimental tests were conducted on the mild steel C45 (XC48) samples possessing the chemical composition in % wt.: C-50, P-0.031, Mn-0.67, Si-0.24, S-0.022. Gravimetric measurements were conducted using mild steel coupons that had a surface area of 7cm<sup>2</sup>. Electrochemical measurements, on the other hand, utilized steel samples with a surface area of 2 cm<sup>2</sup>. All the samples underwent mechanical polishing using emery papers of different grades (320, 400, 600, and 1200). Following the polishing, the samples were cleaned using distilled water, degreased with acetone, and finally dried using warm air.

Solutions with different concentrations were prepared from commercial acid solutions: sulfuric acid (96%), phosphoric acid (85%), hydrochloric acid (36%) as well as solutions of different concentrations of NaCl.



## 2. Gravimetric (weight loss) measurements:

Gravimetric determination of the corrosion rate was realized using the following protocol:

A steel plate of surface ( $S$ ) and initial weight ( $W_i$ ) is immersed in a corrosive medium at a given temperature for a time ( $t$ ) then the final weight ( $W_f$ ) at the end of the analysis is measured. The corrosion rate can be calculated from the relationship:

$$W = \frac{W_i - W_f}{S \cdot t}$$

The obtained values are general and this method does not give the instantaneous corrosion rate which refers to the loss of thickness of a material per unit time and area as follows <sup>11</sup>:

$$v_c = \frac{K \cdot m}{S \cdot t \cdot d}$$

where  $m$  is the mass loss and  $K$  is a constant.

The speed is expressed in millimeters per year (mm/year),  $m$  in milligrams,  $d$  in grams per cubic centimeter,  $S$  in square centimeter,  $t$  in hour, and  $K = 87.6$ . In most applications, a corrosion rate of less than about 0.50 mm/year is acceptable.

## 3. Electrochemical measurements

In all electrochemistry experiments, a three-electrode configuration is utilized to address various limitations associated with the two-electrode setup. The three-electrode system comprises a working electrode, a platinum counter electrode, and a saturated calomel reference electrode. The primary function of the reference electrode is to serve as a reference point for measuring and regulating the potential of the working electrode, without allowing any current to pass through it. To ensure stability in electrochemical measurements, it is crucial for the reference electrode to maintain a constant electrochemical potential, particularly at low current densities. Furthermore, due to the minimal current passing through the reference electrode, the voltage drop between the reference electrode and the working electrode is typically minimal. Consequently, the three-electrode system provides a more stable reference potential and compensates for any voltage drop that may occur across the solution. This translates into superior control over working electrode potential. Among the commonly used reference electrodes in laboratory settings, the Saturated Calomel Electrode (SCE) is widely used. In the three-electrode configuration, the counter electrode serves the sole purpose of carrying the necessary current to balance the observed current at the working electrode. As a result, the counter electrode may often undergo significant potential swings to fulfill this function effectively.

To conduct the electrochemical analysis, a conventional three-electrode cell setup was employed. The experimental setup included an Autolab Potentiostat/Galvanostat Model 128 N for performing the tests, and the resulting data was analyzed using NOVA 2.1 software. In this study, the Saturated Calomel Electrode was utilized as the reference electrode, while a platinum wire served as the counter electrode. The working electrode was a steel coupon in the form of a disc with a surface area of 1 cm<sup>2</sup>, which was embedded in polytetrafluoroethylene (PTFE). Before each measurement, the steel coupon was immersed in a test solution for 30 minutes to achieve a stable open circuit potential (OCP).

When an electric current is concomitant with electrochemical corrosion reactions, the corrosion rate can also be expressed as a function of this current or more

precisely, of the electric current density ( $J$ ), that is to say, the current per unit area corroded. The corrosion rate  $v_c$ , in mole/dm<sup>2</sup>, is calculated using the following equation:<sup>12</sup>

$$v_c = \frac{J}{nF}$$

where  $n$  is the number of electrons associated with the ionization of each metal atom and  $F$  is Faraday's constant (96500 Cmol<sup>-1</sup>).

Besides its sensitivity and accuracy, the electrochemical method allows rapid measurement of near-instantaneous corrosion rates. The measurement of the corrosion potential and corrosion rate are the only recommended techniques because they are not destructive.

## CONCLUSION

The study of the behavior of carbon steel (XC48) in different acid media as well as the factors that affect the corrosion rate of steel, including temperature, acid concentration and time of immersion, allows us to draw the following conclusions:

The corrosion rate increases with the increase in the concentration of the medium (acid or saline) and the temperature, as well as with the immersion time.

Generally, the increase in temperature accelerates the phenomena of corrosion, because it decreases the domains of stability of metals and accelerates the reactions and transport kinetics. The importance of its influence differs, however, depending on the corrosive environment in which the material is found. Passivation film rupture, for example, is faster at high temperature, which means an disapproving effect of temperature on the corrosion of metals. The plot of  $\ln W = f(1000/T)$ , gives a straight line whose slope ( $-E_a/R$ ) allows us to calculate the activation energy in the absence of inhibitor ( $E_a$ ) which represents the energy barrier that must cross an inhibitor so that it is adsorbed on the surface of the plate.

As the concentration of salt increases, the solubility of oxygen in water gradually decreases, which explains the decrease in the corrosion rate at high concentrations of NaCl. The early increase in corrosion rate depends on the change in the protective properties of the rust layer barrier, formed on the corroded steel.

In the acid medium (pH < 4), the iron oxide layer will disappear and in this case the increase in the reaction rate depends both on the high rate of hydrogen release and on the presence oxygen as a depolarizer. In the pH range of 4 to 10, only the rate of oxygen diffusion towards the steel surface defines the rate of corrosion.

The increase in the basicity of the medium (pH > 10) leads to the increase of the pH on the surface of the steel. In this case, the corrosion rate decreases, since the steel becomes more and more passive in the presence of bases and dissolved oxygen.

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