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Sodium nitrate as a corrosion inhibitor of carbon steel in various concentrations of hydrochloric acid solution

Saad A. Jafar[1], Ahmad A. Aabid[2], Ghassan Hassan Abdul Razzaq[1], Jasim I. Humadi[1*]

[1]Petrolum and Gas Refining Engineering, College of Petroleum Processes Engineering, Tikrit University, IRAQ
[2]Petroleum Reservoir Engineering, College of Petroleum and Mining Engineering, Mosul University, IRAQ

*Corresponding Author Email: jasim_alhashimi_ppe@tu.edu.iq

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ABSTRACT

In the chemical and petroleum industries, metals are used in over 90% of construction units. Iron and steel are widely used metals in the fabrication and manufacturing of petroleum field operating platforms. The exposures of metals to the effect of bases or acids in the various industries can be severe to the metals specifications and thus result in suddenly failure of materials in service. So that, the need to investigate the protection of metals when exposed to various environments, as this is a very important factor in the selection of material that determines the service life of it. In the present study, the effect of various concentrations ranging from (25 to 100 mg/l) of sodium nitrate was studied in inhibiting the corrosion of carbon steel placed in different concentrations of hydrochloric acid solution (1 M, 2 M, and 3 M), the results showed that the concentration of (75 mg/l) of sodium nitrate achieved the best inhibition of the acid used in all the concentrations used, as it reduced the corrosion rate by 48.91% for a concentration of 1 M, 39.38% for a concentration of 2 M, and 35.33% for a concentration of 3 M.

1. INTRODUCTION

Carbon steels are widely used in industrial and engineering fields, and are used in construction and design processes. Carbon steels have very excellent chemical and mechanical properties. Despite these specifications, the main problem with its use is its susceptibility to corrosion [1-3]. The corrosion of carbon steel is an inescapable process that can be inhibited and controlled. Inhibitors are essential additives. The use of inhibitors is one of the main factors for corrosion protection of carbon steel [4]. Inhibitors had one of best way consent in the manufacture because it very good anticorrosive. However, some showed up as other effects, than this damage the environment. Thus the scientific community began checking for friendly environmentally inhibitors, like the using organic inhibitors [5-7]. Corrosion inhibitor is a great effective to decrease the corrosion rate by added low amount of inhibitors to an aggressive environment [8]. It has been observed that the presence of Heterogeneous atoms, such as sulfur, nitrogen, and phosphorous in the organic compound molecule results in an improvement its actions as a corrosion inhibitor [9]. Nitrite is one of the frequently used anodic inhibitors, which leads to a reduction in the corrosion rate and a decrease in the corrosion current [10-13]. $NaNO_2$ is a type of anode inhibitor that requires a critical concentration to obtain the best protection for steel [14-16]. When the concentrations are low, the action of nitrite may turn into a reverse state and lead to an increase in corrosion. In addition, the effect of chloride concentration is equally important because "when the chloride / nitrite ratio is high, the negative effect is lost"[17]. When inhibitors containing $NaNO_2$ are used, the cathodic polarization curve is quasi-neutral. The solutions of these materials cut off the anodic polarization curves of steel in the inactive range, providing low corrosion rates [12].

2. EXPERIMENTAL WORKS

2.1 Materials and Tools

2.1.1 Carbon steel

The chemical composition of the carbon steel used in this research paper was imported from (EREĞLI DEMIR VE ÇELIK FABRIKALARI T.A.Ş, TURKEYA) as per ASTM (A192 / A 192M 2004), is (0.156 % C, 0.29% Mn, 0.07% S, 0.1% Si, and 0.01% p). The tensile property of carbon steel is (Tensile strength=342.4 MPa min, Yield strength=239 MPa min, and Elongation 50 mm=46 min, %).

Carbon steel dimensions are (3 cm) length, (1.5 cm) width, and (0.2 cm) thickness. The total surface area is (10.8) cm^2, weight of specimen is (7.2 gm), and the density is (7.86 g/cm3). The geometrical dimensions of the carbon steel specimen used in the present work are shown in Figure 1.

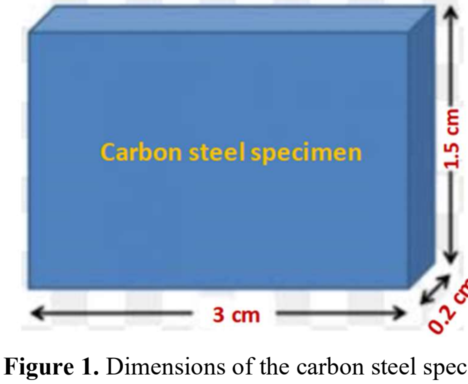

Figure 1. Dimensions of the carbon steel specimen.

2.1.2 Inhibitor

In the present study, the ammonium nitrate (96% purity) purchased from Hadleigh Ipswich Suffolk company was used as inhibitor. The inhibitor concentrations in the range of (25 mg/L - 100 mg/L) have been prepared.

2.1.3 Hydrochloric acid

The aggressive solution (1,2, and 3 M hydrochloric acid has been prepared according to the general dilution law through diluting the analytical grades 36.5-38.0% of HCl, which purchased from J.T BAKER company, with the distilled water.

2.1.4 Electronic balance

In the present work, high accuracy digital balance (AS 220.R1, RADWAG) with four decimal points with maximum load (220) grams and minimum load (0.1 mg) was used for weighting the carbon steel specimens before and after the immersion in the acid solution.

2.2 Experimental methodology

In the present study, the carbon steel specimens placed in acid solution (1 M, 2 M, and 3 M of HCl) respectively for 12 continuous days and the difference in the weight of the specimens measured for each day by using a sensitive electronic balance. Then the inhibitory factor ($NaNO_2$) was added into three acid solution concentrations with various concentrations of the inhibitor material (25 mg/l, 50 mg/l, 75 mg/l, 100 mg/l), and the difference in the weight of carbon steel specimens was also measured according to the mentioned days. The differences between the weight difference with the presence and absence of the inhibitory factor noted and discussed.

2.3 Calculations of corrosion rate

To calculate the corrosion rate of carbon steel specimens in HCl solution, the difference in weight noted as the weight loss in milligrams. The procedure for weight loss determination was according to Eq. (1):

$$Wieght\ loss = Initial\ wieght - Final\ wieght \quad (1)$$

In addition, we calculate the corrosion penetration rate (CPR) of the carbon steel based on equation 2 [18-21]:

$$CPR = \frac{K*W}{A*T*\rho} \quad (2)$$

Where, W: is the lost weight (g), K: is constant (87.6 ml/year, ρ: is the metal density (g/cm3), A: is the surface area of the corrosion (cm^2), T: is the time of the lost weight (hr).

3. RESULTS AND DISCUSSION

3.1 The effect of the inhibitory factor on the corrosion process

During this section, the results of the effect of adding sodium nitrate on preventing or reducing the corrosion of carbon steel placed in different concentrations of hydrochloric solution will be presented and discussed.

When the specimen of carbon steel is immersed in a 1 M, 2 M, and 3 M respectively solution and different concentrations of sodium nitrate are added (25, 50, 75, 100 mg/ l), the corrosion rate starts to drop dramatically in the first two days for all the concentrations used, then the rate begins to slow gradually, meaning that the rate is fixed at Last day (after 12 days). Figure 2 below showed the effect of the corrosion on the carbon steel specimen.

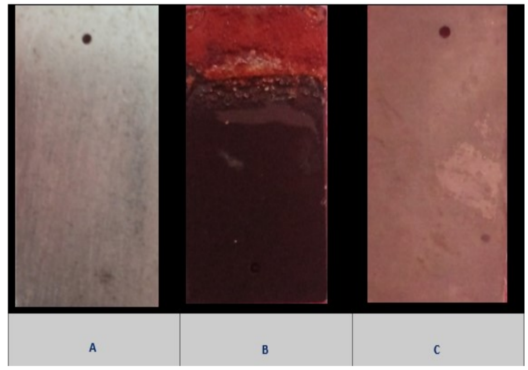

Figure 2. The specimen of carbon steel: a) Before the immersion in the acid, b) After the immersion in the acid (3M HCl) without using inhibitor, c) After the immersion in the acid (3M HCl) with using inhibitor(75 mg/L).

Where the corrosion rate begins to decrease gradually when sodium nitrate is added, and the increase the amount of sodium nitrate, the lower the rate of corrosion, As shown in Figures 3, 4, and 5 . When the addition of sodium nitrate reaches an amount of 75 mg / liter, the best possible result is obtained in reducing the rate of corrosion For all concentrations of hydrochloric acid (1 M,2 M, and 3 M).

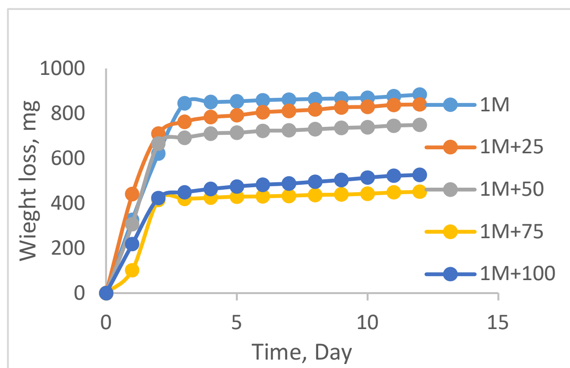

Figure 3. The rate of corrosion of carbon steel in 1 M HCl solution over time, in the presence and absence of sodium nitrate.

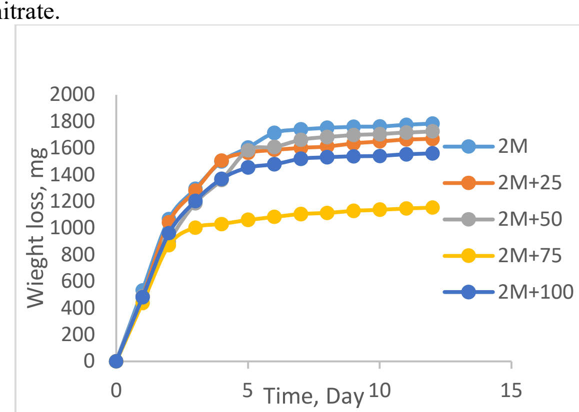

Figure 4. The rate of corrosion of carbon steel in 2 M HCl solution over time, in the presence and absence of sodium nitrate.

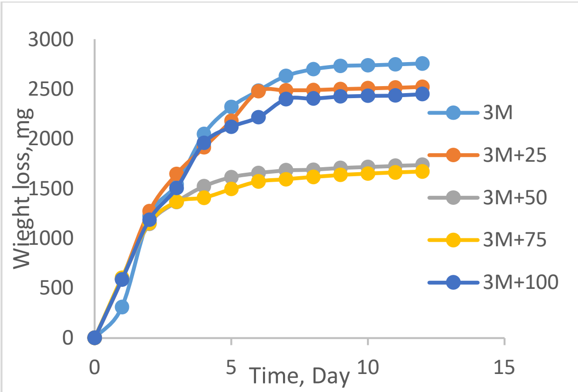

Figure 5. The rate of corrosion of carbon steel in 3 M HCl solution over time, in the presence and absence of sodium nitrate.

The results obtained show that the lost weight decreased from 884.1 to 451.6 mg when adding 75 mg/L of sodium nitrate to a concentration of 1 M of hydrochloric acid with an efficiency of 48.91 %. While the efficiency of the concentration of 75 mg / liter of sodium nitrate in a solution of 2 M of HCL is 39.38%, but when the concentration of the solution is 3 M, the efficiency is 35.33%, figure 6 shows the comparison between the results of different concentrations of the acidic solution. This result agrees with what the researcher [22] found in the effectiveness of sodium nitrate to protect carbon steel with different numbers, because he studied the effect of nitrates in sodium chloride solution, where this researcher says that "the best [NaNO2/NaCl] protection molar ratio of carbon steel was 0.9 at 0 and 350 rpm". While the researcher [23] was studied "the inhibitive effect of Thevetia peruviana on the corrosion behavior of carbon steel in 1 M HCl", This researcher found that " the inhibitive action of Thevetia peruviana extract is basically controlled by the temperature and concentration of the extract; the maximum IE was 90.3 % at 300 ppm".

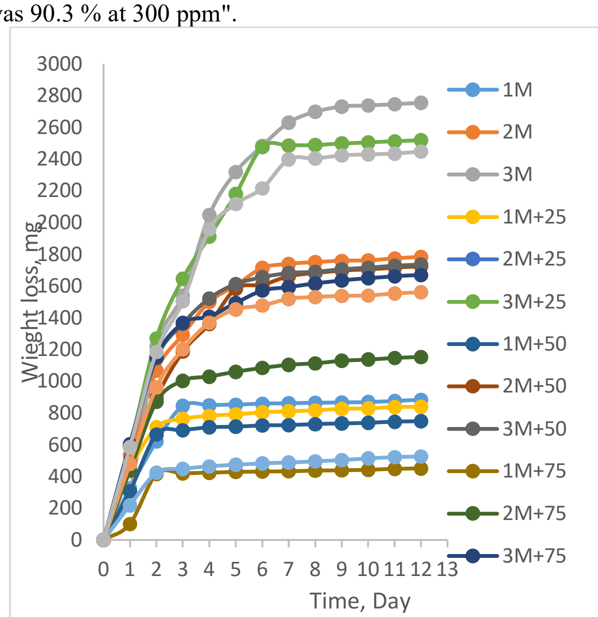

Figure 6. The comparison between the results of carbon steel corrosion in the presence and absence of the inhibitor in various concentrations of the acidic media.

The difference in the efficiency of our work from the above-mentioned works is due to the difference in the inhibitory factor or the difference in the corrosion solution, Hydrochloric acid causes severe corrosion of most alloys and metals [24], Where the researcher [25] found that the inhibition efficiency was 56.7% for the NaCl solution, while the efficiency was 51.7% for the HCl solution when using the 2,6-dimethylpyridine inhibitor.

3.2 Corrosion penetration rate of carbon steel

During this section, we discuss the results of CPR calculations based on Equation 2 mentioned earlier. Where Figure (7) represents the CPR without adding the inhibitor, and the results show the higher its value whenever the molar concentration is greater due to the direct relationship with the acidity function [26].

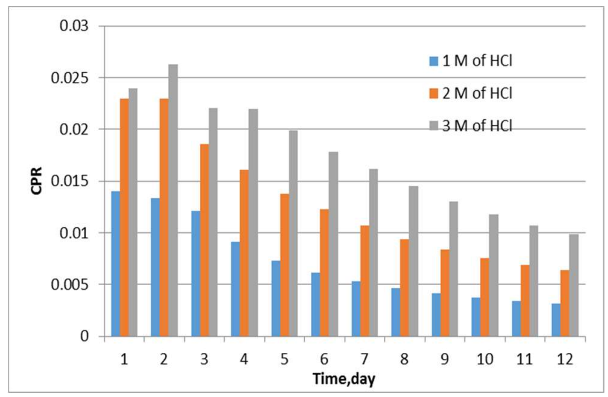

Figure 7. The values of CPR vs time for carbon steel in 1, 2, and 3 M of HCl before adding the inhibitor.

While Figures (8, 9, 10 and 11) show the CPR values after adding the inhibitor at a concentration of 25, 50, 75 and 100 mg/lit, respectively.

The results obtained also indicate that the CPR value increases when the molar concentration is 3 M and then 2 M and the value is as low as possible at 1 M. As shown in the Figures (8 – 11), the results proved that the lowest value of CPR when the added concentration of the sodium nitrate as inhibitor is 75 mg/L.

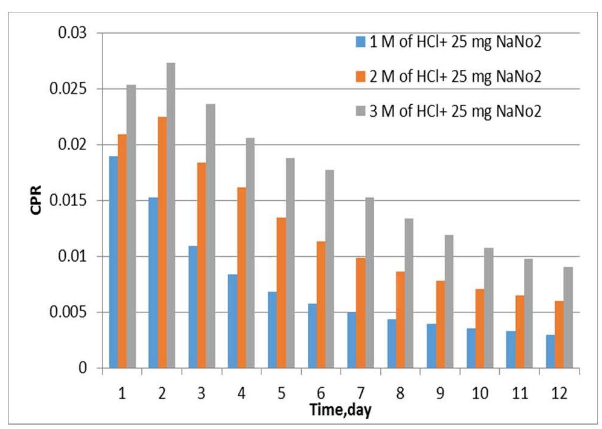

Figure 8. The values of CPR vs Time for 1, 2, and 3 M of HCl after adding 25 mg of the inhibitor.

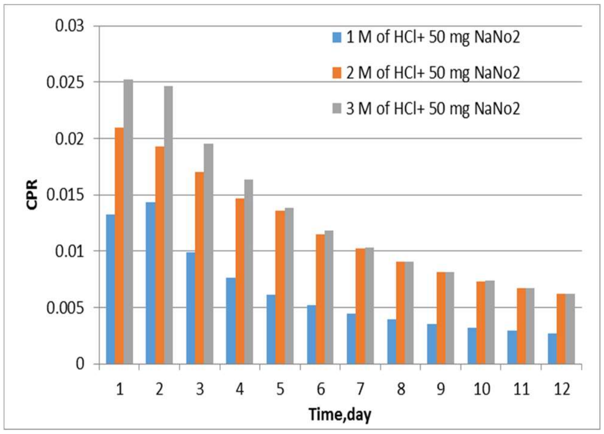

Figure 9. The values of CPR vs Time for 1, 2, and 3 M of HCl after adding 50 mg of the inhibitor.

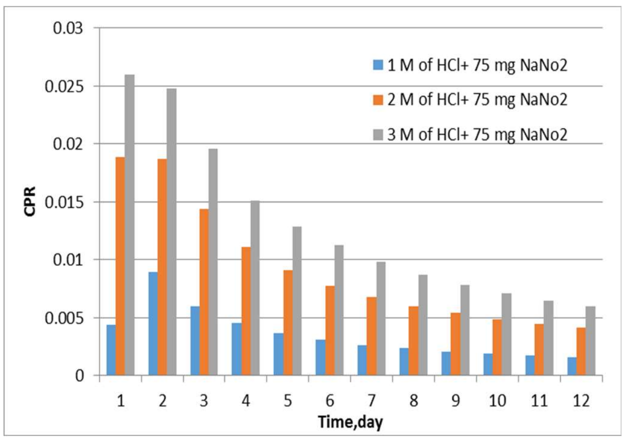

Figure 10. The values of CPR vs Time for 1, 2, and 3 M of HCl after adding 75 mg of the inhibitor.

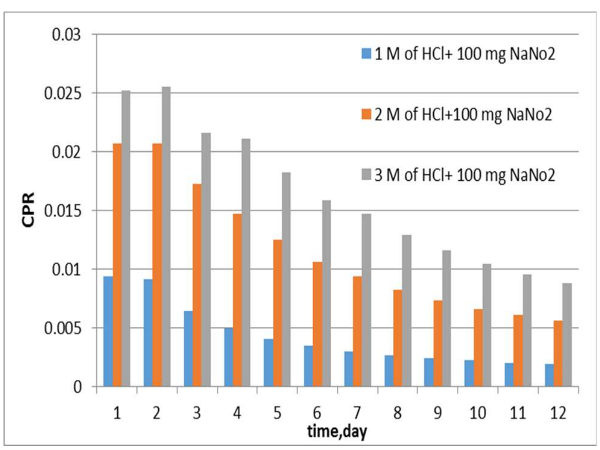

Figure 11. The values of CPR vs Time for 1, 2, and 3 M of HCl after adding 100 mg of the inhibitor.

3.3 Mechanical test

Some mechanical tests carried out for the carbon steel piece before and after it placed in the solution, and the differences that occurred on it noted as noted in Tables 1- 3. Dimensions also measured before and after the corrosion process.

Table 1. Tensile test of specimen and dimensions in IM of HCl

Item	Origin	Without inhibitor	With inhibitor
Length (mm)	30	30	30
Width (mm)	15	15	15
Thickness(mm)	2	1.753	1.873
Surface Area (mm^2)	1080	1057.77	1068.57
Diagonal(mm)	16.723	16.004	16.361
Mass(mg)	7163.1	6279.3	6711.5
Mass/Meter (g/mm)	0.2387	0.2093	0.2237
Yield stress (MPa)	120	118.8	119.4
Ultimate stress (MPa)	135	134.5	134.80
Ultimate load (KN)	4.5	4.5	4.5
Elongation (%)	3.40	3.366	3.385

Table 2. Tensile test of specimen and dimensions in 2M of HCl

Item	Origin	Without inhibitor	With inhibitor
Length (mm)	30	30	30
Width (mm)	15	15	15
Thickness(mm)	2	1.51	1.676
Surface Area (mm^2)	1080	1035.9	1050.84
Diagonal(mm)	16.723	15.227	15.766
Mass(mg)	7127.8	5383.4	5973.8
Mass/Meter (g/mm)	0.2376	0.1794	0.1991
Yield stress (MPa)	120	117.8	118.9
Ultimate stress (MPa)	135	134	134.58
Ultimate load (KN)	4.5	4.5	4.5
Elongation (%)	3.40	3.347	3.364

Table 3. Tensile test of specimen and dimensions in 3M of HCl.

Item	Origin	Without inhibitor	With inhibitor
Length (mm)	30	30	30
Width (mm)	15	15	15
Thickness(mm)	2	1.228	1.535
Surface Area (mm^2)	1080	1010.5	1038.15
Diagonal(mm)	16.723	14.213	15.311
Mass(mg)	7180.9	4408.5	5510.4
Mass/Meter (g/mm)	0.2393	0.1469	0.1837
Yield stress (MPa)	120	115.7	117.5

Ultimate stress (MPa)	135	132.85	134.15
Ultimate load (KN)	4.5	4.5	4.5
Elongation (%)	3.40	3.28	3.33

4. CONCLUSION

This study investigated the effect of various concentrations of the sodium nitrate as inhibitor (25 mg/l – 100 mg/l) on the corrosion rate of the carbon steel in different concentrations of hydrochloric acid solution (1 M, 2 M, and 3 M) using the immersion method. The results showed that the sodium nitrate is effectively reduced the corrosion of carbon steel in HCl solution. The results observed that the best protection with minimum corrosion rate of the carbon steel in various concentrations of HCl solution was when the added concentration of sodium nitrate of 75 mg/l.

As for the dimensions, there was a change in the thickness of the piece due to the large area exposed to the erosion solution, while the length and width did not change due to the small area exposed to the solution. Where it was a major reason to reduce the weight of the metal piece. Also, the corrosion process before and after the addition of the inhibitor affected the mechanical properties of the metal, such as (Yield stress, Ultimate stress, Ultimate load, and Elongation) and changed it in certain proportions.

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