



Experimental study of the inhibitory effect of ceftriaxone sodium and sodium nitrate on corrosion of carbon steel in various acidic media

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Abstract

There are various techniques to protect and decrease the corrosion rate of carbon steel in acidic environments such as using corrosion inhibitors. Therefore, the need to search for corrosion inhibitors that have high efficiency in protecting carbon steel in different acidic media and at low costs was revealed. The inhibitive effect of various inhibitors [100 mg sodium nitrate (SN), 100 mg ceftriaxone sodium (CS), and 50 mg sodium nitrate (SN) + 50 mg ceftriaxone sodium (CS)] on the corrosion behavior of carbon steel in various acidic media (one molarity concentration (1M) of HCl, H₂SO₄, and HNO₃ solutions) was investigated using the weight loss method. The results proved that sodium nitrate was the best inhibitor for protecting and decreasing the corrosion rate of carbon steel in a 1 M HNO₃ environment but the ceftriaxone sodium was the optimum choice for reducing the corrosion behavior of carbon steel in 1 M HCl, 1 M H₂SO₄ solutions. The theoretical parameter (CPR) gave important assistance in understanding the corrosion inhibition behavior and mechanism and are in complete agreement with the experimental data.

Keywords: Carbon steel, the immersion method, acidic environments, CS and SN inhibitory mixture, CPR;

1. Introduction

Carbon steel is widely employed material for construction in many industrial units and petroleum units because of its good mechanical properties and low cost. However, when carbon steel use in acid solutions such as acid cleaning, acid pickling, and acid descaling, etc., it exposed to difference forms of corrosion effects especially uniform corrosion because it has low corrosion resistance in the acid solution [1, 2]. The process of carbon steel corrosion in acidic solutions is an inevitable matter. Corrosion of steel can be prevented or substantially minimized by using it in contaminated water and acidic environments [3]. Corrosion of carbon steel can be controlled using inhibitors. Inhibitors are compounds that are adsorbed onto metal surfaces to control, reduce, or prevent of destructive corrosion reactions processes [4]. Inhibitors are compounds usually used in acid solutions for lowering the corrosion rate of carbon steel in acidic environments. A reliable corrosion inhibitor is controlled by its efficiency in inhibiting the activity of acidic solutions, its economic availability, and its environmental side effects [5]. Nitrites are one of the most widely used

anodic inhibitors, resulting in lower corrosion rate and lower corrosion current [6-9]. Sodium nitrite (NaNO₂) forms a protective oxide film that passivates steel surfaces. Nitrites are environmentally suitable and easy to observe and can reduce corrosion rates to less than (2 mpy). The effect of chloride concentration is important because "when the ratio of chloride / nitrite is high, the negative effect is lost"[9]. When NaNO₂ inhibitors are used, the cathodic polarization curve is quasi-neutral. The behavior of carbon steel in these solutions and anodic polarization curves shift on the positive side, resulting low corrosion rates [8]. In addition, many numbers of organic compounds are suitable as inhibitors of corrosion effects for carbon steel in acidic environment, but only a few environmentally friendly and non-toxic compounds have been screened as corrosion inhibitors[10]. These inhibitors examples are pharmaceutical compounds, leaves, and fruits or seeds extracts[11, 12], novel pyridine derivative[13], ethylated non-ionic surfactant [14], dopamine- produced carbon dots [15], and finally Ceftriaxone Inhibitor [16]. Organic inhibitors are based on its power to adsorb on a surface of the

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metal, which ganged a water molecule at an interface. Ceftriaxone is an antibiotic of 3rd-generation cephalosporin and it has highly broad-spectrum action against positive and negative gram bacteria [17]. The presence of the heteroatoms, such as, sulfur, phosphorous, and nitrogen compounds in the molecule of the organic compounds lead to enhancement of its role as corrosion inhibitor of carbon steel for the reason that they can do chemisorption and because its molecular weight is large which have good advantageous effects upon the physical adsorption behaviour [16].

The aim of this study is focused on the performance of sodium nitrite (NaNO₂) and ceftriaxone sodium as a novel mixture of inhibitors, with various mixing ratios on the corrosion behaviour of carbon steel in 1 M of HCl, H₂SO₄, HNO₃ environments at 300C using immersion method and weight loss calculations.

This research organized as in section 1 introduction explained general description of the corrosion and inhibitors, in section 2 literature survey observed some previous studies on the inhibitory effect of carbon steel in different acidic media, in section 3 research methodology described in detail, in section 4 results & discussion analysed carefully, & final conclusions described in section 5.

2. Literature Survey

Saxena et al. (2013) investigated the activity of various concentration of anisali-dine derivative Schiff bases viz. N- (4-nitro phenyl) p-anisalidine (SB1), N- (4-chloro phenyl) p-anisalidine (SB2), N- (4-phenyl) p-anisalidine (SB3), N- (4-methoxy phenyl) p-anisalidine (SB4), N- (4-hydroxy phenyl) p-anisalidine (SB5) as corrosion inhibitors of mild steel in HNO₃ environment containing using mass loss method. The results proved that the efficiency of inhibitors was found larger in comparison with their parent amines. The performance of synthesized Schiff bases enhance with inhibitor concentration. The efficiency of Inhibition improves up to 98.32% with ansalidine derivative Schiff base [18].

Kalla et al. (2016) studied the performance of ethyl acetate extract (EAE) and butanolic extract (BE) of *Thapsia villosa* as corrosion inhibitors of carbon steel metal in 1 M H₂SO₄ using different methods as follow: electrochemical impedance spectroscopy (EIS) method, potentiodynamic polarization, and weight loss methods. The experimental data observed that EAE and BE are best corrosion inhibitors and the protection efficiency enhanced with rising concentration of the extracts, but reduce with increase in temperature. Also, the EAE and BE act as a mixed types inhibitors of carbon steel [19].

Jafari et al. (2019) studied the performance of 2-mercaptobenzothiazole (MBT) and 2-aminobenzothiazole (ABT) compounds as corrosion inhibition of carbon steel immersed in a 1 M HCl media. The results observed superior inhibition efficiency of MBT in comparison to ABT. This behaviour can cause easier protonation and consequently adsorption on the carbon steel surface occurs [20].

Aabid et al. (2021) investigated the inhibitory effect of ceftriaxone sodium on corrosion of copper in 1M of HNO₃ environment. The results showed that the inhibition efficiency rising with enhance of the Ceftriaxone sodium dose. The maximal the inhibition efficiency of 90.884% has been resulted in presence of (100 mg/L). The inhibitory action of ceftriaxone sodium observed based on the adsorption on the copper surface. This adsorption process follows the kinetic-thermodynamic model and Langmuir isotherm [16].

3. Materials and Methodology

3.1 Materials and specimens

3.1.1 Carbon steel specimens

The carbon steel specimens samples were purchased from EREĞLI DEMİR VE ÇELİK FABRIKALARI T.A.Ş, TURKEYA. The chemical compositions of carbon steel observed in Table 1. In addition, the tensile properties of carbon steel used in the present work illustrated in Table 2. Carbon steel chemical composition and tensile properties were obtained from the company that supplied the samples. The dimensions of carbon steel specimen employed in this work was as follow: length of 3 cm, width of (1.5 cm), and thickness of (0.2 cm).

Table 1. Chemical composition of the carbon steel employed in the present work.

Element	%
Carbon (C)	0.156
Manganese (Mn)	0.29
Sulfur (S)	0.007
Silicon (Si)	0.1
Phosphorus (p)	0.01

Table 2. Tensile properties of the carbon steel used in the present study.

Property	Value
Tensile strength, [MPa]	342.2
Yield strength, [MPa]	239
Elongation 50 mm, %	46

3.1.2 Acids used

1 M solutions of hydrochloric acid, sulfuric acid, and nitric acid have been prepared through diluting the analytical grades of each purchased acid with

distilled water. The specifications of acids summarized in Table 3.

Table 3. Specifications of acids used.

Properties	Hydrochloric acid	Nitric acid	Sulfuric acid
Chemical formula	HCl	HNO ₃	H ₂ SO ₄
Molecular weight (g/mol)	36.46	63.01	98.08
Purity	38 %	65 %	98 %
Density (g/cm ³) at 20 °C	1.19	1.39	1.835

3.1.3 Inhibitors

In the present study, the inhibitors used were:

1-Ammonium nitrate (NaNO₂): This inhibitor purchased from Hadleigh Ipswich Suffolk Company with 96% purity.

2-Ceftriaxone sodium (CTX): This inhibitor purchased from medicine supplier shop. This material produced from North China Pharmaceutical Co., Ltd., Shijiazhuang, China. The ceftriaxone sodium inhibitor is in a pure state.

The dosage of inhibitors used in this study expressed in (mg /L) units.

3.1.4 Electronic balance

As shown in Fig. 1, high digital balance accuracy (AS 220.R1, RADWAG) with (4) decimal points, maximum load (220 gm), and minimum load (0.1 mg). This equipment used for calculating the weight of specimen before and after the immersion in various acid solutions.



Fig. 1. Electronic balance used in the present study.

3.2 Experimental methodology

In this study, a model of carbonate steel immersed in different acidic solutions, which include (1 M of HCL, H₂SO₄, and 1 M HNO₃ solutions) for an immersion period of 1-15days. The weight loss of the model calculated before the immersion process and after the immersion for each day using a sensitive electronic balance. Then different concentrations of corrosion inhibitors used for each concentration of acids. Two types of corrosion inhibitors used for each concentration of acids, namely sodium nitrate (NANO₂) and ceftriaxone sodium. Weight loss of the carbon steel samples calculated during immersion without using inhibitors and by using inhibitors. The experimental results compared and discussed.

3.3 Calculations of corrosion penetration rate

From weight loss data, the corrosion penetration rate (CPR) can be calculated according to the equation (1):

W_{ieght} loss = weight of specimen before immersion - w_{ieght} of specimen after immersion (1)

Then CPR was calculated according to the equation (2)[21-26]:

$CPR = K * W / DAT$ (2)

Where: W is the weight loss (mg), K is constant (87.6 ml/year), D is the metal density (g/cm³), A is the surface area of the immersed sample (cm²), T is the exposure time (hr), CPR is the corrosion penetration rate (mm/year).

4. Results and Discussions

4.1 Influence of inhibitors on the corrosion behaviour of carbon steel in a variety of acidic solutions

4.1.1 The influence of inhibitors on the corrosion behaviour of carbon steel in 1 M HCl solution

Hydrochloric acid solution provides very strong corrosive environments that have their own influence and characteristics when reacted with industrial metal like carbon steel [27]. In the present study, the model specimen of carbon steel samples immersed in acidic solution (1 M HCl) without using inhibitors. The experimental results observed in Fig. 2. The results showed that the amount of weight loss increases rapidly for the first three days. This corrosion behaviour is attributable to the fact that the chemical reaction rate enhances with increasing the concentration of acidic media [28]. After these days, the weight loss increases slowly during a period of 15 days because of the generation of passivating corrosion complexes that naturally shield the surface of carbon steel from the acidic media. The corrosion carbon steel in HCl environment is attributed to the presence of water, air, and H⁺, which accelerated the corrosion of metal [29]. When the inhibitor added (100 mg SN) alone, the results observed that the lost weight has decreased slightly than if this inhibitor was not used, and this indicates the ineffectiveness of the inhibitor SN in decreasing the rate of corrosion of carbon steel in hydraulic acid. As for adding the inhibitor 100 mg CS, we notice that the lost weight and the corrosion speed decrease significantly, and this indicates the effectiveness of this inhibitor (CS) in decreasing the corrosion speed of carbon steel in hydraulic acid (1 M HCl) [30]. When two inhibitors used together (50 mg SN + 50 mg CS), the lost weight and the speed of corrosion decrease significantly, but not as in the case of using CS alone, because the concentration of CS in the mixture has decreased. From the experimental results one may observed the mechanism of inhibitors in reducing the corrosion rate of carbon steel. This suggested that, the formed inhibitive film was strengthened by addition of these corrosion inhibitors and protected the carbon steel from the sever corrosion [31, 32].

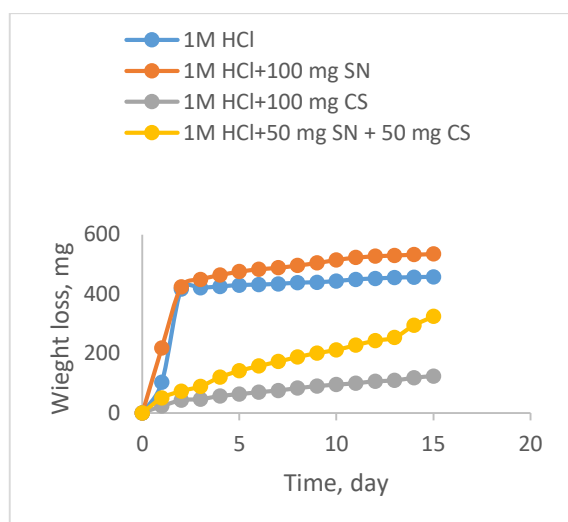


Fig. 2. Weight loss of carbon steel in 1 M HCl solution with time in the presence and absence of sodium nitrate and ceftriaxone sodium inhibitors.

4.1.2 The influence of inhibitors on the corrosion of carbon steel in 1 M H₂SO₄ solution

In this study, the model specimen of carbon steel samples immersed in acidic solution (1 M H₂SO₄) without adding inhibitors. The experimental data showed in Fig. 3. The results showed that the amount of lost weight increases rapidly for the first three days. This behaviour is attributable to the fact that the chemical reaction rate rises with increasing acid concentration [28, 33]. After three days, the weight loss increases slowly during a period of 16 days. This behaviour is significant in that the more the industrial metal is exposed to the acidic environment, the lower the rate of corrosion. This process could be showed from the concept of passivity and the reduce in the strength of the acidic environment as corrosion complexes get formed in the acidic media [34, 35]. When the inhibitor (100 mg SN) added, the results showed that the lost weight has increased slightly than if this inhibitor not used, and this indicates the ineffectiveness of the inhibitor SN in reducing the rate of corrosion of carbon steel in sulfuric acid environment. As for adding the inhibitor (100 mg CS), the results observed that the lost weight and the corrosion speed decrease significantly, and this indicates the effectiveness of this inhibitor (CS) in decreasing the corrosion speed of carbon steel in sulfuric acid (1 M H₂SO₄). When two inhibitors used together (mg SN + 50 mg CS), the lost weight and the speed of corrosion decrease significantly, but not as in the case of using CS alone, because the concentration of CS in the mixture has decreased.

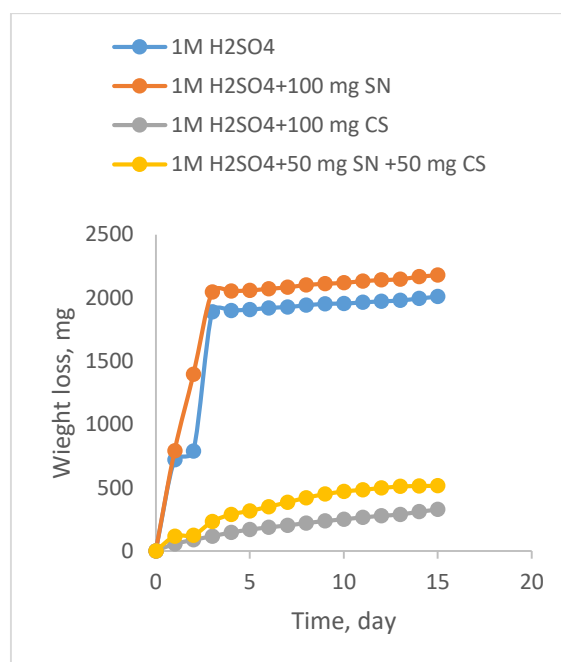


Fig. 3. Weight loss of carbon steel in 1 M H₂SO₄ solution with time in the presence and absence of sodium nitrate and ceftriaxone sodium inhibitors.

4.1.3 The influence of inhibitors on the corrosion behaviour of carbon steel in 1 M HNO₃ solution

In the present work, when immersing a sample of carbon steel in a solution of nitric acid (1M HNO₃) and without using inhibitors Fig.4, the results showed that a rapid increase in the lost weight in the first four days of immersion, after which the weight loss is moderate and slow. The results proved that the corrosion attack in HNO₃ media is highly significant because nitric acid was known to be a very strong oxidizing agent. An autocatalytic mechanism has been proposed to observe the sever corrosion process in this environment [36]. The presence of water, air, and H⁺ in acidic media led to accelerate the corrosion rate of carbon steel [29]. When using the inhibitor (100 mg SN), the results showed that the lost weight and the speed of corrosion decrease significantly and tangibly, and this indicates the effectiveness of this inhibitor SN in reducing the lost weight and the speed of corrosion of iron carbon steel in nitric acid. When the inhibitor (100 mg CS) employed, the results observed that the lost weight reduced in a small and imperceptible way, and this indicates the ineffectiveness of this inhibitor in decreasing the rate of corrosion of carbon steel in nitric acid. When mixture of inhibitors (50 mg SN + 50 mg CS) used, the results observed that the lost weight decreases, but not as in the case of using the inhibitor (100 mg SN) alone, because the concentration of SN in the mixture has decreased.

Fig. 5 showed the effect of the corrosion on the carbon steel specimen.

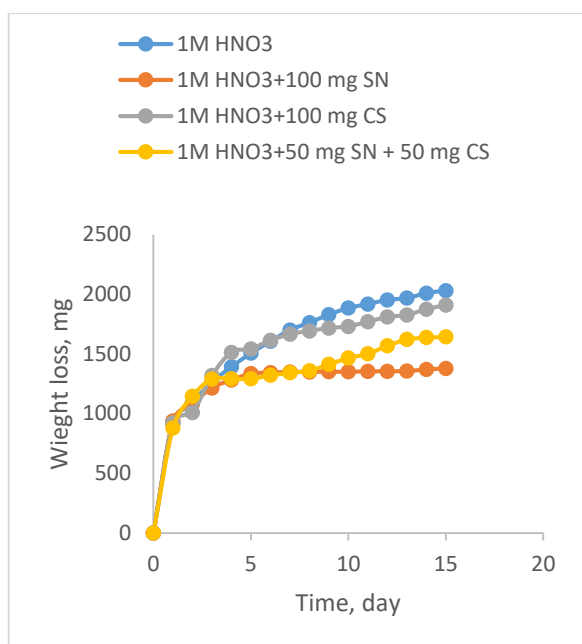


Fig. 4. Weight loss of carbon steel in 1 M HNO₃ solution with time in the presence and absence of sodium nitrate and ceftriaxone sodium inhibitors.

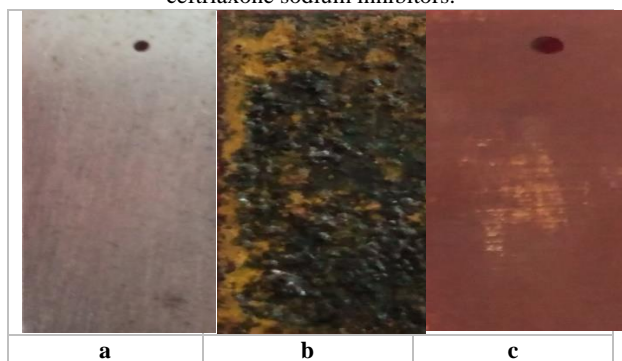


Figure 5. Carbon steel specimen: a) Before the immersion in the acid, b) After the immersion in the acid (1M H₂SO₄) without using inhibitor, c) After the immersion in the acid (1M H₂SO₄) with using inhibitor (CS).

4.2 The influence of inhibitors on the corrosion penetration rate (CPR) of carbon steel in a variety of acid solutions.

4.2.1 The influence of inhibitors on corrosion penetration rate (CPR) of carbon steel in 1 M HCl solution.

Fig. 6 shows the relation between CPR and time of exposure. CPR calculated from equation (2). We note that the adding of inhibitor (100 mg SN) enhances CPR value in first day of immersion and does not effect on the rest of the days, and this indicates that the inhibitor SN is not useful and does not work with the corrosion behaviour of carbon steel in the hydraulic acid environment, as explained earlier. While the addition of the inhibitor (100 mg CS) has a significant effect in reducing CPR value of carbon steel in hydraulic acid [30], the CPR value is reduced from 0.009 to less than 0.001. When two inhibitors employed together (50 mg SN+ 50 mg CS), the results showed a decrease of CPR from 0.009 to 0.0015, because the concentration of the inhibitor CS decreased from 100 mg to 50 mg.

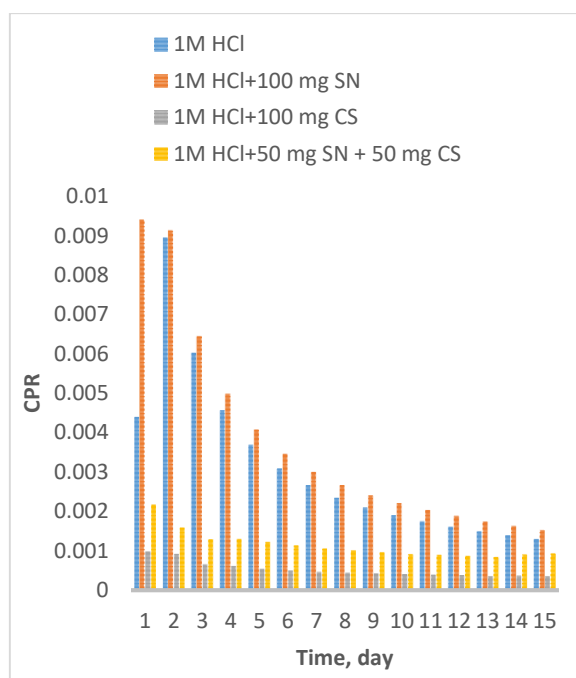


Fig. 6. CPR of carbon steel in 1 M HCl, solution with time, in the presence and absence of sodium nitrate and ceftriaxone sodium inhibitors.

4.2.2 The influence of inhibitors on corrosion penetration rate (CPR) of carbon steel in 1 M H₂SO₄ solution.

Fig. 7 shows the relation between CPR and time of exposure. The results showed that the adding of inhibitor (100 mg SN) enhances CPR value in the first days of immersion and does not effect on the rest of the days, and this indicates that the inhibitor SN is not useful and does not work with the corrosion of carbon steel in the sulfuric acid, as we explained earlier. While the addition of the inhibitor (100 mg CS) has a significant effect in reducing CPR value of carbon steel in sulfuric acid solution. CPR value reduced from 0.03 to less than 0.002. However, in the case of using the two inhibitors together (50 mg SN+ 50 mg CS), the results observed a decrease of CPR from 0.03 to 0.005, because the concentration of the inhibitor CS decreased from 100 mg to 50 mg.

4.2.2 The influence of inhibitors on corrosion penetration rate (CPR) of carbon steel in 1 M HNO₃ solution.

Fig. 8 shows the relation between CPR and time of exposure of carbon steel sample in a solution of nitric acid (1M HNO₃). The results showed that CPR without using inhibitors was between 0.038 and 0.005. When inhibitor (100 mg SN) used, the results observed that it not significantly affected in the first two days of immersion. CPR decreases significantly on the days from 3 to 15, and this indicates the effectiveness of this inhibitor SN in reducing CPR and corrosion of carbon steel in nitric acid solution. When an inhibitor (100 mg CS) employed, the results proved that CPR reduced to a small and imperceptible way, and this indicates the ineffectiveness of this inhibitor (CS) in reducing the rate of corrosion of carbon steel in nitric acid. But when using a mixture of inhibitors (50 mg SN + 50 mg CS), we notice that CPR decreases, but not as in the case of using the inhibitor 100 mg SN alone, because the concentration of SN with

mixing the two inhibitors is decreased from 100 mg to 50 mg.

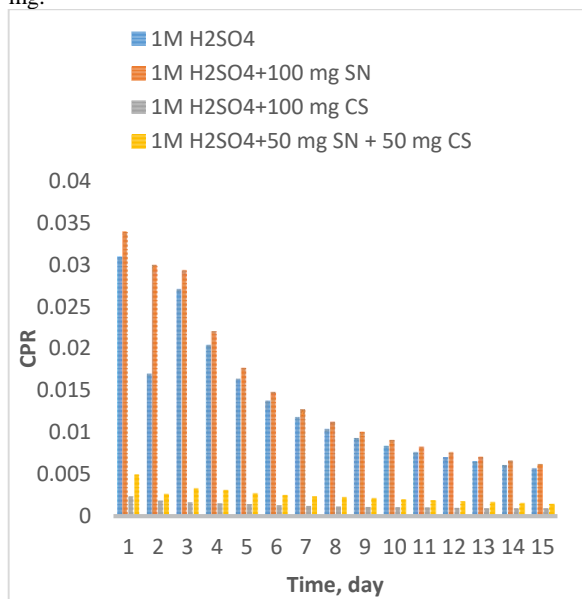


Fig. 7. CPR of carbon steel in 1 M H₂SO₄ solution with time at the presence and absence of sodium nitrate and ceftriaxone sodium inhibitors.

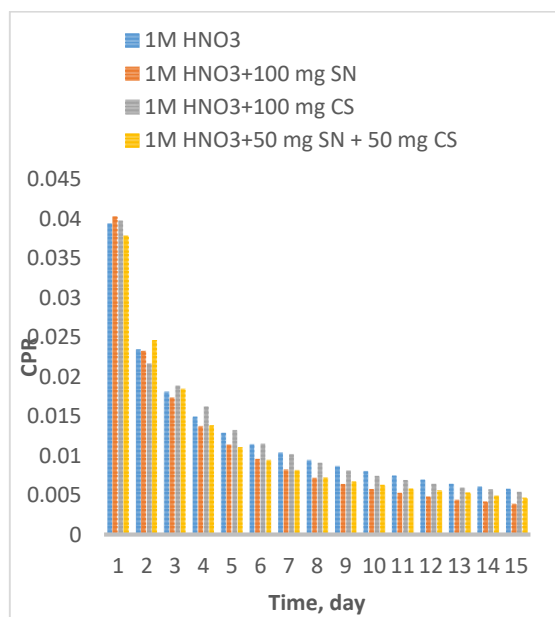


Fig. 8. CPR of carbon steel in 1 M HNO₃ solution with time at the presence and absence of sodium nitrate and ceftriaxone sodium inhibitors.

5. Conclusions

1- In this work, carbon steel was immersed in various acid environments (1 M of HCl, H₂SO₄, HNO₃), the results showed that the amount of lost weight increases rapidly for the first three days, and then the weight loss increases slowly during a period of 15 days.

2- For reducing the corrosion rate of carbon steel in different acidic environments, sodium nitrate and ceftriaxone sodium employed as corrosion inhibitors in the

present study. The results proved that the inhibitor (CS) was highly effective in lowering the corrosion speed of carbon steel while the inhibitor SN was ineffective in reducing the rate of corrosion of carbon steel in hydraulic acid (1 M).

3- The experimental data observed that the inhibitor (CS) was efficient in decreasing the corrosion speed of carbon steel in sulfuric acid environment (1 M). In addition, the results showed that adding the inhibitor SN led to increased lost weight of carbon steel slightly, and this indicates to the ineffectiveness of this inhibitor in protecting of carbon steel from the corrosion effects in this environment.

4- The results showed that the inhibitor SN was effective in reducing the lost weight of carbon steel while the inhibitor CS was ineffective in lowering the corrosion rate of carbon steel in 1 M of nitric acid environment.

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7. Nomenclatures

A	Surface area of the immersed sample (cm ²)
CPR	Corrosion penetration rate (mm/year)
CS	Ceftriaxone sodium
D	Metal density (g/cm ³)
HCl	Hydrochloric acid
HNO ₃	Nitric acid
H ₂ SO ₄	Sulfuric acid
K	Constant (87.6 ml/year)
SN	Sodium nitrate
T	Exposure time (hr)
W	Weight loss (mg)

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