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Red pepper extract as eco-friendly corrosion inhibitor for Carbon steel N80 in 1 M HCl: Electrochemical and surface morphological studies

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ABSTRACT

Four different concentrations of a plant inhibitor (dry red pepper) were created to investigate its effectiveness in preventing corrosion of a N80 carbon steel alloy used in petroleum pipe manufacturing. This was done in a 1M HCl acidic solution at various temperatures using electrochemical techniques and surface analysis. The inhibitor was discovered to be effective and efficient. As inhibitor concentrations rise, inhibition also increases because the protective layer becomes thicker. At a concentration of 200 ppm at a temperature of 298 K, the inhibition efficiency reached 92.69%. Corrosion rate decreases in the presence of the plant inhibitor. Despite the presence of the plant inhibitor, the corrosion rate in the acidic media (HCl 1M) was 15.58 mpy lower than when the inhibitor was absent. It reached 1.138 when it was. This is because of the reduction in the current density of Icorr. The polarisation results showed that the addition of the inhibitor reduced the corrosion current density of the steel. The Carbon N80 corrosion rate ranges from 34.22 µA/cm2 for the sample without inhibitor to 2.5 µA/cm2 for the sample including 200 ppm of inhibitor (C). The polarisation curves and electrochemical investigations suggest that the corrosion inhibitor exhibits both anodic and cathodic inhibition processes, indicating a mixed kind of inhibition. FT-IR technology analysed the inhibitor's chemical composition and revealed the presence of functional groups and heteroatoms. SEM was utilised to locate the inhibitor layer on the carbon steel alloy surface, which serves to prevent corrosion.

1. Introduction

Corrosion is a natural and spontaneous phenomenon that leads to the transformation of pure metals and their alloys into several stable forms, such as sulphides, oxides, hydroxides, etc., as a result of chemical or electrochemical interactions with the surrounding environment [1].Corrosion is also known as a chemical or electrochemical reaction between any specific material, usually metal, and its surrounding environment, which ultimately leads to the deterioration of the material and its

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properties [2]. The corrosion of metal compounds and alloys, as well as the deterioration of their properties, is a major industrial problem that is considered a worrying source of environmental pollution, especially in the carbon steel industry [3]. Most crude oil wells contain both hydrogen and oil, making corrosion control easier than with gas systems that only contain carbon dioxide. Corrosion becomes a problem when water exceeds 30% by volume. However, damping of downhole equipment must provide sufficient damping of the flow lines. A low oil speed can cause water to seep into the flow lines [4]. Corrosion The deterioration of a metal or its properties attacks every component at every stage of every oil and gas field's life. Corrosion, an adversary worthy of all our technology and research, affects everything from casing chains to production platforms. Because oxygen plays a significant role in corrosion, we classify the economic costs of corrosion into two categories: 1. The cost of direct losses is quantifiable. This includes costs associated with replacement, protection and corrosion prevention, and research and development. We cannot quantitatively evaluate the cost of indirect losses. Examples include loss of products due to spillage and fire, loss of revenue due to downtime, loss of equipment efficiency, product contamination, and environmental pollution [5] [1]. With the development of industrial technologies, new problems regarding corrosion constantly appear that require finding effective methods of protection. Given the different nature and types of corrosion that can occur and also the different conditions that help these different types to occur, this necessitates the use of several methods to protect against corrosion. There are four fundamental methods to combat and safeguard against corrosion, which involve implementing specific measures. These measures may pertain to the choice and application of metals and alloys, or to the medium or environment these materials encounter, as they may interfere with corrosion-causing environmental factors. These procedures include external intervention techniques that use specific electrochemical methods to protect materials. Combining two or more of these methods results in effective corrosion control [6]. Corrosion-resistant materials 2: Protection by paint 3. Cathodic protection and anodic protection 4: Protection by design 5: Protection by inhibitors [7] The ideal inhibitor has certain characteristics. The indicated inhibitors must be able to perform the following actions to avoid or reduce the corrosion of metal materials [7]. First, it must provide protection for the entire exposed area from corrosion attack. Second, it must maintain its suitability in working conditions (and at high temperatures). Application should not significantly delay the speed of wear. Third, the rust must be eliminated. I People often use inhibitors due to their ease of application and the benefit of on-site application. When choosing an inhibitor, there are many factors that determine it, including cost, ease of availability, and most importantly, environmental safety and its types [8]. Green inhibitors are classified as environmentally friendly inhibitors that are produced from renewable, low-cost, non-toxic sources and provide a high rate of inhibition efficiency [9]. They are represented by plants such as "extracts and oils," pharmaceutical liquids, ionic, etc. [10], These products are compatible with both humans and the environment due to the ease with which they can extract their components [11]. Natural product extracts contain many organic molecules that contain aromatic rings or functional groups such as hydroxyl, carbonyl, and carboxyl, as well as 2 NH, CO, and CHO, which are responsible for corrosion prevention properties. The metal surface absorbs these compounds, forming a protective layer. We use this type of inhibitor in acidic environments [12] [13]. The electrons of the aromatic ring's bonds and the free (unpaired) electronic pairs N, S, and O adsorb on the metal's surface, explaining the inhibition mechanism [14]. The inhibitor solution provides an unbonded electron pair to the N and S atoms while the metal is present. The metal's vacant orbitals form strong and stable bonds with the inhibitor on the metal surface. There are several methods for determining the rate of corrosion speed of metals or alloys, including the electrochemical method (Tafel plots), which is one of the most commonly used methods. We use the experimental cell and the Potentiostate device, a sensitive electronic device that modifies the metal's potential difference. To measure the intensity of the current, the cell consists of three electrodes: the working electrode (which is the electrode carrying the carbon steel model), the reference electrode, such as the calomel electrode or the silver electrode, and the auxiliary electrode. This method involves plotting the voltage as a function of the current (the logarithm of the current density). The plant used in this study: dry red pepper (C), the scientific name of which is Capsicuum annum, contains various biologically active compounds with potential health-promoting properties, such as carotenoids, capsaicinoids, phenols (flavonoids), vitamin C, vitamin E, and fatty acids. The color of ripe red pepper fruits is determined by the accumulation of various carotenoids [15]. Peppers are an excellent source of essential vitamins, minerals and nutrients and hence have great importance for human health. Peppers are also rich in a number of phytochemicals such as carotenoids, capsaicins, flavonoids, ascorbic acid and tocopherols. These compounds are known to prevent inflammatory diseases associated with oxidative damage to maintain optimal health [16]. In Ethiopia, red pepper is grown in many parts of the country, and is an important source of income for smallholder producers. Results showed that red pepper seeds were (on a dry weight basis): ash 3.05%, water 6.63%, oil 18.39%, protein 28.33 %, and total carbohydrates 43.60%. In addition, the results showed that the predominant fatty acids were linoleic, palmitic, and oleic acids. The highest and lowest linoleic acid content (76.54%) were found in pepper seed oils extracted with the help of microwave (76.54%) and Soxhlet (73.65%), respectively [17].

The aim of this study is to control corrosion caused by acidic solutions in industrial environments through:

1. Extraction and development of new natural inhibitors, readily available, non-toxic, inexpensive and environmentally friendly
2. Study of corrosion rates of low-carbon steel in a solution of (1M) hydrochloric acid HCl and different temperatures ranging from (298-318K).
3. The study focuses on the surface morphology of low-carbon steel using a scanning electron microscope (SEM).
4. Study or measure the rate of corrosion speed (CR) using the extrapolation Tafel plot method.
5. Calculate the inhibition efficiency (IE) and study the effect of concentration and temperature

Calculate the activation energy Ea and thermodynamic functions.

2. Experimental

2.1. Equipment and materials used

Deionized water and special high-purity chemicals were used for the analysis. We purchased the chemicals and solvents from BDH. The filter paper used is NEWSTAR type (15cm) of Chinese origin. We purchased SiC2 silicon carbide paper and Harmal seeds from a local store nearby. SOC provides an N-80 carbon steel alloy. The instrument used to measure the infrared spectra was an FT-IR-8400S Fourier transform infrared instrument. In the laboratories of the University of Tehran in the Islamic Republic of Iran. Use the MS:5973 gas chromatography-mass spectrometer-type selective grid mass detector to identify and analyze the chemical components present in plants. In the laboratories of the University of Tehran in the Islamic Republic of Iran. Use DMSO-d6 as a solvent. Using the instrument Bank Eieiktronkik Intelligent Controls is a Type M laboratory located in Germany and was established in 2007. This research aims to determine the corrosion rate of the N80 carbon steel alloy. The University of Tehran in Iran used a scanning electron microscope (SEM) to examine the morphological changes that occur on the surface of carbon steel alloys. Table 1 shows the proportions of carbon steel alloy components.

2.2. Alloys Use

This study utilised a carbon steel alloy known as Carbon Steel N-80, which was Prepare it by the South Oil Company. Table 2 displays the proportions of the components of this alloy [18].

Table 2. Components of carbon steel alloy

Element	**Fe**	**S**	**P**	**C**	**Mn**
Percentage (%)	98.39	0.06	0.05	0.3	1.2

2.3. Preparation of Corrosion Solution

The corrosion solution was prepared from concentrated hydrochloric acid (HCl) at a concentration of 1 M by the dilution method.

2.4. Prepare Red pepper extract

This fruit is readily accessible in Iraqi markets and is inexpensive. The Red pepper powder is finely ground, and then 10 g of it is weighed and placed in a 500-ml glass beaker. Subsequently, 300 ml of non-ionic water is added to the powder for the extraction procedure. The mixture is then heated to 70 degrees Celsius for 30 minutes with a mechanical stirrer. After cooling for two hours, the solution was filtered with filter paper. The filtrate was dried at 50°C for 48 hours. Therefore, a dry powder weighing 1.5 mg was acquired. The extract was then produced. The conventional method involved dissolving 1 gramme of the extract in 1000 millilitres of distilled water in a one-litre volumetric flask. A standard solution with a concentration of 1000 parts per million (ppm) was prepared, followed by the creation of various concentrations through dilution [19].

2.5. Determining corrosion rate using electrochemical Tafel Plot Extrapolation technique.

This method is utilised for measuring the corrosion rate efficiently and economically. It involves connecting the metal sample to an electrochemical cell, which is linked to a device providing detailed corrosion-related information displayed through curves on a computer screen. The logarithm of the current (I) change is shown by an icon on the screen. The device comprises a measuring cell with three electrodes: the working electrode in contact with the sample, the platinum auxiliary electrode, and the calomel reference electrode. This method involves monitoring the corrosion current and corrosion voltage and creating a diagram known as a Tafel curve. Once the model (a piece of clean carbon steel alloy) is cleaned and prepared, it is attached to the working electrode and placed inside the test cell. Both the auxiliary electrode and the reference electrode are positioned in the same cell after filling it with the correct volume of a (1M) hydrochloric acid solution. The cell is connected to the device, which inputs necessary data such as the start and finish of the effort, process time, and presents the findings in a Tafel chart graph. Subsequently, the device is halted, the cell's contents are emptied and purified, and the procedure is reiterated with a fresh carbon steel alloy. The cell is replenished with the corrosive solution containing varying quantities of the inhibiting chemical, and The measurement process is repeated again[20].

3. Results and discussion

3.1. Fourier transform infrared (FTIR) spectra

The primary process in corrosion inhibition involves the adsorption of inhibitors onto the metal surface to provide protection. FT-IR research is conducted to investigate the interaction between the adsorbed inhibitor and the carbon steel surface in an acidic environment of 1M HCl with the plant extract. The strength of inhibition is influenced by the molecular structure of the inhibitor. Red pepper extract (C) is analysed to determine the primary functional groups present. Table 2 and Figure 1 display the findings of the infrared spectra. The extracts display several bands, with the most significant ones being:

Table (2). Infrared spectra frequency values in units (cm^{-1}) of plant extract C

No	*υ(O-H)*	*υ(C-H)* *ali*	*υ(N-H)*	*υ(C=O)*	*υ(CH2)*
1	3415	2927	1650	1614	1402
No	*υ(C-O) ast*	*υ(C-N)*	*υ(C-Br)*	**υ(C=N)**	(C=C) υ
2	1246	1076	634	1614	1580

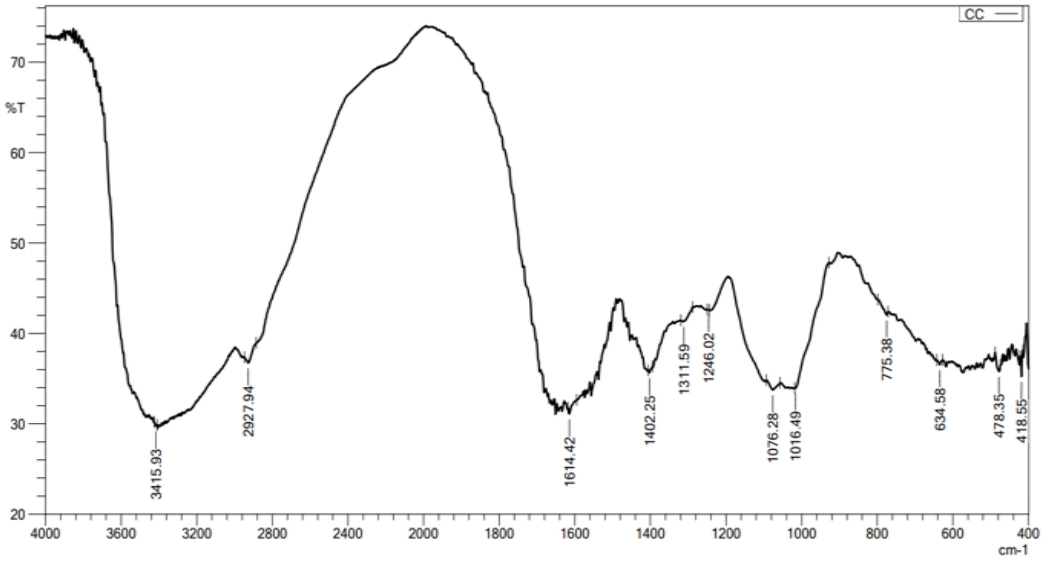


Fig 1. Infrared spectrum of the inhibitor (**C**)

3.2. Mass- Spectrum Extracted Plant (GC - mass)

GC-MASS spectroscopy was conducted on plant extract (**C**) to identify the chemical compounds present in it and explain the mechanism of inhibition of the extract. The table (3) represents the key components that appeared in the plant inhibitor (**C**). Figure (2) represents a spectrum GC-mass spectrum

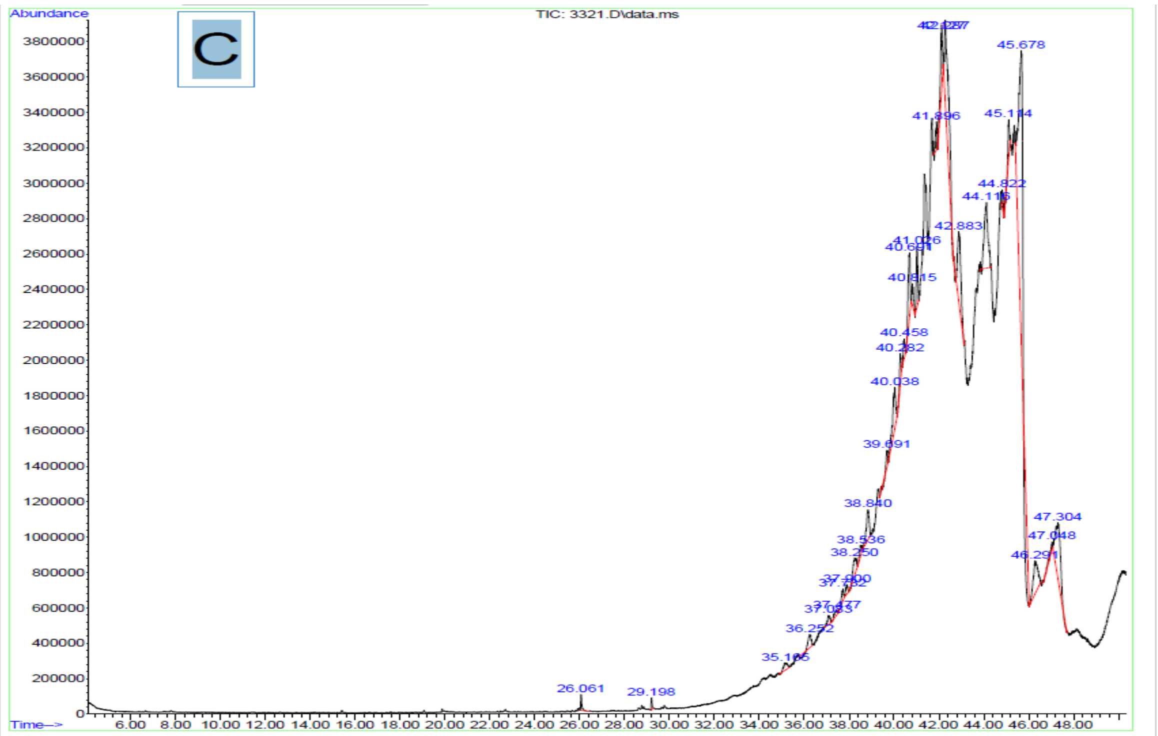


Fig 2. represents the mass spectrum of the aqueous extract of the plant (**C**).

Table 3. represents the most important components that appeared in the plant inhibitor (**C**).

c

No	RT (min)	Area%	Name	Quality	CAS Number
1	**26.061**	**0.35**	**Pentadecanoic acid, 14-methyl-, methyl ester**	**98**	**005129-60-2**
2	**29.2**	**0.23**	**Octadecanoic acid, methyl ester**	**98**	**000112-61-8**
3	**36.251**	**0.57**	**Dipyrazino[2,3-b:2',3'-i][1,4,8,11]tetraaza**	**50**	**120757-23-5**
4	**37.73**	**0.47**	**1 2'-anilino-5'-bromo-2-carbometho**	**72**	**108694-39-9**
5	**38.249**	**0.98**	**1 METHYL ESTER OF 4-CHLORO-3-(2-CH...**	**80**	**066385-22-6**
6	**38.534**	**2.13**	**2'-anilino-5'-bromo-2-carbomethoxybenzophenone**	**86**	**108694-39-9**
7	**40.693**	**20.64**	**Oleic acid, eicosyl ester**	**64**	**000000-00-0**
8	**45.668**	**61.14**	**Stearin, 1,3-dipalmito-2-**	**90**	**108694-39-9**

3.3. Study of the efficiency of aqueous extract (C) as a corrosion inhibitor using the Tafel curve method

The study examined the effectiveness of the aqueous extract (C) as a corrosion inhibitor for carbon steel in a 1 M acidic solution of HCl at temperatures of 298 K, 308 K, and 318 K. The research was conducted with and without the plant inhibitor at various concentrations using the complementary polarisation method. The study's findings are as follows:

a) Polarisation curves, or what are called Tafel lines

We aim to investigate the mechanism by which the aqueous solution (C) prevents corrosion in carbon steel by analysing the anodic and cathodic reactions through the electrochemical technique known as the polarisation curve method, both with and without varying concentrations of the plant extract (C). The corrosion current (I corr), corrosion voltage (E corr), cathodic (βc), and anodic (βa) Tafel constants were determined using the data presented in Figures (3)-(5), and Table 4. It was observed that when adding plant inhibitors (C) in different concentrations, the shape of the Tafel curve does not change much as it tends to reduce the reaction occurring at the anode and cathode equally, meaning that the inhibitors affect the anodic and cathodic reactions, which indicates that they are of the mixed type [21]. This means that adding the inhibitor to the acidic solution hinders the anodic reaction and delays the process of hydrogen gas release during the cathode reaction. Through its adsorption on the metal surface, inhibitor C reduces the number of active reaction sites that participate in the corrosion reaction [22]. It was also observed that when adding the inhibitor C in different concentrations, the shape of the Tafel curve does not change much, as it tends to reduce the reaction occurring at the anode and cathode electrode in an approximately equal manner, meaning that the inhibitors affect the anodic-cathode reaction with approximately the same effect, which indicates that the inhibitors are of the mixed type [21]. The percentage of inhibition efficiency (IE%) can be calculated using equation (1) [23]:

$$\%\,\mathrm{IE} = \left(\frac{\mathrm{I^{\circ}corr} - \mathrm{Icorr}}{\mathrm{I^{\circ}corr}}\right) \times 100) \text{ ------------------------------------ } (1)$$

The area of the part covered by the damper (Ө) was calculated according to equation (2):

$$\Theta = \left(\frac{\mathrm{I^{\circ}corr} - \mathrm{Icorr}}{\mathrm{Icorr}}\right) \text{ --- } (2\,)$$

Where Icorr and Icorr represent the corrosion current densities in the absence and presence of the inhibitor, respectively, it is noted that the values of the corrosion current densities for the blank solution of plant extracts used as inhibitors are more than the values of the corrosion current densities in the presence of inhibitors with the temperature constant. The value of the corrosion current density decreases with increasing inhibitor concentrations at each temperature, which indicates that adding the inhibitor hinders the corrosion attack. This suggests that the addition of an inhibitor hinders the corrosion attack. Although there are anodic and cathodic curves when adding an inhibitor, the slope of the anodic curve is slightly greater compared to the cathodic curve. This means that the kinetics of both the dissolution reaction of carbon steel and the release of hydrogen change when inhibitors are added. The most affected factor is the dissolution of steel. Changes in the values of βa and βc are also caused by other kinds of negative ions in the solution that take part in the adsorption process [1].

b) Corrosion Rate (CR)

The rate of corrosion speed (CR) was calculated in units (mpy) in acidic media in the absence and presence of different concentrations of plant extracts as inhibitors and within the temperature ranges (308,318298,) K. The relationship (3) yielded the value of the corrosion speed rate (CR) [24].

$$\mathrm{CR} = \mathrm{K} \times \frac{\mathrm{Icorr}}{\rho} \times \mathrm{E.W} \quad \underline{\hspace{6cm}} \; (3)$$

It represents:

CR/corrosion rate in units (mpy)

I corr /corrosion current density in the presence of the inhibitor in units (µA/Cm2)

EW / equivalent weight of metal or alloy (E. WFe =27.8 gm / mol)

ρ /density of the metal or alloy (ρFe = 7.86 g/cm3)

K / constant value equal to (0.1288 mpy g / µA cm).

Equation (3) shows the dependence of the corrosion speed CR on the corrosion current density (Icorr)

Table (4) shows that the rate of corrosion speed (CR) is relatively high in the absence of inhibitors, and that this increase is due to the disintegration of the metal in the anodic reaction. The presence of the inhibitor reduces the rate of corrosion speed of the carbon steel alloy due to the decrease in the corrosion current on the surface of the alloy [25]. In addition, we find that the rate of corrosion speed (CR) decreases with an increase in the concentration of the plant inhibitor C used with constant temperature, while the rate of corrosion speed (CR) increases with increasing temperature and constant concentration, due to the collapse of weak physical adsorption towards increasing temperature [26].

c) Effect of Temperature

The inhibitory efficiency and corrosion speed rate (CR) data from Table (4) and Figure (6) can be summarised as follows:

- The increase in the values of the corrosion rate (CR) with increasing temperature and its decrease with increasing inhibitor concentration, as mentioned at the end of the previous paragraph.

- The values of inhibition efficiency %IE decrease with increasing temperature for the same concentration. It increases as the inhibitor concentration increases with constant temperature. This may be due to the process of physical adsorption of the inhibitor on the surface of carbon steel, which prefers a lower temperature, so the inhibition efficiency decreases as the temperature increases. While the inhibition efficiency increases with increasing temperature in chemisorption. [27]

Table 4. presents the polarisation curve data for the corrosion of carbon steel alloy N80 in hydrochloric acid solution (**1 M**) at temperatures ranging from 298 to 318 K, with varying doses of inhibitor (**C**).

Temp (K)	**Inhibitor Conc(ppm)**	**Ecorr (mV)**	**CR (mpy)**	**Icorr (μA/Cm2)**	**βa (mv/Dec)**	**βc (mv/Dec)**	**% IE**	**θ**
298	blank	-439.1	15.58	34.22	105.7	-128.6	0	0
308		-449.0	18.92	41.54	113.2	-159.1	0	0
318		-449.3	22.39	49.15	80.5	-59.4	0	0
298	50 ppm	-439.2	5.08	11.17	82.5	-154.9	67.35	0.67
308		-438.5	7.05	15.48	97.1	-141.4	62.73	0.62
318		-449.2	10.96	24.07	85.9	-116.9	51.02	0.51
298	100 ppm	-428.4	3.58	7.86	67.0	-131.7	77.03	0.77
308		-439.3	5.48	12.03	79.1	-135.9	71.03	0.71
318		-437.4	9.17	20.15	78.2	-161.1	59.00	0.59
298	150 ppm	-438.9	2.39	5.26	55.1	-126.1	84.62	0.84
308		-438.8	4.21	9.25	59.5	-126.1	77.73	0.77
318		-448.9	7.51	16.49	68.1	-137.2	66.44	0.66
298	200 ppm	-439.1	1.138	2.5	48.6	-97.7	92.69	0.92
308		-449.3	2.90	6.38	53.8	-115.3	84.64	0.84
318		-449.1	4.92	10.81	46.6	-80.2	78.00	0.78

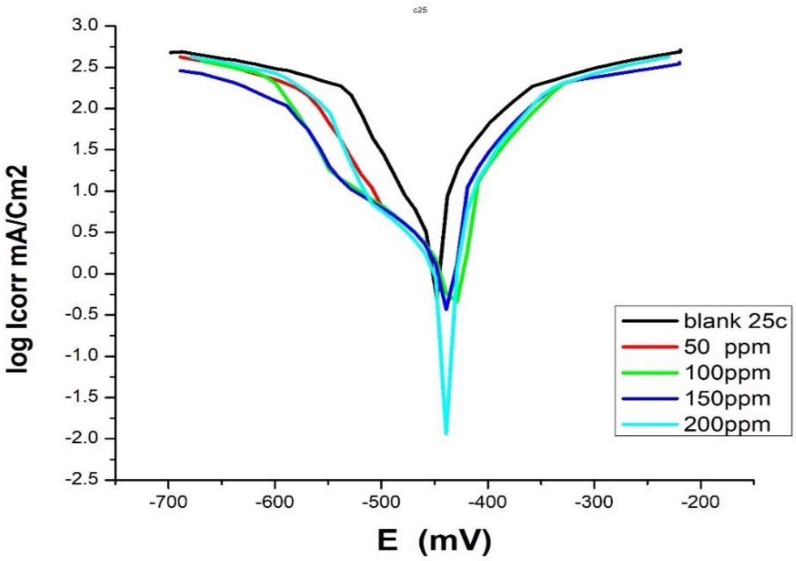


Fig 3. Polarization curves for corrosion of carbon steel with different concentrations of inhibitor (C) at 298 K

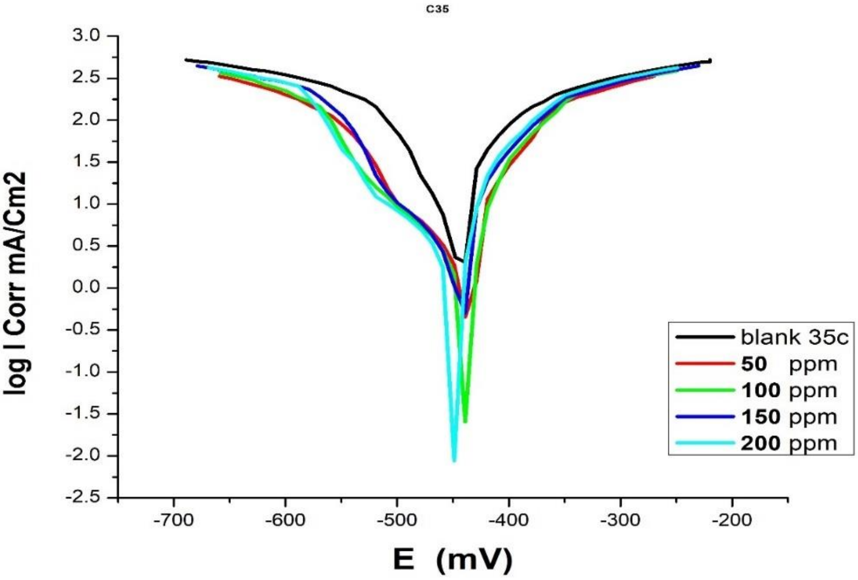


Fig 4. Polarization curves for corrosion of carbon steel with different concentrations of inhibitor (C) at 308 K

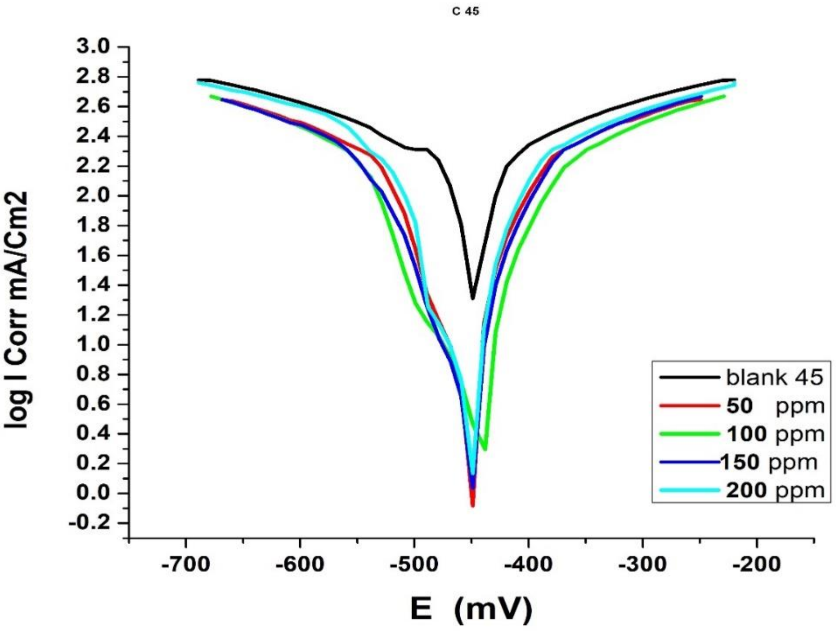


Fig 5. Polarization curves for corrosion of carbon steel with different concentrations of inhibitor (C) at 318 K

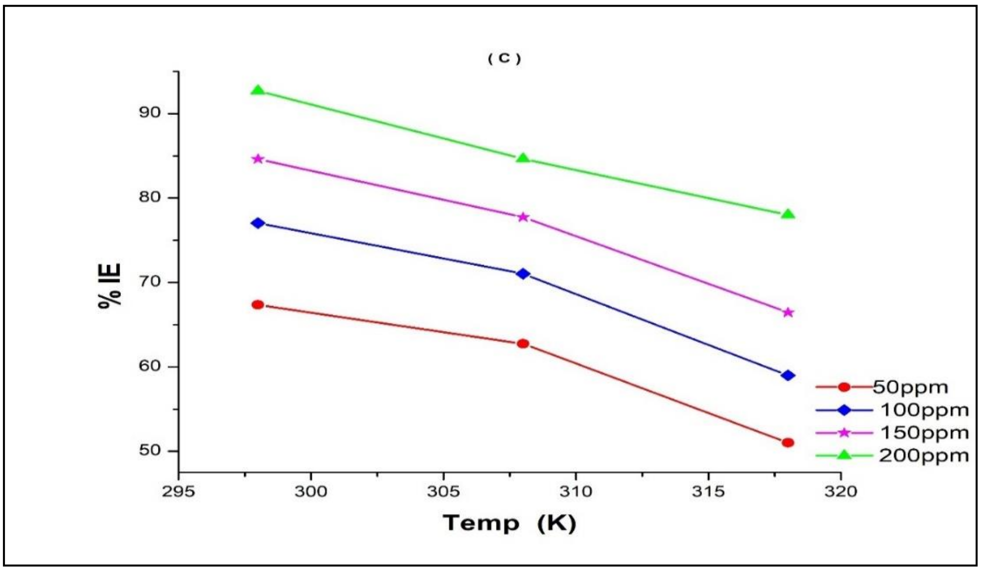


Fig 6. The relationship between inhibition efficiency and temperature in acidic solutions with different concentrations of inhibitor (C) and for a range of temperatures (298 – 318 K)

d) The study focuses on the kinetic variables of the corrosion process.

We traced the kinetics of the corrosion reaction and studied the effect of temperature on a carbon steel alloy in a corrosive medium of hydrochloric acid at a concentration of 1 M, both in the absence and presence of inhibitors, and at specific concentrations. We also calculated a number of thermodynamic functions for the adsorption process to understand the behavior and strength of the specific inhibitor's adsorption on the alloy's surface. We studied the effect of temperature on corrosion speed within the experimental temperature range using the Arrhenius equation (4) [28].

Log Icorr=Log A- Ea/ (2.303 RT) ____________________ (4)

The equation (Icorr) represents the corrosion current, (A) the Arrhenius constant, (Ea) the activation energy, and (T) the temperature. (R) gas constant. 8.3143 (J. K-1. Mol-1) Using Equation (3) to find the activation energy (Ea), we can draw a straight line between the values of Log Icorr versus the values of 1/T as shown in Figure (7). We used the transition state equation (5) to figure out the kinetic functions of the activated complex. These included the enthalpy of activation (ΔH^*) and the entropy of activation (ΔS^*). These functions show how the activated complex is formed for the corrosion process in acidic media [29].

$$\text{Log}\ \frac{\text{Icorr}}{\text{T}} = \text{Log}\ \frac{\text{R}}{\text{N h}} + \left(\frac{\Delta\ S^*}{2.303}\right) - \left(\frac{\Delta\ H^*}{2.303\ \text{RT}}\right) \text{----------------(5)}$$

Figure 8. shows a linear relationship with a slope of ((-ΔH^*)/ (2.303 R)), allowing for the determination of the value of (ΔH*). The intercept is also indicated. [Log$\frac{\text{R}}{\text{hN}} + (\frac{\Delta S^*}{2.303\ \text{R}})$] Through which the value of (ΔS*) is found

After finding the values of (ΔS *) and (ΔH *), ΔG^*can be calculated according to equations (6) [30].

$$\Delta G^* = \Delta H^* - \text{T}\ \Delta S^* \quad \text{--- (6)}$$

Table (5) shows the values of (Ea.), (ΔS*), (ΔH*), and (ΔG*) for the corrosion of carbon steel in hydrochloric acid (1M) in the presence and absence of the inhibitor, as an increase in activation energy (Ea.) is observed. For the corrosion process in the presence of the inhibitor compared to its absence, which explains the formation of a thin layer of inhibitor that is adsorbed on the surface of the alloy used, it is of a physical nature (electrostatic) [31]. This corresponds to the decrease in the efficiency of inhibition with increasing temperature, which means that a physical adsorption process occurs in the first stage, followed by the desorption process. Chemist [32]. Positive values of the enthalpy of activation (ΔH^*) also indicate that the nature of the reaction is endothermic, that is, chemical adsorption, and that it increases with an increase in the concentration of the inhibitor compared to its absence. This means that the dissolution reaction of cardboard steel in hydrochloric acid (1M) is an absorbent reaction, and the dissolution process is difficult [33]. The negative values of the activation entropy (ΔS^*) may be higher in the presence of the inhibitor, which increases with increasing concentration, which indicates less random adsorption of the reactants, which are transformed into active complexes adsorbed on the surface of the carbon steel alloy. High and positive values of the hard free energy of adsorption (ΔG*) indicate that the corrosion reaction on the alloy is not spontaneous [34].

Table 5. shows the values of some kinetic functions, such as ΔG*, ΔH*, ΔS*, and Ea, in acidic media and at temperatures between 298 and 318 K, with and without different concentrations of the inhibitor (**C**).

Comp.	Conc.	Ea. (KJ.mol^{1})	ΔS* (KJ. mol^{-1}. K^{-1})	Δ H* (KJ.mol^{-1})	Δ G* (KJ.mol^{-1})		
					298 K	308 K	318 K
HCL	1 M	14.27	-0.18	11.71	64.20	66	67.80
C	50 ppm	30.19	-0.13	27.63	67.07	68.39	69.72
	100 ppm	37.04	-0.11	34.48	67.93	69.06	70.18
	150 ppm	45.00	-0.08	42.44	68.90	69.78	70.68
	200 ppm	57.85	-0.05	55.28	70.58	71.09	71.61

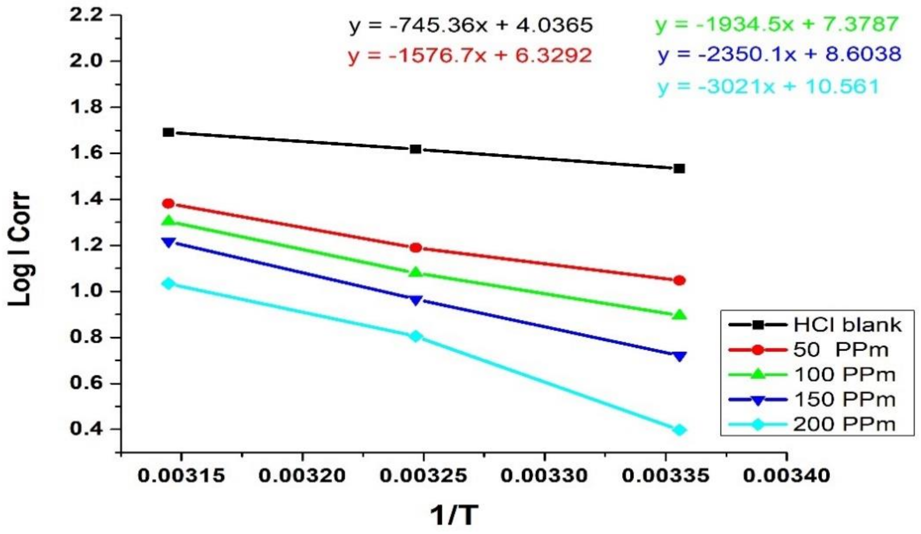


Fig 7. Arrhenius relationship in the presence and absence of inhibitor (C) within the temperature range of 298–318 K

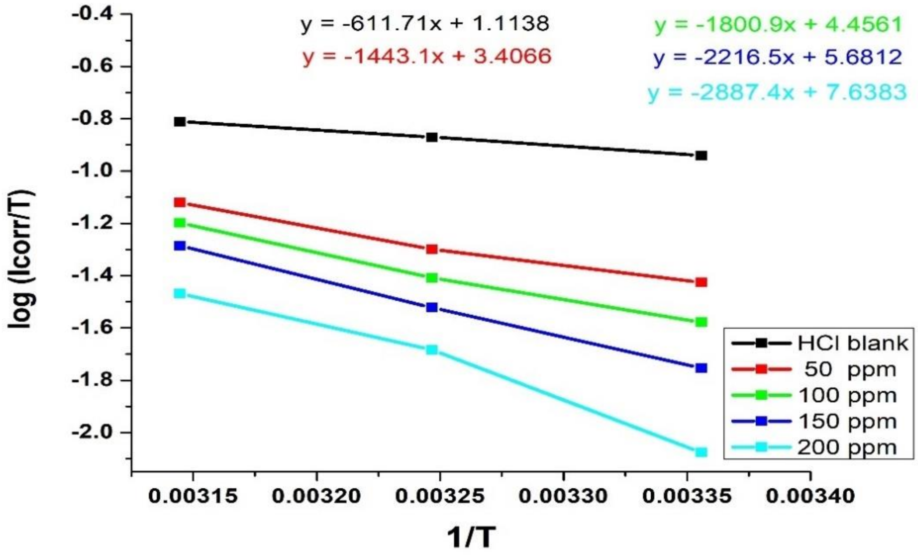
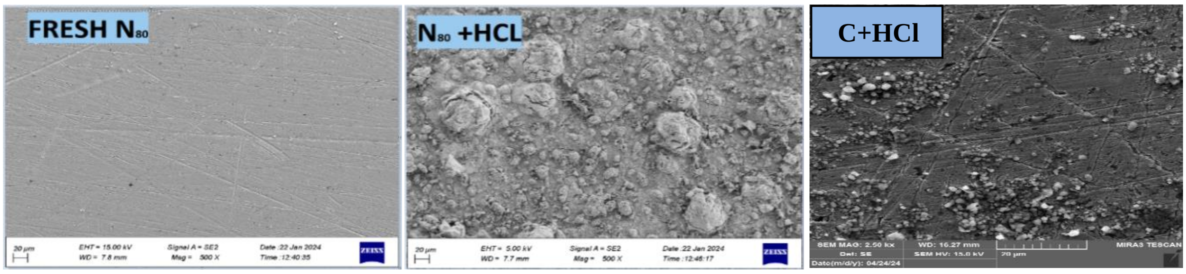


Fig 8. The relationship between the transition state and the calculation of enthalpy and entropy in the absence and presence of the inhibitor (C) and within the temperature range (298–318 K)

3.4. Study of the surface morphology of a carbon steel alloy using scanning electron microscopy (SEM) technology

SEM technique was utilised to examine the morphological alterations on the surface of the carbon steel alloy. The SEM images of the carbon steel surface reveal the absence of corrosive acidic conditions. Image No. **1** demonstrates that the alloy's surface remains smooth and undamaged in the absence of the corrosive medium, even with the presence of the optimal inhibitor concentration (200 PPM) at 25°C during a 1-hour immersion period. Microscopic image No. (**2**) shows severe damage and deformation due to corrosion by HCl acid in the absence of inhibitors. In contrast, microscopic image No. (**3**) in **Figure (9)** displays the presence of an inhibitor (**C**) on the surface, which prevents such damage. The surface is evidently smooth with minimal damage or deformation. The high level of protection on the surface of carbon steel is achieved through the creation of a thin layer resulting from the chemical or physical adsorption of inhibitors.



(1) **(2)** **(3)**

Fig 9. Technical images (SEM) of carbon steel in the three cases

3.4. Explanation of inhibition mechanisms

Specific aqueous plant extracts impede the process of metals separating when they are immersed in corrosive substances. The substance's ability to suppress corrosion is due to its organic components, which can adsorb onto the metal surface and create an insulating layer. The effectiveness of these materials is attributed to the presence of atoms or groups with strong electronegativity. The compounds under investigation may include atoms (N, O, S) or groups (C=N, N=N, C=C), coupled with the presence of a π system, which refers to an electron provided by the aromatic rings. Therefore, one possible route that might clarify the mechanism of the compounds being studied for inhibition is as follows [35]:

1. One possibility is that the aromatic ring of the inhibitor could interact with the atoms on the metal surface. This could cause the π electrons of the aromatic ring to interfere with the d orbitals of the metal surface. The interaction creates a protective barrier on the metal surface, which hinders the penetration of corrosive chemicals and reduces the rate of chemical corrosion [36]. This is illustrated in Figure 10.

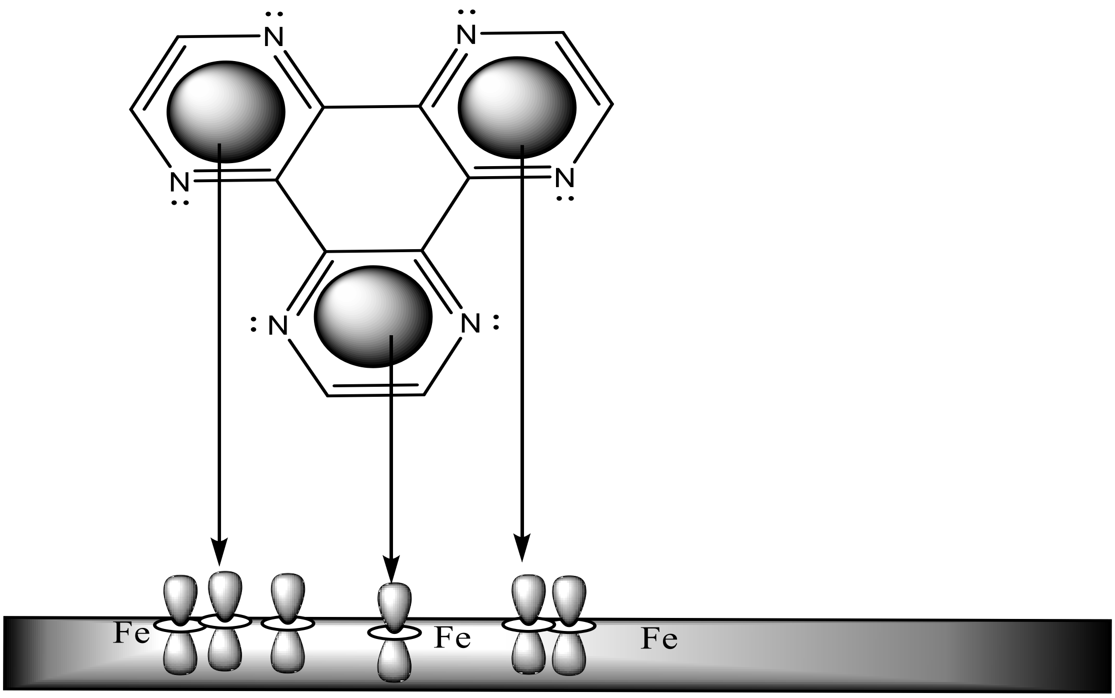


Fig 10. The overlap of the π electrons of the aromatic ring present in the compound Dipyrazino [2,3-b:2',3'-i] [1,4,8,11] Tetraaza represents one of the inhibitor compounds (**C**) with orbitals d present in iron atoms.

2. The plant inhibitor can chemically adsorb onto the metal surface by interacting with the unpaired electron pairs on the nitrogen (N) and oxygen (O) atoms. This interaction can take place through coordination, ionic, or covalent interactions with the unoccupied or partially occupied d-orbitals in the metal. Consequently, the inhibitor molecules stick to the surface. The alloy efficiently prevents the corrosive medium from reaching it, leading to a reduction in chemical corrosion [37], as seen in figure 11.

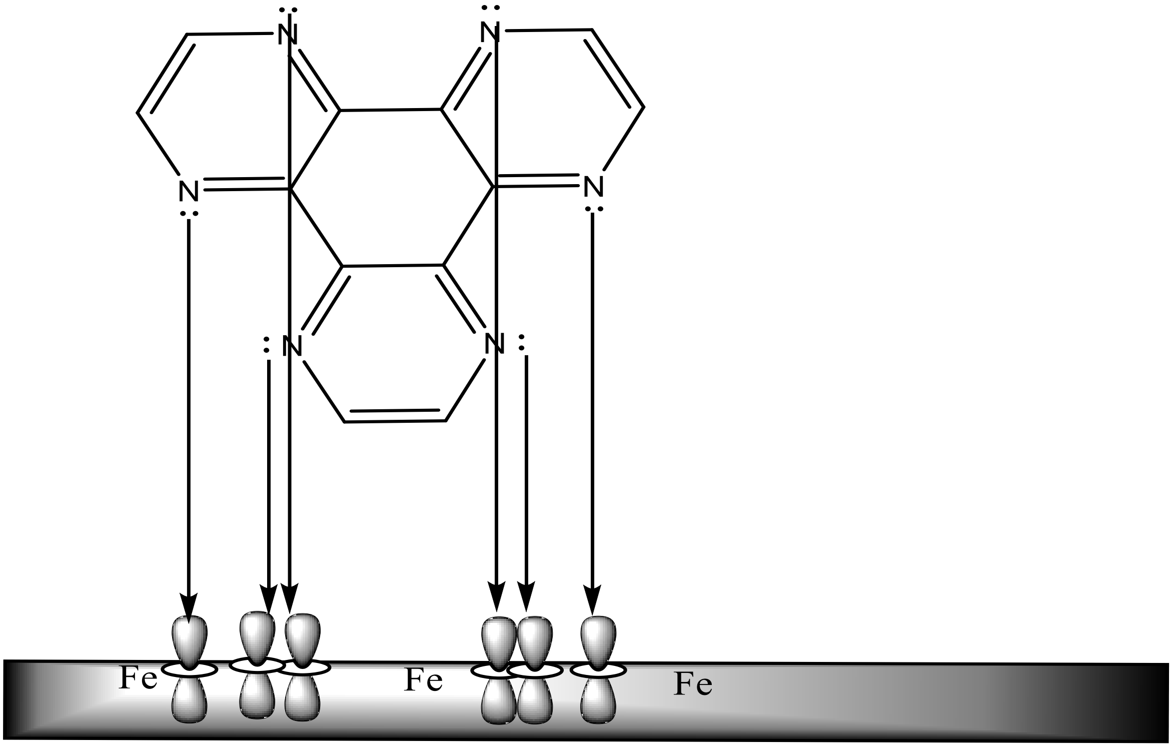


Fig 11. Interference between the free electronic pairs on the nitrogen atoms (N) present in the compound Dipyrazino [2,3-b:2',3'-i] [1,4,8,11] tetraaza with the d-orbitals in the iron atoms. Carbon steel surface in damper (**C**)

4. Conclusions

The inhibitor (**C**) hinders the corrosion of N80 carbon steel in a 1M acidic solution of HCL. Electrochemical experiments indicated that **C** is effective as a corrosion inhibitor for N80 carbon steel. The most significant level of inhibition occurred at a temperature of 298 K with a concentration of 200 PPm. Electrochemical experiments indicated that inhibition efficiency reduces as temperature rises and increases with higher inhibitor concentration (**C**).

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مستخلص الفلفل الأحمر كمثبط تآكل صديق للبيئة للفولاذ الكربوني N80 في 1 مولاري من حمض الهيدروكلوريك: دراسات كهروكيميائية ومورفولوجية سطحية

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الملخص

تم تحضير أربع تراكيز من المثبط النباتي (الفلفل الأحمر الجاف) لدراسة فعالية التثبيط لتآكل سبيكة من الفولاذ الكربوني N80 والمستعملة في صناعة الانابيب النفطية في محلول حامضي من (HCl 1M) بدرجات حرارة مختلفة باستخدام التقنية الكهروكيميائية وتحليل السطح، وجد ان المثبط كان فعال وان كفاءة التثبيط تزداد بزيادة تركيز المثبط بسبب زيادة سمك الطبقة الواقية. و تم الوصول الى اعلى كفاءة تثبيط 92.69 عند تركيز(200 ppm) وبدرجة حرارة 298 K وان سرعة التآكل (CR) تقل بوجود المثبط النباتي(C). كانت سرعة التآكل في الوسط الحامضي (HCl 1M) بدون وجود المثبط (15.58mpy)، في حين أصبحت (1.138 mpy) بوجود المثبط النباتي المستخدم ويعود بسبب ذلك نقصان كثافة التيارIcorr وأيضا كشفت نتائج الاستقطاب في حال إضافة المثبط تنخفض كثافة تيار التآكل للفولاذ الكربونيN80 من ($\mu A/Cm^2$) 34.22 للعينة بدون مثبط الى ($\mu A/Cm^2$) 2.5 للعينة التي تحتوي على (200 ppm) من المثبط (C),وتشير منحنيات الاستقطاب و الدراسة الكهروكيميائية ان مثبط التآكل من النوع المختلط (آلية التثبيط الأنودية والكاثودية), أثبتت تقنية FT-IR وجود المجموعات الوظيفية والذرات المتغايرة في المثبط ودراسة التركيب الكيميائي له, وأيضا تم استخدام الفحص المجهري الالكتروني الماسح (SEM) من اجل التعرف على الطبقة الرقيقة التي تكونت من المثبط على سطح سبيكة الفولاذ الكربوني لحمايتها من التآكل.

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