

Cefuroxime: A Potential Corrosion Inhibitor for Mild Steel in Sulphuric Acid Medium

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ABSTRACT

An antibiotic drug, cefuroxime, is applied on the mild steel surface after the expiry date is over, in various concentrations in 0.5 M sulphuric acid solution, to study the corrosion inhibition by using the weight loss method at various temperatures ranging from 298 to 338 K. Potentiodynamic polarization techniques, i.e., polarization resistance and tafel polarization and Electrochemical Impedance Spectroscopy studies were done at room temperature and the results are in good agreement with the weight loss data. It has a high inhibition activity at lower temperatures. It is found that inhibition efficiency decreases with the increase in time and acid concentration. The activation parameters, Gibbs free energy, enthalpy, and entropy of the reaction were also calculated. It is postulated that the inhibition process is the physical adsorption of the cefuroxime on the metal surface. Langmuir's adsorption isotherm governs the adsorption process. It is also supported by the roughness calculation done by the atomic force microscopic technique. Prog. Color Colorants Coat. 16 (2023), 125-138© Institute for Color Science and Technology.

1. Introduction

Every year, industrialized and emerging nations spend billions of dollars on capital replacement and corrosion control measures for architecture [1, 2]. Latterly, as the world's focus and alertness have shifted toward environmental preservation and the dangers of utilizing synthetic substances on the ecological balance, the use of climate-friendly inhibitors to replace the older and more toxic corrosion inhibitors has increased [3-5]. Various methods are available to mitigate corrosion in different environments [6-9]. The uses of inhibitors are one of the most ubiquitous and cost-effective methods

of combating metal corrosion [10, 11]. The presence of inhibitors in tiny amounts in an aggressive media delays the corrosion by altering the metal surface due to the adsorption of the inhibitor layer. Due to the lower toxicity and environmental friendliness, organic inhibitors have been widely used in cleaning solutions for industrial equipment, as components in pre-treatment compositions, and acidification of oil wells [12, 13]. Organic compounds, which have a wide range of applications and have been widely researched and utilized as corrosion inhibitors, frequently contain oxygen, nitrogen, and phosphorus atoms, along with

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multiple bonds.

Several studies on using medicines as corrosion inhibitors for various metals in different media have been conducted and reported as less toxic corrosion inhibitors [14-16]. Many pharmaceutically active drugs such as Cefadroxil, Floxacillin, and Streptomycin have been reported as low toxic and benign corrosion inhibitors [14-16]. Pharmaceutically active compounds are employed as corrosion inhibitors because they contain many functional groups and unsaturation as adsorption centers. They are biodegradable and can be cheaply manufactured and purified. In the present investigations, using weight loss and electrochemical studies, the corrosion inhibition behavior of cefuroxime was investigated on mild steel in sulphuric acid at various temperature ranges. Cefuroxime is an oral cephalosporin antibiotic of the second generation. It is an orally effective acetoxyethyl ester prodrug of cefuroxime [17]. The following facts influenced the choice of this inhibitor:

- They can efficiently adsorb on the metal surface because of the presence of different types of heteroatoms as reactive centers.
 - They can easily dissolve in water.
 - They pose no health risks and have a wide range of biological and pharmacological applications [18].
- Thus, using cefuroxime as a corrosion inhibitor is risk-free. The detailed chemical structure of cefuroxime is reported in Figure 1.

2. Experimental

2.1. Inhibitor

Cefuroxime is procured from a local pharmacy and stored until the expiry date, after which a stock solution of this chemical is prepared in the acidic solution made by double distilled water. This stock solution was utilized for all the experiments performed by dilution method for the appropriate concentration of inhibitors.

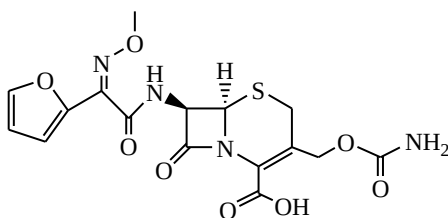


Figure 1: Chemical structure of cefuroxime.

2.2. Corrosion measurements

Corrosion measurements performed on mild steel surfaces that have been cleaned with different grades of emery paper, rinsed with distilled water, degreased with acetone and dried in a hot air blower for experiments.

2.3. Weight loss measurements

Weight loss was measured on a 10 cm² rectangular sheet of mild steel in 100 mL acid solution in the absence and presence of different inhibitor doses. Experiments also were conducted at different temperatures, exposure times, and acid concentrations. All tests were carried out, and the average values were used to calculate the various parameters. The percentage of Inhibition efficiency, corrosion rate, surface coverage, and adsorption characteristics were computed according to the literature (Eqs. 1 and 2) [19, 20].

$$I.E.(\%) = \frac{W_o - W_i}{W_o} \times 100 \quad (1)$$

$$\theta = \frac{W_o - W_i}{W_o} \quad (2)$$

W_o and W_i represent the weight loss of metal in the absence of inhibitor and in the presence of inhibitor concentration, respectively.

Thermodynamic and adsorption isotherm parameters were computed with the weight loss data calculated from this study.

2.4. Electrochemical studies

Electrochemical measurements were performed with a Gamry instrument, Galvanostat/ potentiostat ESA400. It was controlled by the Echem analyst version 5.50 software program. This potentiostat is linked to a double-walled one-compartment cell with three electrodes. Calomel electrode was used as reference electrodes, Platinum as the counter electrode, and metal sample used for testing as a working electrode. The surface area of the working electrode exposed to the electrolyte was 1 cm². Potentiodynamic polarisation parameters (polarisation resistance, tafel polarization), and electrochemical impedance spectroscopy (EIS) measured using a three-electrode assembly. The influence of temperature on inhibitor efficiency was thermostatically regulated in a temperature range of 293 to 338 K.

3. Results and Discussions

3.1. Weight loss studies

The weight loss data on different temperature ranges, namely weight loss (in mg), inhibition efficiency (%), corrosion rates (Cr, in mmpy), and surface coverage (Θ), were reported in Table 1. As per the data represented in Table 1, inhibition efficiency (%) increases with an increase in inhibitor concentration 0 to 4.5×10^{-4} M. Table 1 also displays that when the

temperature of the 0.5 M H_2SO_4 solution was varied from 298 K to 338 K, the inhibitor efficiency was always highest at 4.5×10^{-4} M inhibitor percentage. Figures 2 and 3 show that the increase in the inhibitor concentration with the change in the temperature against the inhibition efficiency a corrosion rate, respectively, and it is found that at all studied temperature parameter inhibition efficiency increases with an increase in temperature, whereas corrosion rate decreases with increase in inhibitor concentration.

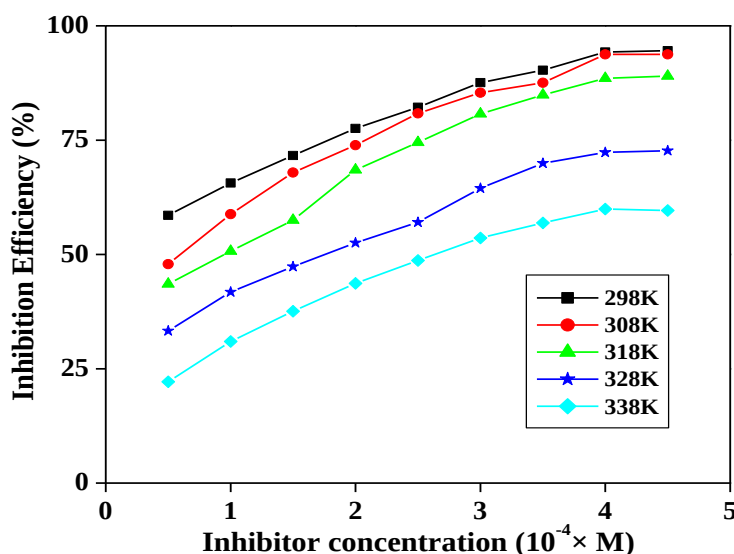


Figure 2: Inhibitor efficiency graph of various concentrations of cefuroxime at different temperatures.

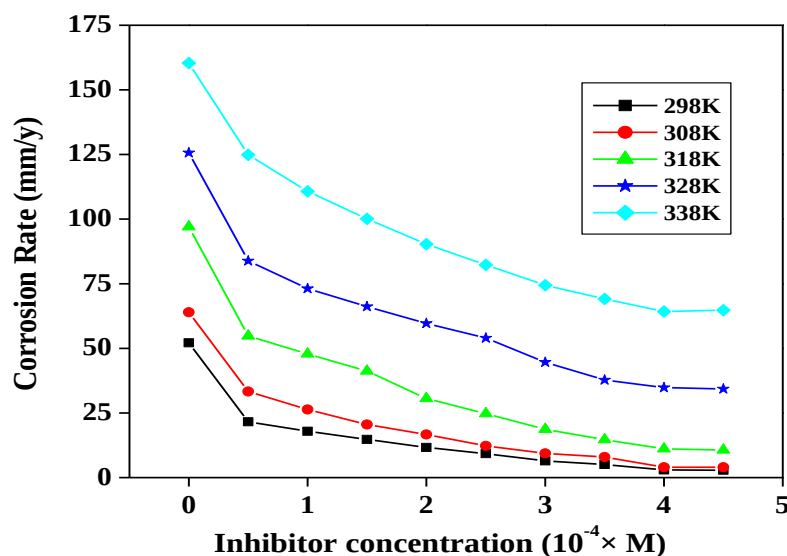


Figure 3: Corrosion rate graph of various concentrations of cefuroxime at different temperatures.

Table 1: Weight loss data of the cefuroxime with mild steel at various temperature ranges.

Temperature (K)	Concentration of inhibitor (M)	Weight loss (in mg cm ⁻¹)	Inhibition efficiency (η) (%)	Corrosion rate (C _r) (mm/y)	Surface coverage (θ)
298	Blank	14.00	-	52.14	-
	0.5×10 ⁻⁴	5.80	58.57	21.60	0.586
	1.0×10 ⁻⁴	4.81	65.64	17.91	0.656
	1.5×10 ⁻⁴	3.97	71.64	14.79	0.716
	2.0×10 ⁻⁴	3.14	77.57	11.69	0.776
	2.5×10 ⁻⁴	2.49	82.21	9.27	0.822
	3.0×10 ⁻⁴	1.74	87.57	6.48	0.876
	3.5×10 ⁻⁴	1.36	90.29	5.07	0.903
	4.0×10 ⁻⁴	0.80	94.29	2.98	0.943
	4.5×10 ⁻⁴	0.76	94.57	2.83	0.946
308	Blank	17.17	-	63.95	-
	0.5×10 ⁻⁴	8.95	47.87	33.33	0.479
	1.0×10 ⁻⁴	7.07	58.82	26.33	0.588
	1.5×10 ⁻⁴	5.51	67.91	20.52	0.679
	2.0×10 ⁻⁴	4.48	73.91	16.69	0.739
	2.5×10 ⁻⁴	3.29	80.84	12.25	0.808
	3.0×10 ⁻⁴	2.51	85.38	9.35	0.854
	3.5×10 ⁻⁴	2.14	87.54	7.97	0.875
	4.0×10 ⁻⁴	1.07	93.77	3.99	0.938
	4.5×10 ⁻⁴	1.07	93.77	3.99	0.938
318	Blank	26.05	-	97.02	-
	0.5×10 ⁻⁴	14.71	43.53	54.79	0.435
	1.0×10 ⁻⁴	12.84	50.71	47.82	0.507
	1.5×10 ⁻⁴	11.07	57.50	41.23	0.575
	2.0×10 ⁻⁴	8.21	68.48	30.58	0.685
	2.5×10 ⁻⁴	6.64	74.51	24.73	0.745
	3.0×10 ⁻⁴	5.02	80.73	18.70	0.807
	3.5×10 ⁻⁴	3.94	84.88	14.67	0.849
	4.0×10 ⁻⁴	2.99	88.52	11.14	0.885
	4.5×10 ⁻⁴	2.86	89.02	10.65	0.890

Table 1: Continue.

Temperature (K)	Concentration of inhibitor (M)	Weight loss (in mg cm ⁻¹)	Inhibition efficiency (η) (%)	Corrosion rate (C_r) (mm/y)	Surface coverage (θ)
328	Blank	33.74	-	125.66	-
	0.5×10^{-4}	22.51	33.28	83.84	0.333
	1.0×10^{-4}	19.64	41.79	73.15	0.418
	1.5×10^{-4}	17.77	47.33	66.18	0.473
	2.0×10^{-4}	16.01	52.55	59.63	0.525
	2.5×10^{-4}	14.49	57.05	53.97	0.571
	3.0×10^{-4}	11.98	64.49	44.62	0.645
	3.5×10^{-4}	10.14	69.95	37.77	0.699
	4.0×10^{-4}	9.34	72.32	34.79	0.723
	4.5×10^{-4}	9.21	72.70	34.30	0.727
338	Blank	43.06	-	160.38	-
	0.5×10^{-4}	33.52	22.16	124.84	0.222
	1.0×10^{-4}	29.73	30.96	110.73	0.310
	1.5×10^{-4}	26.88	37.58	100.11	0.376
	2.0×10^{-4}	24.25	43.68	90.32	0.437
	2.5×10^{-4}	22.1	48.68	82.31	0.487
	3.0×10^{-4}	19.98	53.60	74.42	0.536
	3.5×10^{-4}	18.56	56.90	69.13	0.569
	4.0×10^{-4}	17.26	59.92	64.28	0.599
	4.5×10^{-4}	17.39	59.61	64.77	0.596

The present study found that at 298 K, the maximum inhibitor efficiency was reported to be 94.57 %, which appears to be decreasing with increasing temperature change in the 4.5×10^{-4} M inhibitor mixture. So 4.5×10^{-4} M inhibitor percentage was discovered to be the best-suited amount in a mixture to provide 94.57 % inhibitor efficiency at 298 K temperature on mild steel surface in 0.5 M H₂SO₄ solution. The molecular adsorption of cefuroxime causes this inhibitory effect at the metallic surface. Adsorption occurs because of the presence of both π -electrons and non-bonding electron pairs.

3.2. Effect of immersion time

The effect of immersion time on corrosion inhibition property of mild steel in the presence of inhibitor has been studied from 3 to 8 hours durations. The calculated inhibition efficiency against the time graph has been

reported in Figure 4. It is evident from Figure 4 that with the increase in time duration of contact with a corrosive environment, inhibition efficiency decreases. This may be due to the desorption of the inhibitor film formed with the longer exposure in an acidic environment. Such results find when the physical adsorption of the inhibitor predominates on the mild steel surface. [21, 22]

3.3. Effect of acid concentration

Weight loss studies were also conducted at various acid concentrations (0.5 to 3.0 M) at optimum inhibitor concentration, and the results of inhibition efficiency are reported in Figure 5. It is evident from Figure 5 that the sharp decrease in the inhibition efficiency with the increase in acid concentration is due to the dissolution of the inhibitor film in highly acidic media [21, 22].

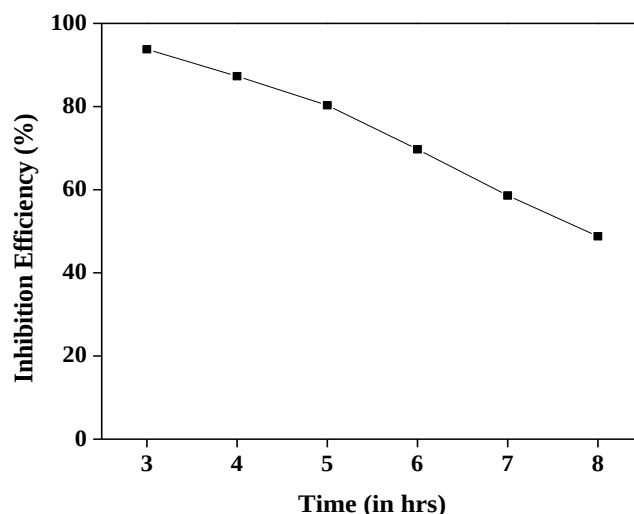


Figure 4: Inhibition efficiency graph at different time intervals at an optimum inhibitor concentration.

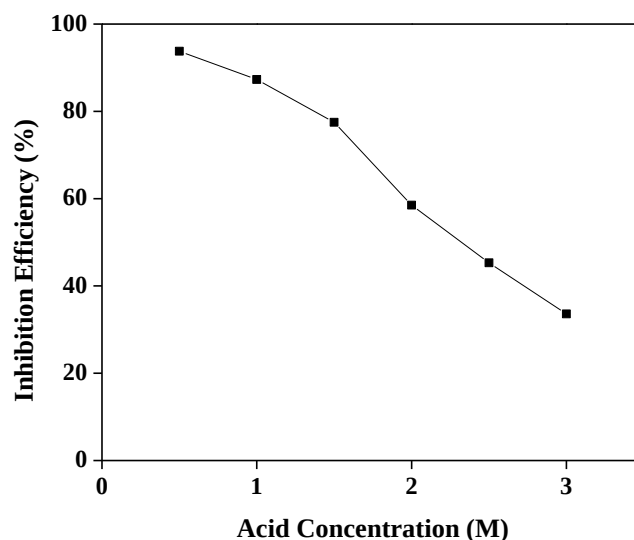


Figure 5: Inhibition efficiency graph at different acid concentration ranges at an optimum inhibitor concentration.

3.4. The effect of temperature on the adsorption isotherm

It was evaluated using the experimental data for the isotherms via C_{inh} versus C_{inh}/θ graph [23, 24]. It is found that, similar to other pharmaceutically active compounds, cefuroxime is also best fitted with Langmuir adsorption isotherm. Langmuir adsorption isotherm was considered appropriate as it shows the approximately linear regression coefficients (R^2) representation. It has been reported that various temperature ranges from 298 to 338 °K are shown in Figure 6. Table 2 shows that the R^2 value ranges from 0.99666 to 0.99496, increasing the temperature range of the combination from 298-338 K. Because of p electrons, quaternary atomic nitrogen, the group of

amines, and a bigger molecular size with the presence of electrons, quaternary nitrogen atom, cefuroxime has proved to be ideally appropriate for 4.0×10^{-4} M at a temperature of 298 K at the mild steel surface. This behavior might be due to inhibitor desorption. The calculated $-\Delta G_{ads}$ value, shown in Table 2, is between 31.43 and 38.98 KJ mol^{-1} ; the value of $-\Delta G_{ads}$ up till 20 KJ mol^{-1} the adsorption was assumed to be physisorption which means that the inhibitor adsorption on the metal surface is physical. The negative ΔG_{ads} values are compatible with the spontaneity of the adsorption process and cohesion of the adsorbed layer on the mild steel surface. As a result, cefuroxime adsorption on mild steel surfaces is spontaneous, supporting the physical adsorption

process [25].

The equilibrium constant of adsorption obtained from the Langmuir adsorption isotherm is related to the equilibrium constant of adsorption according to the equation (Eq. 3).

$$\Delta G_{\text{ads}} = -2.303 RT \log (55.5K) \quad (3)$$

Where,

K= Adsorption Equilibrium Constant

55.5 = Molar concentration of water

ΔG_{ads} = Adsorption Free energy

R = Gas constant

T = Temperature

Table 2: Adsorption parameters of corrosion inhibition of mild steel in cefuroxime at different temperature ranges

Temperature (°K)	K _{ads} (Mol ⁻¹)	Slope	R ²	-ΔG _{ads} (KJ mol ⁻¹)
298	5.8 × 10 ³	0.94	0.99666	31.43
308	7.7 × 10 ³	0.90	0.99669	33.21
318	1.01 × 10 ⁴	0.90	0.99222	35.00
328	1.3 × 10 ⁴	1.09	0.98834	36.79
338	1.9 × 10 ⁴	1.23	0.99496	38.98

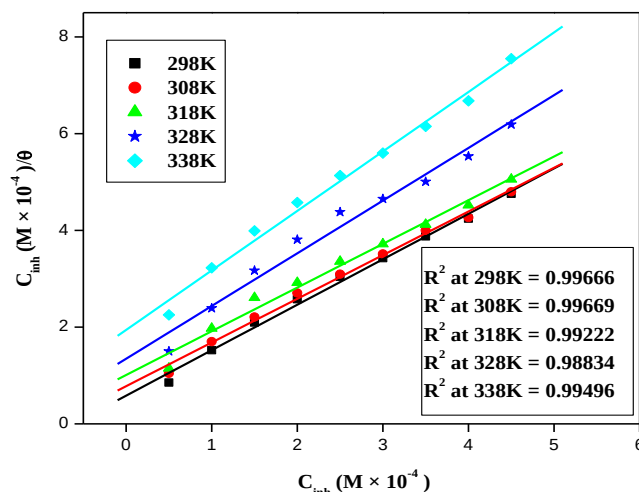


Figure 6: Langmuir's adsorption isotherm plots for the adsorption of different concentrations of cefuroxime in 0.5 M sulphuric acid solution.

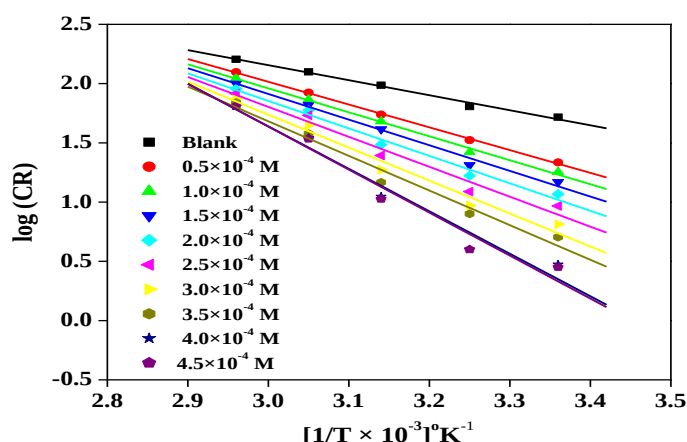


Figure 7: Transition state plot for mild steel corrosion in 0.5 M sulphuric acid in the absence and presence of different concentrations of cefuroxime.

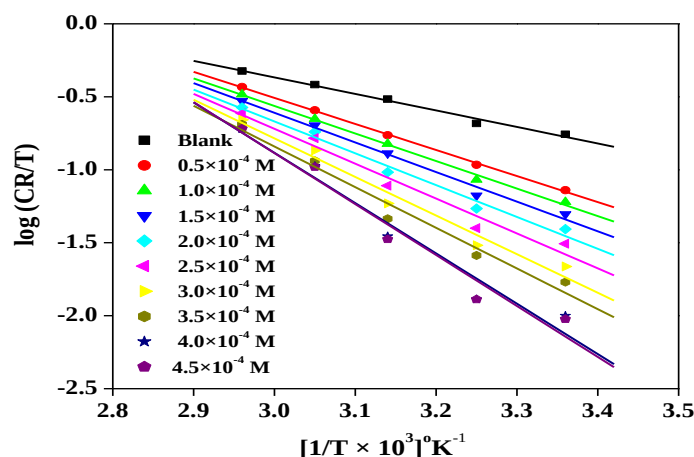


Figure 8: Arrhenius plot of $\log (CR/T)$ versus $1/T$ different concentrations of the cefuroxime in 0.5 M sulphuric acid solution.

3.5. Activation parameters on the inhibition process

Understanding the inhibitive process of corrosion needs an understanding of the adsorption behavior at different temperature ranges with various concentrations of inhibitor. In the present study, all the studies were done for different cefuroxime concentrations at temperatures ranging from 298 to 338 °K. The inhibition effectiveness and corrosion rate were calculated and given in Table 1. The Arrhenius equation was calculated from the data reported in the table to explain the relationship between mild steel corrosion rate and acidic media [26-28]. The Arrhenius equation relates the corrosion rate at different solution temperatures and inhibitor concentrations (Eq. 4).

$$\log(C_r) = \frac{-E_a}{2.303 RT} + \log \lambda \quad (4)$$

where,

E_a = apparent effective activation energy,

R = molar gas constant

λ = Arrhenius pre-exponential factor.

Figure 7 shows a graph of corrosion rate vs. $1/T$, with the regression coefficient being relatively close to one. The curve's slope may be used to determine activation energy (E_a). The slope of the curve is equal to $(-E_a/2.303 R)$, and the pre-exponential factor (λ) may be derived from the intercepted log. The computed values for these two are shown in Table 3. The inhibitor's activation energy is greater than that of the uninhibited sample, and it rises as the inhibitor concentration increases, suggesting that the inhibitor adsorption on the mild steel surface is physical. The dramatic rise in activation energy also indicates that the inhibitor is less

effective as temperature increases toward the mild steel surface in 0.5 M sulphuric acid medium. According to the Arrhenius equation, the corrosion rate is also influenced by λ raising the value, which lowers the corrosion rate [29].

The enthalpy of activation (ΔH) and entropy of activation (ΔS) values for the formation of the activated complex in the transition state equation can be calculated by the alternative Arrhenius equation, i.e., transition state equation (Eq. 5) [30, 31].

$$C_r = \frac{RT}{Nh} \exp\left(\frac{\Delta S}{R}\right) \exp\left(-\frac{\Delta H}{RT}\right) \quad (5)$$

where,

h = Planck's constant,

N = Avogadro's number,

ΔS = entropy of activation

ΔH = enthalpy of activation.

A graph of $\log (CR/T)$ versus $1/T$ has been plotted as represented in Figure 8. a straight line. Values of enthalpy of activation (ΔH) and entropy of activation (ΔS) have been calculated from the slope and intercept of the curves. The values are listed in Table 3. According to Table 3, the enthalpy's value increases with accelerations in the inhibition process. The positive value of enthalpy of activation signifies that the corrosion inhibition process is endothermic and dissolution of the metal used is difficult due to increasing the inhibitor concentration [32].

ΔS is negative, indicating that the activated complex represents an association and not a dissociation step, which shows that a decrease in disorder occurs from reactant to activated complex. Therefore the inhibition efficiency will be increased.

Table 3: Thermodynamic parameters of inhibition of mild steel in the sulphuric acid medium in the absence and presence of different concentration ranges of cefuroxime.

Concentration of inhibitor (M)	E_a (KJ mol ⁻¹)	λ (mg cm ⁻²)	ΔH (KJ mol ⁻¹)	ΔS (J mol ⁻¹ K ⁻¹)
Blank	24.29	9.14×10^5	21.68	-139.59
0.5×10^{-4}	36.81	6.05×10^7	34.19	-104.05
1.0×10^{-4}	38.75	1.08×10^8	36.14	-99.94
1.5×10^{-4}	41.48	2.58×10^8	38.87	-92.66
2.0×10^{-4}	44.40	6.46×10^8	41.79	-85.04
2.5×10^{-4}	48.38	2.41×10^9	45.77	-74.06
3.0×10^{-4}	53.26	1.21×10^{10}	50.65	-60.67
3.5×10^{-4}	55.97	2.82×10^{10}	53.35	-53.63
4.0×10^{-4}	68.63	2.46×10^{12}	66.02	-16.47
4.5×10^{-4}	69.48	3.32×10^{12}	66.86	-13.97

3.6. Linear polarization

Data on linear polarization have been determined and are given in Table 4. Polarization resistance rises as inhibitor concentration increases, resulting in increased inhibition effectiveness of the cefuroxime employed in the study. Maximum inhibition efficiency is around 90.4 %, consistent with the cefuroxime efficiency observed in weight reduction trials.

3.7. Tafel polarization

Figure 9 shows potentiodynamic polarisation images of mild steel with and without cefuroxime in 0.5 M H₂SO₄. The figure shows that following the buildup of cefuroxime in the acidic solution, both the hydrogen evolution (cathodic) and steel dissolution (anodic) processes were affected [33]. Despite this, cefuroxime did not affect the overall mechanism since neither anodic nor cathodic shifts were observed. A slight shift towards the cathodic area may be seen as a result of cefuroxime adsorbing to the steel, thereby inhibiting corrosion media assault on the working electrode, as evidenced by β_c values in Table 4 [34]. As a result, the addition of cefuroxime to the acidic medium did not affect the overall mechanism of corrosion. There was also a little shift in the anodic values of β_a , which might be attributed to the formation of a protective coating of cefuroxime molecules on the mild steel, which further blocked the progressive centers existing on the steel,

therefore delaying the dissolution process.

Table 4 shows the electrochemical properties of plots, such as the density of corrosion current (I_{corr}), the potential for corrosion (E_{corr}), the anodic slopes (β_a and β_c), the resistance to polarization (R_p), and the inhibitor performance (IE %) [35]. The highest inhibitory efficacy of 91.1 % was obtained at 4.0×10^{-4} concentration, indicating a reduced corrosion rate in the presence of cefuroxime. The corrosion potential exhibited no fluctuation or shift and was fairly constant. According to the findings of the study articles, if the shift or movement in corrosion potential is ≥ 85 mV concerning the blank (0.5 M H₂SO₄) solution, cefuroxime may be characterized as an anodic or cathodic inhibitor [36]. However, based on Figure 6 and Table 4, the shift is visible and measured to be ≤ 85 mV. Cefuroxime can thus be categorized as a mixed-type inhibitor based on this idea.

The inhibitor results in a lower I_{corr} corrosion current density, indicating that a mixed form inhibitor (i.e., prevents both anodic and cathodic corrosion) is adsorbed on the surface, preventing corrosion [37]. Without an inhibitor, the ability of mild steel became involved and changed to 455 mV (SCE) as a more negative value due to the dissolution of an air-molded oxide film. The potential moved to the positive side when an inhibitor was added to the solution, and the shift grew more dramatic as the inhibitor's concentration increased. As cefuroxime levels rose, the established I_{corr} density

reduction was found shown in Table 4, suggesting that the inhibitor's inhibitory effectiveness increased as the inhibitor's concentration increased, marking the start of the manufacture of protective oxide-and-cefuroxime films. Corrosion inhibitors are used to keep metals protected from corroding. The tafel polarization behavior is comparably more similar to the other drugs reported as corrosion inhibitors, and it shows better inhibition efficiency than many other drugs reported in the literature [38].

3.8. Electrochemical impedance spectroscopy technique

Figure 10 shows the Nyquist figures of mild steel in 0.5 M H_2SO_4 with and without cefuroxime. It can be seen that the width of the semicircle increases with increasing Cefuroxime adsorption. This increase in semicircles of capacitance suggests cefuroxime's mitigation behavior. It occurred due to its suitable attachment to the mild steel surface without varying corrosion processes [39-41].

Figure 10 also depicts the higher and lower frequency regions with identical capacitance but differing diameters. R. Idouhli said that an analog circuit with a constant phase angle was presented to illustrate the data pertinent to the iron/acid contact model. An equivalent circuit was used at a constant phase angle to illustrate the impedance data relevant to the iron/acid contact concept [42]. The relevant circuit parameters (R_s , R_t , Y^0 , and n) for electrochemical impedance have been determined and given in Table 5. The adsorption action of the inhibitor is comparable to the impedance distribution on the metal surface. Polarization resistance R_p is caused by the adsorption of pharmacological inhibitor molecules, and it rises with the quantity of adsorbed molecules. Additionally, the deposited inhibitor layer decreases capacitance at the metal-solution interface by lowering the dielectric constant between metal and electrolyte and increasing metal thickness [43-45]. The EIS parameters are similar to the other drugs reported as corrosion inhibitors, showing better inhibition efficiency than many other drugs reported in the literature [38].

Table 4: Potentiodynamic polarization parameters for mild steel at different concentrations of cefuroxime in sulphuric acid medium

Inhibitor Conc.	Tafel data					Linear Polarization data	
	$-E_{corr}$ (mV vs SCE)	β_a (mVdec ⁻¹)	β_c (mVdec ⁻¹)	I_{corr} ($\mu A\ cm^{-2}$)	IE (%)	R_p ($\Omega\ cm^2$)	IE (%)
Blank	455	69	143	1275	-	55.3	-
1.0×10^{-4}	461	70	161	601	52.9	114.8	51.8
2.0×10^{-4}	469	74	159	414	67.5	184.9	70.1
3.0×10^{-4}	474	73	151	255	80.0	297.5	81.4
4.0×10^{-4}	477	77	161	114	91.1	574.8	90.4

Table 5: Electrochemical impedance parameters values of different concentrations of cefuroxime in 0.5 M sulphuric acid solution.

Inhibitor concentration (ppm)	R_s ($\Omega\ cm^2$)	R_p ($\Omega\ cm^2$)	Y^0 ($\mu F\ cm^{-2}$)	N	C_{dl} ($\mu F\ cm^{-2}$)	IE (%)
Blank	1.13	53.3	1181.5	0.858	55	-
1.0×10^{-4}	0.99	122.4	211.6	0.842	52	56.5
2.0×10^{-4}	0.91	171.6	124.9	0.838	46	68.9
3.0×10^{-4}	1.03	265.7	89.8	0.835	42	79.9
4.0×10^{-4}	1.10	351.7	81.3	0.833	39	84.8

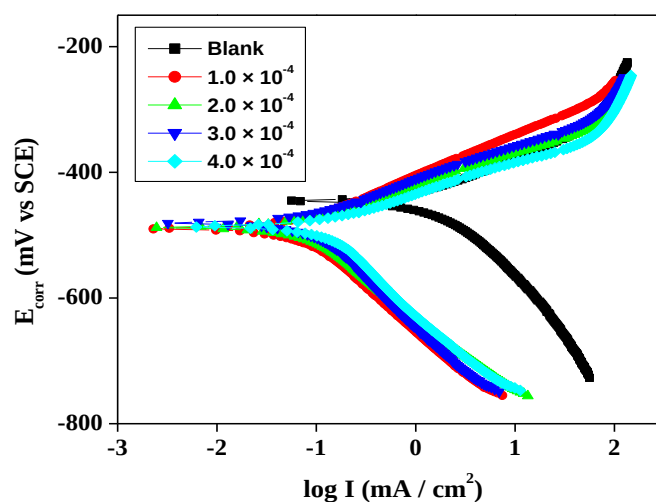


Figure 9: Tafel polarization graph in absence and presence of different concentrations of cefuroxime at mild steel surface in 0.5 M sulphuric acid medium.

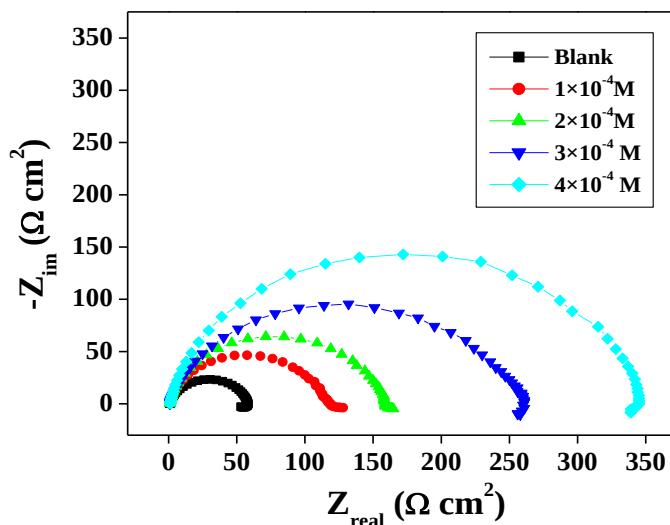


Figure 10: Nyquist plot of electrochemical impedance spectroscopy in absence and presence of different concentrations of cefuroxime at mild steel surface in 0.5 M sulphuric acid medium.

3.9. Surface study: AFM study

AFM is a strong tool for investigating the surface structure, and it has emerged as a novel option for studying the effect of the inhibitor on the formation and progression of corrosion at the metal/solution interface (46-48). The atomic force microscopy method was utilized to determine the surface morphology of untreated mild steel surface, mild steel exposed in 0.5 M H_2SO_4 , and the presence of the optimal concentration of the corrosion inhibitor, as illustrated in Figure 11a-c. Untreated and uninhibited surfaces of

mild steel with surface ruggedness are 51, 590 and 168 nm. The reduction of surface roughness suggests that cefuroxime is effective.

3.10. Mechanism of inhibition

Generally, corrosion occurs in the acidic media by the interaction of the acid with the iron molecule on the surface. The electron-rich part of the acid reacts with electropositive metal and salt, which dissolve in the medium. When the inhibitor molecule comes into the close interaction of the metal surface, it adsorbed on

the surface of the metal from its lone pair of electron and π electron cloud of the unsaturated part of the inhibitor. This phenomenon avoids the contact of the acidic molecule from the metal surface by making a uniform film on the surface. A schematic representation is shown in Figure 12 [49, 50].

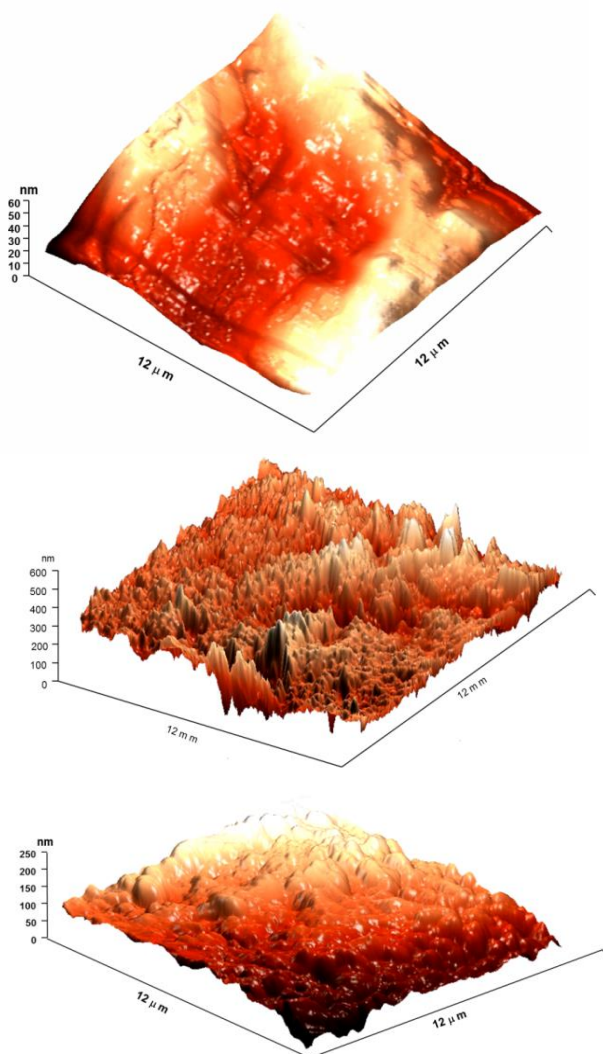
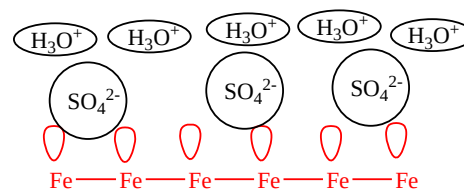
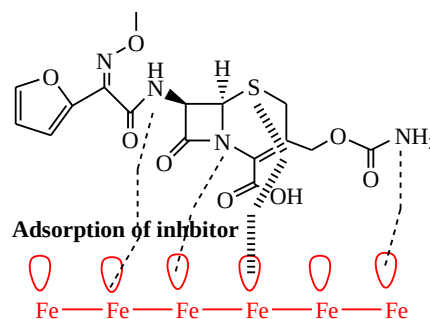


Figure 11: represents AFM studies of mild steel surface (a) polished surface (b) surface exposed in 0.5 M sulphuric acid without inhibitor (c) surface exposed in 0.5 M sulphuric acid with optimum concentration of cefuroxime inhibitor.



In absence of Cefuroxime



In presence of Cefuroxime

Figure12: Schematic representation of adsorption of the inhibitor molecule.

4. Conclusion

In 0.5 M sodium sulphuric acid, cefuroxime expired form exhibits more than 94 % inhibition efficiency at 4.0×10^{-4} M concentration towards mild steel surface in 0.5 M sulphuric acid. By increasing solution temperature, inhibitor efficiency decreases, indicating that it is a potential corrosion inhibitor at lower temperature ranges. Cefuroxime lowers the inhibition efficiency with increased acid concentration and on more prolonged time exposure. With this, it can be deduced that cefuroxime is an excellent corrosion inhibitor for lower temperature concentrations in mildly corrosive environments and shorter exposure duration. Electrochemical investigations reveal that the adsorption of the inhibitor form monolayer on the metal surface and shows a mixed type inhibition reaction, i.e., inhibition of the cathodic and anodic reaction. Adsorption of Cefuroxime on the surface of mild steel obeys Langmuir adsorption isotherm. Thermodynamic and adsorption parameters indicated that the interaction of inhibitor on mild steel surface is adsorbed physically.

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