International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 11s, 2025
https://theaspd.com/index.php

Evaluation Of Antibacterial And Corrosion Inhibition Activities Of N,N'-Bis (Salicylidene) Ethylenediamine For Mild Steel In 1M H_2SO_4

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Abstract
The most effective corrosion inhibitors are compounds containing high electron density functional groups in their structure, such as heteroatoms and aromatic rings. They are favored for their effective corrosion protection properties, including some Schiff bases. The corrosion protection behavior of Schiff base N,N'-bis(salicylidene)ethylenediamine as a mild steel corrosion inhibitor at different concentrations in 1 M H2SO4 solution was studied using potentiodynamic polarization techniques and thermometry (thermometry). The results showed that N,N'-bis(salicylidene)ethylenediamine significantly reduced the corrosion of mild steel in acidic solution (H2SO4). In contrast, the inhibition efficiency (%IE) increased with increasing inhibitor concentration but decreased with increasing temperature. According to the Langmuir adsorption isotherm, the inhibitor spontaneously adsorbed on the metal surface. In this paper, the performance of expired N,N'-bis(salicylidene)ethylenediamine as a mild steel corrosion inhibitor in H2SO4 solution was investigated. N,N'-Bis (salicylidene) ethylenediamine inhibitory efficiencies increased at the temperatures 303 and 308 K in comparison with other degrees. The minimum inhibitory concentrations of 3 Klebsiella pneumoniae isolates by using the Schiff base were evaluated by microtiter plate assay with resazurin dye. The results revealed that the range of minimum inhibitory concentrations were (300-400 ppm). By using resazurin dye in a microtiter plate test, the minimum inhibitory doses of N,N'-Bis (salicylidene) ethylenediamine against 3 S. aureus isolates were assessed. The range of inhibitory action, according to the results, was (300-400 ppm). This study provides theoretical support for the experimental results. The Schiff base can be used as an economical, effective and safe corrosion inhibitor for the system studied. In conclusion, N,N'-bis(salicylicaldehyde)ethylenediamine is an effective corrosion inhibitor in the presence of Schiff base. The active compound molecules attach to the surface of mild steel, thereby preventing corrosion.
Keywords: *Antibacterial, Mild Steel, H_2SO_4, Corrosion inhibitor, N,N'-Bis (salicylidene) ethylenediamine.*

INTRODUCTION

Corrosion can be controlled through a variety of processes including anodizing, corrosion inhibitors, conversion coatings, and painting, allowing the equipment to perform its intended function properly over its expected service life. One of the most practical and cost-effective ways to reduce metal corrosion is through the use of inhibitors (Eliaz, 2019). The effectiveness of corrosion inhibitors on metal surfaces depends on their ability to donate electrons to the metal's predominantly occupied electron orbitals, thereby forming bonds. Therefore, compounds with high electron density functional groups are the most effective corrosion inhibitors. In addition, inhibitors containing heteroatoms (O, S, N, etc.) and aromatic rings in their structure are preferred for their anti-corrosion effects (Jalab *et al*., 2024).Metal-Salen complexes (N,N′-bis(salicylaldehyde) ethylenediamine) are coordination compounds that have attracted much attention in the field of inorganic chemistry due to their unique structures and multifunctional properties. “Salen” refers to Schiff base ligands formed by the condensation of salicylaldehyde and diamine. These ligands can bind to various metal ions to form stable complexes. Therefore, salen complexes formed with various metal ions such as Mn3+ and Fe3+ have been proposed as potential anticancer drugs (Yu *et al*., 2017; Milbeo *et al*., 2021). Many local studies have pointed out the role of organic materials as corrosion inhibitors for steel (Saeed *et al*., 2025; Safi *et al*., 2024).Several studies have confirmed that the use of pharmaceuticals for corrosion inhibition is an environmentally friendly and side-effect free method. Pharmaceutical substances can compete with environmentally friendly corrosion inhibitors. Many natural resources can be used to synthesize most products. Several factors influence the selection of the best corrosion inhibitor (Tanwer *et al.*, 2022). Due to the large number of previous research results on environmentally friendly compounds as corrosion inhibitors, research has turned to the possibility of using expired pharmaceuticals as corrosion inhibitors; many expired pharmaceuticals have been shown to be very effective corrosion inhibitors for protecting mild steel in acidic media (Dina *et al.*, 2018; Sheit *et al.*, 2024).Studies have shown that there are many benefits of using expired drugs as corrosion inhibitors. Many drugs such as antibiotics, antihypertensives, mucolytics, antihistamines, anxiolytics, antivirals, hypogonadism, antidepressants, antidiabetics, and analgesics (e.g., Declophen and paracetamol) have been studied for various clinical applications (Baari and Sabandar, 2021). The present study aimed to investigate the inhibitory and antimicrobial effects of different concentrations of N,N'-bis(salicylicaldehyde)ethylenediamine in 1 molar H2SO4 solution on mild steel. Thermodynamic parameters such as enthalpy, entropy, Gibbs free energy of adsorption, and pre-exponential factors were calculated using experimental data of the corrosion inhibition process measured at different temperatures. The effect of activation energy on the corrosion rate of mild steel was also investigated. The corrosion inhibition mechanism was explored using the dipole moment, total energy, energy gap, and electron orbital density distribution of the highest occupied molecular orbital (HOMO) and lowest unoccupied molecular orbital (LUMO) of the N,N'-bis(salicylaldehyde)ethylenediamine molecule (Figure 1).

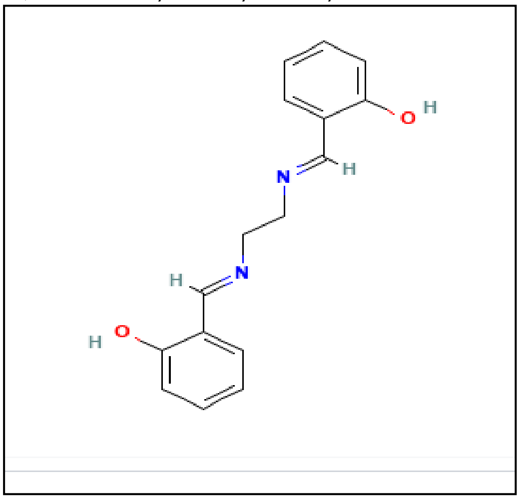

Figure 1. The chemical Structure of N,N'-Bis (salicylidene) ethylenediamine.

Experimental Section
Samples and materials
The mild steel sample used in the investigation has a high level of purity-99.5%. Using emery paper in grades 320, 500, 1000, 2400, and 4,000 as well as diamond product spray, the test specimen was polished containing ethanol and diamond particles of varying sizes (1µm, 3µm, 6µm, and 9µm). For this investigation, the H2SO4 solution from (THOMAS BAKER, India) was utilised. Purchased from (MACKLIN, China), N,N'-Bis (salicylidene) ethylenediamine (99% pure) with the molecular formula $C_{16}H_{16}N_2O_2$ was utilized without additional purification. All solutions were prepared using distilled water. One molar of newly made H_2SO_4 solution was used in each experiment, and the inhibitor concentrations (N,N'-Bis (salicylidene) ethylenediamine) were (100, 200, 3004, 400 and 500 ppm). Different temperature degrees (298,303, 308, 313, and 318 K) were used in this experiment.

Potentiodynamic Polarization Measurements The study employed mild steel as the working electrode (WE), saturated calomel electrode (SCE) as the reference electrode (RE), and platinum type as the auxiliary electrode. The glass electrochemical cell's specimen working electrode (holder), reference, also auxiliary electrodes were all positioned in their correct locations, with the reference electrode being put around 1 mm from the specimen's surface for examination. The agitated and aerated electrolyte was used up to one liter.A potentiostat (SCI-MLab corrosion measuring system and WENKING MLab multichannel GmbH, Germany) can be used to apply constant potentials, either cathodic or anodic, to the specimen. The standard reference electrode used in this experiment can be made to have a constant voltage between −2V and +2V by using this potentiostat. With the MLabSci computer software running on Windows XP, The potential difference between the reference electrode (RE), working electrode (WE), and any current passing through the circuit between the auxiliary electrode and working electrode can all be automatically recorded. The scan rate is another option. During the testing, a brief, gradual sweep of the potential was used to measure the cell current. In terms of open circuit potential (OCP), the sweep was conducted between -200 and +200 mV. The potential weep's speed in mV/sec throughout this range is defined by the scan rate.

Microbial Strains Tested

Two bacterial strains, Staphylococcus aureus and Klebsiella pneumoniae, were used to test the antibacterial activity of N,N'Bis (salicylidene) ethylenediamine. Ciprofloxacin was used as a reference medication for antibacterial evaluations. The University of Baghdad's College of Science's Biology department provided the bacterial strains.

The Minimum Inhibitory Concentration (MIC) of N,N'-Bis (salicylidene) ethylenediamine

The microdilution method (Microtiter Plate Assay with Resazurin Dye) was used to detect the MIC (CLSI, 2021). A concentration of N,N'-Bis (salicylidene) ethylenediamine was used is 2000 μg/mL as stock solution by using Dimethyl sulfoxide (DMSO) solvent (to prepare a serial dilutions from 1000 to 12.5 μg/mL). The bacterial isolates *K. pneumoniae* (and *S. aureus*) subcultures in brain heart agar that had been cultured for 18 to 24 hours at 37 °C before the test were used to create the bacterial inoculum. To reach a turbidity of 0.5 on the McFarland scale, the bacterial suspension was diluted to $1x10^8$ CFU/mL. The ultimate concentration of $5x10^5$ CFU/mL was subsequently achieved by diluting the sample in Muller Hinton broth medium (MHB). Serial dilutions were made by adding 1000 μg/mL of the medication to a 96-well plate that contained the diluted bacterial solution. One hundred μL of drug and 100 μL of diluted bacterial solution were combined to create the final amount of 200 μL each well. By adding *K. pneumoniae* with MHB medium to one line of the wells and MHB medium alone to the other, negative and positive growth controls were carried out, respectively. Resazurin (0.015%) was applied to each well (20 μl per well) after a 24-hour incubation period at 37 °C. It was then incubated for 20 minutes to see if the color changed. After incubation, columns that showed no color change (the blue resazurin hue stayed the same) were rated as being above the MIC value. At the end of the incubation period, the minimum inhibitory concentration (MIC) was determined to be the lowest chemical concentration at which no bacterial growth was seen.

RESULTS AND DISCUSSION

Potentiodynamic Polarization Measurements

Tafel Polarization

The results in Figure 2 and Table 1 summarize the electrochemical results of mild steel samples with and without the addition of corrosion inhibitor solution. In addition to the corrosion potential (Ecorr) and corrosion current density (icorr), the collected data also include the Tafel slopes of the anodic (ba) and cathodic (bc) regions in 1 M H_2SO_4 aqueous solution at five different temperatures (298–318 K) for different concentrations of N,N'-bis(salicylicaldehyde)ethylenediamine solutions. The Tafel behaviors of the anodic (ba) and cathodic (bc) regions are similar compared to the solution without corrosion inhibitor. The presence of N,N'-bis(salicylicaldehyde)ethylenediamine solution significantly changes these regions. Obviously, the icorr values decrease significantly with increasing corrosion inhibitor concentration. This indicates that the protective effect of the corrosion inhibitor on mild steel gradually increases with the increase of the corrosion inhibitor concentration. At 500 ppm, the corrosion inhibition efficiency reaches a peak of 81.63%. According to previous studies, paracetamol can inhibit the corrosion of mild steel and XC48 steel in 1 M HCl solution. The results showed that the product is an effective steel corrosion inhibitor with significant inhibition efficiency at a concentration of 5×10-3 (M). The inhibitor adhered to the surface of mild steel MS and metal XC48 (Merimi *et al.,* 2023). Therefore, the presence of N,N'-bis(salicylicaldehyde)ethylenediamine interfered with the cathodic and anodic reactions. This indicates that N,N'-bis(salicylicaldehyde)ethylenediamine effectively inhibited the cathodic hydrogen reduction reaction and anodic dissolution of mild steel. The adsorbed inhibitor anions formed strong contacts with the metal surface atoms, potentially limiting oxidation. In the presence of the inhibitor, the corrosion potential (θcorr.) shifted towards more negative values. Table 1 shows that the corrosion current density (θcorr.) decreased with increasing N,N'-bis(salicylicaldehyde)ethylenediamine concentration in 1M H_2SO_4 aqueous solution. However, an increase in temperature also leads to an increase in (θcorr.). This may be due to the fact that the corrosion inhibitor molecules cover the mild steel surface, thereby reducing the available area of active sites for the reaction without changing the mechanism of hydrogen evolution via charge transfer (Hegazy, 2009).

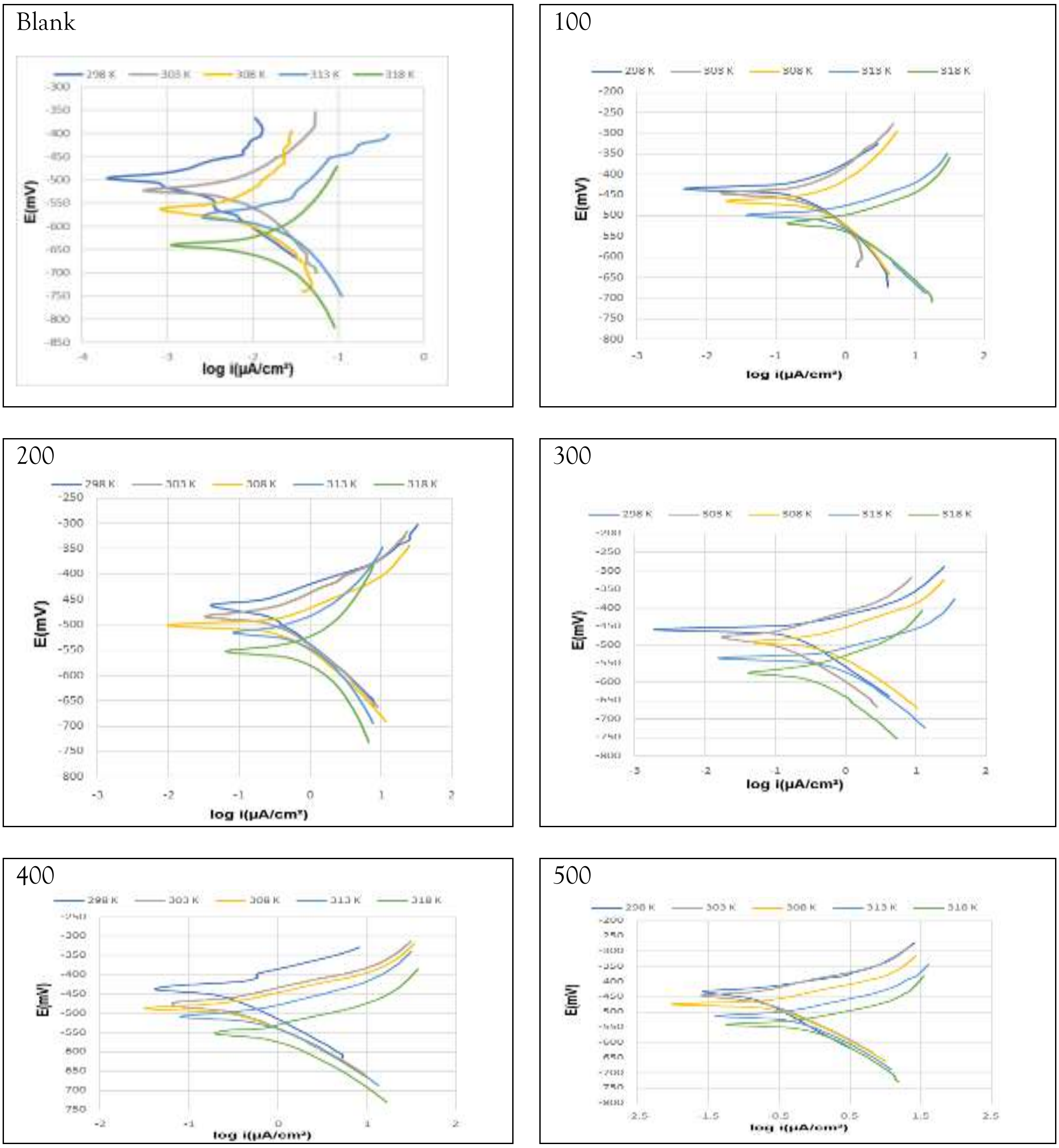

Figure 2. Polarization curves for the corrosion of mild steel without, and with different concentrations of N,N'-Bis (salicylidene) ethylenediamine in 1M H_2SO_4 aqueous solution at different temperatures.

Table 1. Potentiodynamic polarization parameters of mild steel without, and with different concentrations of N,N'-Bis (salicylidene) ethylenediamine in 1M H_2SO_4 aqueous solution at different temperatures.

nc.	K	OCP/ mV	Ecorr/m V	icorr/ µA.cm^{-2}	bc/ mV.dec^{-1}	ba/ mV.dec^{-1}	C_R /g.m^{-2} .dl^{-1}	P_R/ mm.y^{-1}
Blank	298	- 498	- 495	343.83	-89.9	69.9	8.7	4.05
	303	- 535	-528	536.16	-86.5	70.4	13.4	6.22
	308	- 566	- -562	693.23	-90.0	75.7	17.3	8.05
	313	- 587	- 579	845.18	-96.9	78.9	21.1	9.81
	318	- 645	- 643	1550.0	-99.8	79.9	29.2	18.25
100 ppm	298	- 438	- 434	189.98	-122.7	87.4	4.75	2.21
	303	- 454	- 442	207.74	-123.8	88.5	5.19	2.41
	308	- 468	- 465	313.37	-116.2	89.9	7.83	3.64
	313	-493	-488	507.62	-107.5	90.4	12.7	5.89
	318	- 519	- 517	760.20	-109.8	95.9	19.00	8.82
200	298	- 475	- 469	164.74	-120.6	88.4	4.12	1.91
	303	- 489	- 483	206.95	-118	89.5	5.17	2.40
	308	- 503	- 499	260.39	-112.9	89.2	6.51	3.02
	313	- 536	- 532	502.73	-105.6	92.7	12.6	5.84
	318	- 562	- 554	630.52	-100.1	88.7	15.8	7.32
300	298	- 466	- 461	144	-130	91	3.60	1.67
	303	- 489	- 478	198.47	-119	92.5	4.96	2.30
	308	- 498	- 495	254.64	-111	89.9	6.37	2.96
	313	- 533	- 529	407.75	-98.6	85.8	10.2	4.73
	318	- 587	- 582	623.95	-99.9	90.6	15.6	7.24
400	298	- 451	- 448	110.82	-90.8	69.9	2.77	1.29
	303	- 478	- 472	195.60	-92.3	77.9	4.89	2.27
	308	- 494	- 485	213.79	-93.6	78.7	5.34	2.48
	313	- 522	- 511	327.97	-90.4	80.7	8.20	3.81
	318	- 549	- 543	500.80	-89.8	82.4	12.5	5.81
500	298	- 440	- 433	88.83	-90.6	70.1	2.32	1.08

	303	- 456	- 447	98.45	-88.9	69.8	2.21	1.03
	308	- 471	- 468	131.08	-85.9	70.2	3.28	1.52
	313	- 513	- 508	321.11	-84.7	75.8	8.03	3.73
	318	-545	-537	491.14	-86.9	80.1	12.3	5.7

Polarization Resistance

The Stern-Geary equation was used to determine the polarization resistance (Rp): The formula for Rp is equal to **:**

Rp= ba.bc/ 2.303 (ba + bc) icorr........(1)

Where, ba, bc are the anodic and cathodic Tafel slopes, respectively, and icorr is the corrosion current density. The polarisation resistance (Ω cm2) and temperature values of the experimental solution including 1M H_2SO_4 aqueous solution of N,N'-Bis (salicylidene) ethylenediamine were presented in Table 2. The findings show that the Rp values rose with rising temperatures and fell with rising the Schiff base concentrations. This demonstrates the physical adsorption of N,N'-Bis (salicylidene) ethylenediamine on mild steel surfaces. When the Rp value rises in response to an increase in inhibitor concentration, it means that the efficiency of inhibition is increasing; conversely, when the Rp value falls in response to an increase in temperature, it means that the efficiency of inhibition is decreasing.It was shown that the enhanced inhibition efficacy was unaffected by the corrosive environment or the concentration of SCLE. In this investigation, polarization resistance values rise noticeably as N,N'-Bis (salicylidene) ethylenediamine concentration rises to 500 ppm. Low metal dissolution is correlated with an increase in polarization resistance value, which lowers the rate of corrosion (Alamry *et al.*, 2023).

Table 2. Potentiodynamic polarization parameters of mild steel without, and with different concentrations of N,N'-Bis (salicylidene) ethylenediamine in 1M H_2SO_4 aqueous solution at different temperatures.

	$Rp\times10^3$ Ω.cm^2					
K	Blank	100 ppm	200 ppm	300 ppm	400 ppm	500 ppm
298	0.396	0.6943	0.872	0.9146	1.1898	1.514
303	0.306	0.6487	0.777	0.9087	1.1084	1.432
308	0.298	0.5503	0.708	0.8064	1.0041	1.272
313	0.218	0.4861	0.652	0.7038	0.9957	0.975
318	0.112	0.4326	0.536	0.6772	0.8669	0.904

Surface coverage and inhibition efficiency

Equations 2 and 3, respectively, were used to compute the mild steel's degree of surface covering (θ) and inhibitory efficiency (%IE) in 1M H_2SO_4 in the presence of N,N'-Bis (salicylidene) ethylenediamine at five distinct experimental temperatures and varied concentrations. The findings are shown in Table 3.

$\theta = 1- (i_2/i_1)$ .... (2)

% **IE = 100 × [1- (i_2/i_1)] .... (3)**

where i1 and i2 are the corrosion current densities in a 1M H_2SO_4 aqueous solution when N,N'-Bis (salicylidene) ethylenediamine is present and absent, respectively (Rosliza, 2012).In general, the inhibition efficiency of an inhibitor for a physical adsorption mechanism decreases with temperature, whereas the inhibition efficiency of an inhibitor for a chemical adsorption mechanism increases with temperature (Chaouiki *et al.*, 2022). In an aqueous solution of 1M H2SO4, Table 3 showed the inhibition effectiveness values and the degree to which N,N'-Bis (salicylidene) ethylenediamine inhibited mild steel corrosion. The inhibition's capacity increased with concentration. The highest level of inhibitory efficiency is 92%

at 500 ppm. However, N,N'-Bis (salicylidene) ethylenediamine 's inhibitory efficiencies decrease with increasing temperature, indicating that it inhibits mild steel's physical adsorption.

Table 3. Surface coverage and protection efficiency values on pure mild steel surfaces at different temperatures for varying concentrations of N,N'-Bis (salicylidene) ethylenediamine in a 1M H_2SO_4 aqueous solution.

	N,N'-Bis (salicylidene) ethylenediamine conc. (ppm)									
T [K]	100		200		300		400		500	
	θ	%IE	θ	%IE	θ	%IE	θ	%IE	θ	%IE
298	0.45	44.74	0.52	52.08	0.58	58.11	0.68	67.76	0.74	74.16
303	0.61	61.25	0.61	61.40	0.63	62.98	0.64	63.51	0.82	81.63
308	0.55	54.79	0.62	62.43	0.63	63.26	0.69	69.16	0.81	81.09
313	0.40	39.93	0.41	40.51	0.52	51.75	0.61	61.19	0.62	62.00
318	0.51	50.95	0.52	52.08	0.60	59.74	0.68	67.69	0.68	68.31

Kinetic parameters

Equation 4 of the Arrhenius equation was utilised to investigate how temperature affected mild steel's inhibited corrosion reaction.

Log icorr.= log A – Ea/ R T .... (4)

where T is the temperature in Kelvin, A is the pre-exponential factor (measured in molecules cm-2 s-1), R is the gas constant, and Ea is the energy activation of the corrosion reaction (kJ mol-1). In Fig. (3), the slopes of the linear connection between (log icorr) versus (1/T) yielded the values of Ea, whereas the intercepts yielded the values of (A). Entropy of activation (ΔS*) and pre-exponential factor (A) are connected as (Acharya and Upadhyay, 2004):

A = k T/ h exp (ΔS*/ R) .... (5)

where T is the temperature (Kelvin), h is Plank's constant, and k is the Boltzmann constant. The pre-exponential factor (A), activation energy (Ea) and entropy of activation (ΔS*) values for mild steel were shown in Table (4) with and without varying dantrolene dosages. Since all of the Ea values are greater than the blank value (58.65 kJ/mol), it may be concluded that dantrolene slows down the mild steel's corrosion response. Additionally, it validates the occurrence of physical adsorption (Obot and Obi-Egbedi, 2010).

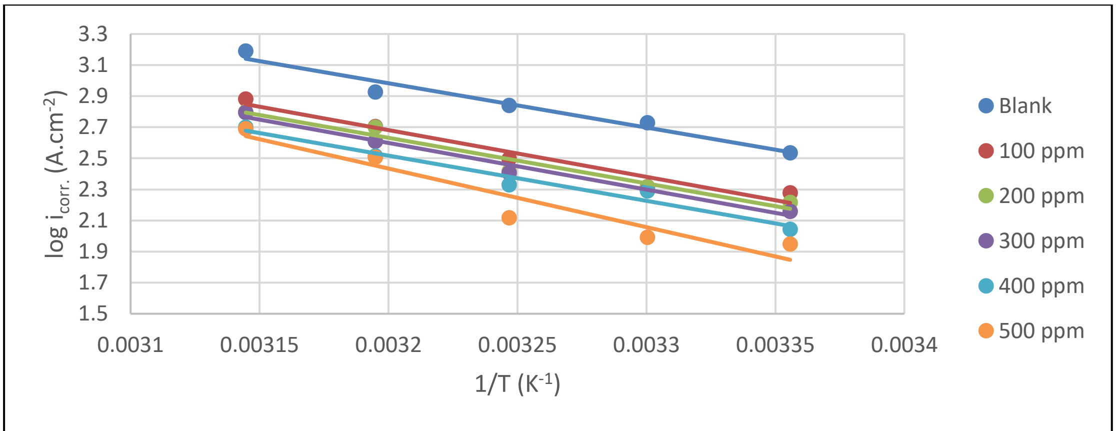

Figure 3. Arrhenius plots of log icorr vs 1/T for mild steel using N,N'-Bis (salicylidene) ethylenediamine in an aqueous solution of 1M H_2SO_4 showing the presence and absence of various Dantrolene concentrations.

Table 4. The corrosion of mild steel utilizing N,N'-Bis (salicylidene) ethylenediamine in a 1M H2SO4 aqueous solution, in the absence and presence of varying concentrations of Dantrolene at different

temperatures, is investigated for its activation energy (Ea), pre exponential factor (A), and entropy of activation (ΔS*).

Conc. [M]	R^2	Ea [kJ.mol^{-1}]	A [molecule.cm^{-2}.s^{-1}]	ΔH* [kJ.mol^{-1}]	ΔS* [J.K^{-1}.mol^{-1}]
0	0.963	54.56	7.83×10^{30}	42.82	-52.62
100	0.957	57.60	1.26×10^{31}	55.05	-48.53
200	0.954	56.17	6.49×10^{30}	53.73	-53.69
300	0.983	57.44	9.81×10^{30}	54.90	-50.57
400	0.967	55.67	4.10×10^{30}	53.06	-58.03
500	0.910	72.19	1.96×10^{33}	69.96	-50.63

Adsorption Consideration and Thermodynamic parameters

The adsorption of corrosion inhibitors on metal surfaces is the first step in their function. Subsequently, the adsorbed corrosion inhibitors slow down the electrochemical corrosion reactions at the cathode and/or anode. Adsorption isotherms can provide basic information about the interaction between corrosion inhibitors and structural steel surfaces. In this study, Langmuir adsorption isotherms were used to describe the optimal adsorption behavior of dantrolene on structural steel in 1M H_2SO_4 aqueous solution. The equation describing the Langmuir adsorption isotherm (Abd-El-Nabey *et al.*, 2012):

[θ/(1-θ)]=Kads [Cinh] .... (6)

where θ represents surface coverage, Cinh is the inhibitor concentration, and Kads is the adsorption process equilibrium constant.

Fig. (4) illustrates the dependence of the fraction Cinh/θ on Cinh for Dantrolene. The inhibitor's plots that were obtained are nearly linear. The standard free energy of adsorption ΔGads and the equilibrium constant of adsorption Kads are connected by the following equation (Kosari *et al.*, 2012):

Kads=1/55.5 exp (-ΔGads./RT) .... (7)

where T is the absolute temperature, R is the gas constant, and 55.5 is the water concentration in solution expressed in millimeters.Tables 5 and 6 list the thermodynamic parameters for the adsorption of N,N'-bis(salicylimide) ethylenediamine on mild steel surfaces in 1 M H2SO4 aqueous solution. In general, the ΔGads values are applicable. Electrostatic interactions (physical adsorption) are consistent with values of about -20 kJ mol-1 or less, while electron transfer to form chemical bonds (chemisorption) occurs at values of -40 kJ mol-1 and above (Singh and Quraishi, 2010). The equilibrium constant derived from the Langmuir isotherm has a high value (Kads = 2221.4 L mol-1). The adsorption of N,N'-bis(salicylimide)ethylenediamine on mild steel surfaces in 1 M H2SO4 aqueous solution is high, as determined by its Kads value. The ΔGads value of -30.22 kJ mol-1 was determined, which is consistent with the stability of the adsorption layer on the mild steel surface and the spontaneity of the adsorption process of N,N'-bis(salicylimide)ethylenediamine. The latter is required for chemical adsorption and is well below the threshold of -40 kJ mol-1. The ΔGads value determined in this study indicates that the adsorption of EDC goes beyond physical and chemical adsorption. Therefore, this ΔGads value suggests that the adsorption of EDC may involve further interactions beyond simple physical adsorption (Zarrok *et al.*, 2012). One of the local studies found that the concentration of the inhibitor and the solution temperature affect its corrosion inhibition ability. As the inhibitor concentration increases, its corrosion inhibition effect also increases, reaching a peak of 96.5% at 0.5 M (Salman *et al.*, 2019). The organic molecules form a protective film on the inhibitor molecules on the mild steel surface (Ali *et al.*, 2021).Therefore, the mechanism by which N,N'-bis(salicylidene)ethylenediamine prevents mild steel corrosion in acidic aqueous solutions can be explained by adsorption on metal surfaces. Unlike photosynthetic and electrostatic interactions, atoms in aromatic molecules form coordination bonds with lone pairs of heteroatoms (N, S, and O) and metal atoms through donor-acceptor interactions. The interactions between metals and N,N'-bis(salicylidene)ethylenediamine - physical adsorption, chemical adsorption, or a mixture of these processes - can be used to adsorb molecules (Gholivand *et al.*, 2022).

International Journal of Environmental Sciences
ISSN: 2229-7359
Vol. 11 No. 11s, 2025
https://theaspd.com/index.php

Table 5. The thermodynamic and kinetic parameters at different temperatures for mild steel with different concentrations of N,N'-Bis (salicylidene) ethylenediamine in 1M H_2SO_4.

Conc.	T/ K	Ecorr/ mV	icorr / µA.cm-2	-ΔG/kJ. mol-1	-ΔH/kJ. mol-1	ΔS/J.K-1 .mol-1	Ea/kJ. mol-1	A Molecules .cm-2 .S-1	Rp×10^3 Ω.cm^2	IE%
Control	298	- 495	343.83	95.5202	494.602	-1.3392	54.1462	$6.28*10^{35}$	0.396	
	303	-528	536.16	101.888	507.666				0.306	
	308	- -562	693.23	108.449	520.923				0.298	
	313	- 579	845.18	111.73	530.899				0.218	
	318	- 643	1550.0	124.08	549.945				0.112	
100 ppm	298	470	164.74	90.696	158.879	-0.8182	57.45291	$1.12*10^{36}$	0.6943	44.74
	303	483	206.95	93.205	160.558				0.6487	61.25
	308	499	260.39	96.292	161.658				0.5503	54.79
	313	532	502.73	102.66	159.4775				0.4861	39.93
	318	554	630.52	106.905	159.419				0.4326	50.95
200 ppm	298	470	164.74	90.696	158.879	-0.8375	55.85796	$5.42*10^{35}$	0.872	52.08
	303	483	206.95	93.205	160.558				0.777	61.40
	308	499	260.39	96.292	161.658				0.708	62.43
	313	532	502.73	102.66	159.4775				0.652	40.51
	318	554	630.52	106.905	159.419				0.536	52.08
300 ppm	298	461	144	88.9592	248.019	-1.1308	57.07572	$8.01*10^{35}$	0.9146	58.11
	303	478	198.47	92.2397	250.393				0.9087	62.98
	308	495	254.64	95.5202	252.766				0.8064	63.26
	313	529	407.75	102.081	251.8593				0.7038	51.75
	318	582	623.95	112.309	247.286				0.6772	59.74
400 ppm	298	448	110.82	86.4506	176.922	-0.8838	55.08058	$3.07*10^{35}$	1.1898	67.76
	303	472	195.60	91.0818	176.709				1.1084	63.51

	308	485	213.79	93.5905	178.62				1.0041	69.16
	313	511	327.97	98.6077	178.0217				0.9957	61.19
	318	543	500.80	104.783	176.265				0.8669	67.69
500 ppm	298	433	88.83	83.556	225.827	-1.0382	71.8688	$1.61*10^{38}$	1.514	74.16
	303	447	98.45	86.2576	228.317				1.432	81.63
	308	468	131.08	90.31	229.455				1.272	81.09
	313	508	321.11	98.0288	226.9278				0.975	62.00
	318	537	491.14	103.625	226.522				0.904	68.31

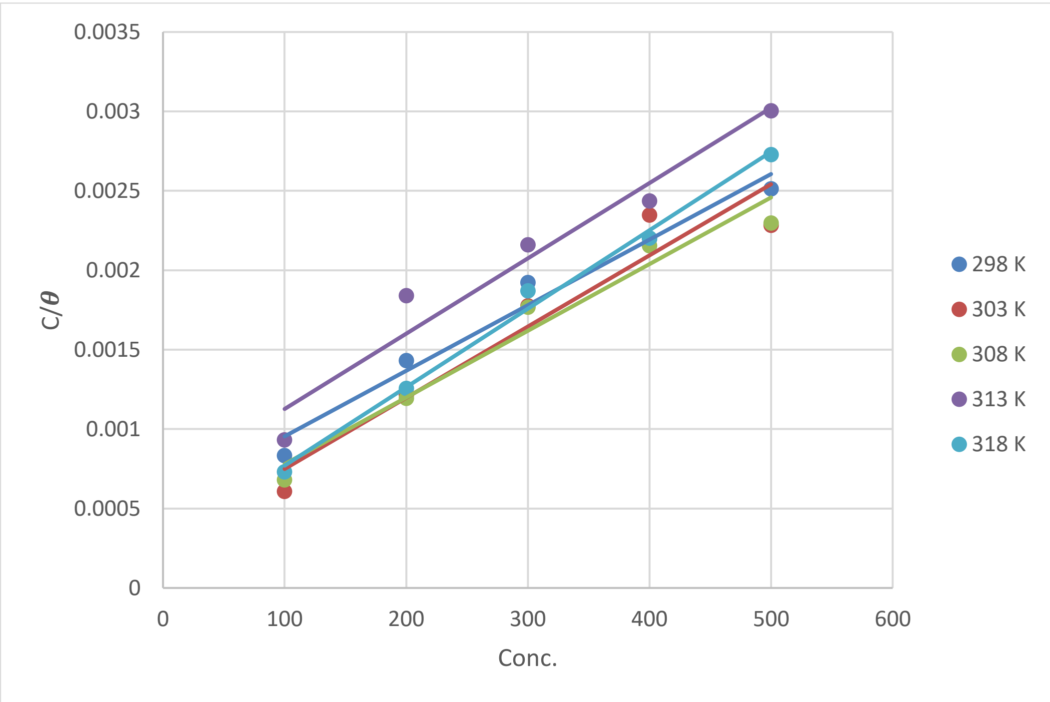

Figure 4. The adsorption of N,N'-Bis (salicylidene) ethylenediamine (Langmuir isotherm plot) on the surface of mild steel.

Minimum Inhibitory Concentrations (MICs) of N,N'-Bis (salicylidene) ethylenediamine against *Klebsiella pneumoniae* bacteria (Gram-negative)

The minimum inhibitory concentrations of 3 *K. pneumoniae* isolates by using the antibiotic N,N'-Bis (salicylidene) ethylenediamine were evaluated by microtiter plate assay with resazurin dye. The results revealed that the range of minimum inhibitory concentrations were (300-400 ppm) as showed in the figure 1.

Minimum Inhibitory Concentrations (MICs) of N,N'-Bis (salicylidene) ethylenediamine against *S. aureus* bacteria (Gram-positive)

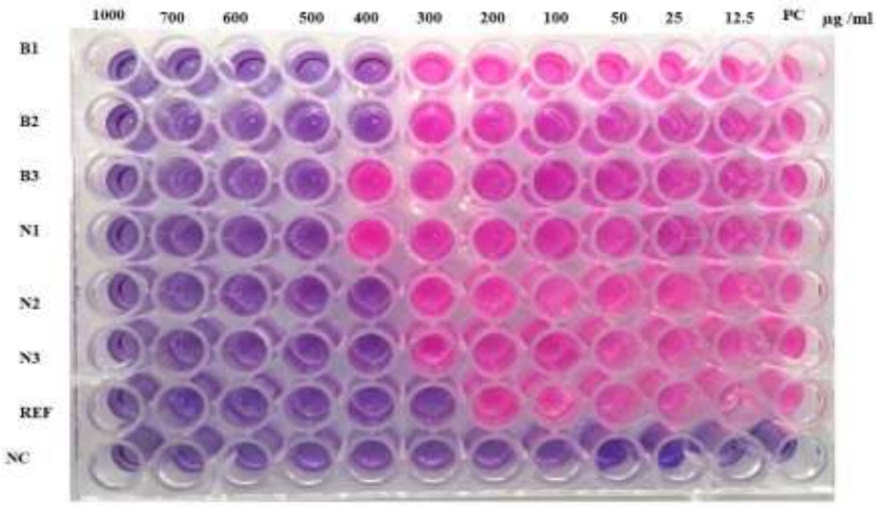

Figure 5. The minimum inhibitory concentrations (MICs) of N,N'-Bis (salicylidene) ethylenediamine against *K. pneumoniae* at the concentrations 100- 1000 ppm by Microtiter Plate Assay with Resazurin Dye.

Also, the minimum inhibitory concentrations of 3 *S. aureus* isolates by using the antibiotic N,N'-Bis (salicylidene) ethylenediamine were evaluated by microtiter plate assay with resazurin dye. The results revealed that the range of minimum inhibitory concentrations were (300-400 ppm) as showed in the figure 1. According to a study, the Schiff base ligands of the selected cationic complexes were different from salophen and salen types. In vitro activity was evaluated using Gram-negative (*Escherichia coli* and *Pseudomonas aeruginosa*) and Gram-positive (*Staphylococcus aureus* and MRSA). [(N,N'-bis(salicylaldehyde)-1,2-phenylenediamine] iron(III) chloride showed the best MIC90 value against Staphylococcus aureus (0.781 µg/ml = 1.93 µmol/L). This efficacy suggests that salophen-iron (III) complexes are potential lead structures for the development of further antimicrobial metal complexes (Baecker *et al*., 2021). Salicylaldehyde ethylenediamine showed effective inhibitory effects against the fungi *Aspergillus niger* (20 mM, 100 mg/ml), *Fusarium* spp. (17 mM, 100 mg/ml), and *Candida albicans* (32 mM, 100 mg/ml). Given that salicylaldehyde ethylenediamine and its lanthanide(III) complexes have demonstrated antimicrobial activity against bacterial and fungal isolates in vitro, ampicillin (between 17 and 20 mM) showed significant inhibitory effects against *Escherichia coli* (8 mM at 100 mg/ml), *Pseudomonas aeruginosa* (6 mM at 100 mg/ml), and *Pseudomonas aeruginosa* (7 mM at 100 mg/ml). mM) and *Klebsiella* (13 mM at 100 mg/mL) showed high antimicrobial effects (Mahmud *et al*., 2022).

CONCLUSION

Potentiodynamic polarization results show the effectiveness of N,N'-bis(salicylidene)ethylenediamine as a corrosion inhibitor for mild steel in H2SO4 aqueous solution. When the concentration of N,N'-bis(salicylidene)ethylenediamine is 500 ppm, the inhibition efficiency reaches 81.63%. Polarization results show that N,N'-bis(salicylidene)ethylenediamine is a mixed corrosion inhibitor, and its adsorption on the surface of mild steel follows the Langmuir adsorption isotherm. Negative ΔGads values indicate that the adsorption is spontaneous. The ability of N,N'-bis(salicylidene)ethylenediamine as a corrosion inhibitor has been theoretically confirmed, and the results are in good agreement with the experimental results.

Acknowledgements

The authors would like to thank all workers in Department of Chemistry, College of Science, Al-Nahrain University, Baghdad, Iraq.

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