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Studying the Effectiveness of an Expired Betamethasone Drug in Sulfuric Acid Solutions to Examine the Corrosive Behavior of Copper Using Weight Loss and Experimental Design

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Abstract: Utilizing expired pharmaceuticals as corrosion inhibitors for copper in acidic environments offers compelling advantages, including cost-effectiveness, reduced toxicity compared to traditional inhibitors, and contribution to pharmaceutical waste reduction through recycling. This study investigates the corrosion inhibition of copper in a sulfuric acid solution using varying concentrations of Expired Betamethasone Drug, employing weight loss and Experimental Design methods. The influence of temperature on copper's corrosion behavior is examined within the range of 293–333 K. Results show that inhibition efficiency increases with higher inhibitor concentrations but decreases with rising temperature. Thermodynamic analyses elucidate adsorption and activation processes, revealing that the adsorption of Expired Betamethasone Drug on copper surfaces is characterized as endothermic and spontaneous, aligning well with the Langmuir and Frumkin adsorption isotherms. The activation and free energies of inhibition reactions support a mechanism of physical adsorption. To establish the relationship between factors and responses, we employ response surface methodology (RSM) with regression statistical analysis and probabilistic assessment. Statistical analysis demonstrates highly significant quadratic models for inhibition efficiencies (IE) with a coefficient of multiple regressions (R^2) of 0.999. Further model validation confirms a strong fit (adjusted R^2 = 0.997), with experimental observations closely matching predictions and a highly significant model (Q^2 = 0.989). The findings reveal that this expired drug exhibits substantial inhibitory power, exceeding 96%, in both experimental and predictive calculations.

Keywords: Corrosion inhibition, Copper, Expired Drug, Adsorption isotherms, Thermodynamic parameters, Experimental Design

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1. INTRODUCTION

Copper stands out among other metals due to its unique combination of corrosion resistance, electrical and thermal conductivity, and mechanical properties (1). It is considered a relatively noble element, contributing to its resistance to rapid corrosion in various atmospheres and chemical environments. Even in corrosive electrolytes such as acids, it effectively shields itself from degradation by developing a protective, non-conductive oxide film (2).

Equipment such as heat exchangers, boilers, pipelines, coils, electrical boards, and circuits constructed from copper and copper alloys often find themselves close to corrosive environments within desalination systems or petroleum pipelines. This has led to numerous studies addressing the degradation of copper and copper alloys under various climatic conditions, including both natural and artificial settings. To protect metal and alloy surfaces from corrosion resulting from atmospheric attack, appropriate inhibitors can be applied (3,4).

Among these inhibitors, both inorganic and organic types are found. Organic compounds and their derivatives, such as azoles, amines, and amino acids, take precedence. Notably, the presence of heteroatoms like oxygen, nitrogen, sulfur, and phosphorus within organic compound molecules enhances their effectiveness as copper corrosion inhibitors (5-7). This phenomenon is attributed to the existence of vacant d orbitals in copper atoms, facilitating the formation of coordinative bonds with atoms capable of donating electrons. Additionally, interactions with rings containing conjugated bonds and pi electrons are also observed (8, 9).

In recent years, the utilization of expired medications as corrosion inhibitors for various metals and alloys has emerged as a novel challenge. These medications, which are increasingly prevalent in households, pharmacies, hospitals, and other sources, present an opportunity for repurposing as corrosion inhibitors. Notably, most of these compounds exhibit high solubility in aqueous solutions and maintain stability in diverse aggressive environments (10). Research has indicated that a significant portion of medications, approximately 90%, retain their active constituents and stability beyond their expiration dates (11,12). These findings suggest that expired medications can be safely repurposed for corrosion inhibition purposes. Their non-toxic attributes and minimal environmental impact position them as potential candidates to replace traditional toxic chemical corrosion inhibitors (13). Expired medications have even been recognized as part of the family of green corrosion inhibitors.

Furthermore, a comprehensive literature survey reveals that a wide range of pharmaceuticals has been successfully employed as sustainable corrosion inhibitors for various metals and alloys. These pharmaceuticals encompass a diverse group, including Phenobarbital (14), Modiaquine (15), Doxycycline (16), Tenormin (17), Ethambutol (18), Salazopyrin (19), Atenolol (20), Ciprofloxacin (21), Moxifloxacin, Betamethasone (22), Tetracycline and Streptomycin (23), Ibuprofen and Diclofenac (24), Telmisartan (25), Cephalothin (26), Tramadol (27), Cephapirin (28), Cefixime and Cefpirome (29), Glimepiride (30), Spironolactone (31), Povidone Iodine (32), Amoxicillin (33, 34), and more.

The statistical design of experiments (DOE) is a technique used to construct an experimental model, aiming to reduce the required number of tests compared to conventional methods. This is achieved by considering selected or all relevant parameters within the experiment. DOE also generates mathematical models for statistical assessment of influencing factors and potential interactions among variables (35, 36). Applying experimental design methods yields more precise results for final responses, such as inhibition efficiency (IE), and interactions among studied parameters. The response surface method (RSM) is an effective tool in this context (37, 38), consistently used for developing, enhancing, and optimizing experimental processes influenced by multiple factors (39). The Central Composite Design was employed to identify optimal inhibition efficiency. The corrosion inhibition efficiency was evaluated using the weight loss method, and collected data were used to formulate a predictive model for corrosion inhibition performance through ANOVA.

This research investigates the corrosion inhibition potential of betamethasone, an expired pharmaceutical drug, in acidic environments by employing the weight loss method. Additionally, it explores the interactive effects of inhibitor concentration, operating temperature, and immersion duration on inhibition performance using response surface methodology (RSM). The study also estimates and discusses various isotherm models and thermodynamic parameters related to inhibitor adsorption on the copper surface.

2. EXPERIMENTAL

2.1. Materials and methods

A test solution of 0.5 mol/L sulfuric acid was prepared by diluting analytical grade 98% H_2SO_4 with double-distilled water to a final volume of 50 mL. The copper specimen's surface was pre-treated by polishing with various abrasives (ranging from 600 to 1200), followed by washing with double-distilled water and then acetone. After drying, the specimens were weighed before immersion in the freshly prepared test solution. Subsequently, the copper specimens were retrieved, cleaned, and reweighed. Weight measurements were taken using an analytical balance before and after exposure, and recorded to the nearest five decimal places. The expired drug used in this research is Betamethasone 0.5MG/ML (0.05%) SOL.BUV (CELESTENE).

2.2. Weight loss measurements

Weight loss assessments were conducted using copper rectangular specimens. Each specimen was immersed in triplicate within a solution of 0.5 mol/L sulfuric acid, both in the absence and presence of various concentrations of expired Betamethasone drug. This procedure was carried out across different immersion periods and temperatures. The acquired weight loss data was then used to determine corrosion rate (CR), inhibition efficiency (IE), and surface coverage (θ) through the following equations (1,2 and 3) (40):

$$CR = (W - W_{Inh}) / S \times t \quad (1)$$

$$IE(\%) = 100 \times (CR - CR_{Inh}) / CR \quad (2)$$

$$\theta = IE / 100 \quad (3)$$

Where, $W - W_{inh}$ represents the weight loss, which is the difference in mass between the absence and presence of the inhibitor, expressed in milligrams (mg). The sample area S is given in square centimeters (cm^2), and the immersion time t is denoted in hours (h). CR represents the corrosion rate observed in the absence of the inhibitor, while CR_{inh} corresponds to the corrosion rate obtained in the presence of the inhibitor.

2.3. Adsorption Isotherm and Thermodynamic Parameter Determination

Adsorption isotherm studies provide a descriptive mechanism for understanding how organic inhibitors adsorb onto metal surfaces. The most suitable adsorption isotherm model that accurately characterizes the adsorption of expired Betamethasone drug on copper in a 0.5 mol/L sulfuric acid medium was determined by fitting various adsorption isotherm models, including Langmuir, Freundlich, Frumkin, Tempkin, Flory-Huggins, and El Awady, expressed in linear form as follows:

Langmuir adsorption isotherm is represented by Equation (4) (41):

$$C / \theta = 1 / K_{ads} + C \quad (4)$$

By taking the logarithm of both sides of Equation (4), we arrive at Equation (5).

$$\log(C / \theta) = \log C - \log K_{ads} \quad (5)$$

Freundlich adsorption isotherm (42):

$$\log(\theta) = n \log C + \log K_{ads} \quad (6)$$

Frumkim adsorption isotherm model (43):

$$\log\left[C(\theta / 1-\theta)\right] = 2\alpha\theta + 2.303 \log K_{ads} \quad (7)$$

Temkin adsorption isotherm model (44):

$$\theta = \ln C + K_{ads} \quad (8)$$

Flory-Huggins adsorption isotherm is expressed by Equation (9) (45):

$$\log(\theta / C) = b \log(1-\theta) + \log K_{ads} \quad (9)$$

El-Awady adsorption isotherm is formulated as follows (46):

$$\log(\theta / 1-\theta) = y \log(C) + y \log K_{ads} \quad (10)$$

where *C* represents the concentration of the inhibitor, K_{ads} is the adsorption-desorption constant, *θ* denotes the degree of surface coverage by the inhibitor, *n* is the positive constant known as the Freundlich exponent, *a* describes the lateral interaction term characterizing the interaction within the adsorbed layer, *b* serves as the size parameter, measuring the substitution of adsorbed water molecules with a specific inhibitor molecule, and *y* indicates the number of inhibitor molecules occupying one active site.

The linear regression coefficient of determination (R^2) was employed to assess the model that best aligns with the experimental values.

The expression for the change in Gibbs free energy of adsorption, as presented in Equation (11) (47), was employed to explore the feasibility and nature of the adsorption process.

$$\Delta G_{ads} = -RT \ \ln(55.5\ K_{ads}) \quad (11)$$

Where, K_{ads} represents the adsorption equilibrium constant obtained from the isotherm, and the value 55.5 corresponds to the molar concentration of water in the solution

By utilizing the thermodynamic relation (Eq. 12), it becomes possible to calculate the changes in the enthalpy of the adsorption process at different temperatures (48).

$$\Delta G_{ads} = \Delta H_{ads} - T\Delta S_{ads} \quad (12)$$

The change of ΔG_{ads} concerning temperature forms a straight line with an intercept ΔH_{ads} and a slope ($-\Delta S_{ads}$).

2.4. Determination of Thermodynamic Activation Parameters

The inhibitory mechanism of the investigated inhibitor can be elucidated by examining the thermodynamic and activation parameters. The impact of temperature on the inhibitory effect can be aptly elucidated through the utilization of the Arrhenius equation. This equation is represented as follows (32):

$$CR = A \times \exp(-\Delta E_a / RT) \quad (13)$$

where CR denotes the corrosion rate of copper, A represents the Arrhenius pre-exponential factor, ΔE_a (kJ/mol) represents the activation energy, R signifies the gas constant (8.314 J/mol K), and T represents the temperature (K).

The plot of ln of corrosion rate, against 1/T in Eq. (13) gives a slope from which the activation energy, was estimated.

The activation enthalpy (ΔH_a) and activation entropy (ΔS_a) can be determined by analyzing the slope ($-\Delta H_a/R$) and intercept [$\ln(R/Nh) + (\Delta S_a/R)$] of the plot ln(CR/T) versus 1/T. This analysis employs the following equation for the transition state (6):

$$ln(CR/T) = [ln(R/Nh)+(\Delta S_a/R)]-\Delta H_a/RT \quad (14)$$

Where h represents Planck's constant, N stands for Avogadro's number, ΔS_a signifies the activation entropy, and ΔH_a indicates the activation enthalpy.

2.5. Design of experiments study

In this paper, the experimental design and statistical analysis were performed using MODDE Software Version 9.1. The individual and interactive effects of the corrosion process on the independent factors were determined using the standard Response Surface Methodology (RSM) based on the Multiple Linear Regression method. Specifically, the

process variables investigated in sulfuric acid included the concentration of the inhibitor (A), temperature (B), and immersion time (C). These three variables were examined at three different levels. The settings and levels of each parameter are provided in Table 1.

Table 1: Optimization of Betamethasone Drug Inhibition Efficiency on Copper in Acid Medium: Weight Loss and RSM Approach.

Variables	Levels		
	– 1	**0**	**+ 1**
A: Inhibitor concentration (%,v/v)	1	2.5	5
B: Temperature (°C)	20	40	60
C: Immersion time (h)	0.5	1	1.5

3. RESULTS AND DISCUSSION

3.1. Adsorption Isotherm and Determination of Adsorption Thermodynamic Parameters

3.1.1. Adsorption Isotherm

The R^2 values associated with each isotherm model presented in Table 2 were used to identify the most suitable model. While the data in Table 2 exhibited fits with Freundlich, Langmuir, Frumkin, Temkin, Flory-Huggins, and El-Awady's isotherms, the Langmuir and Frumkin isotherms demonstrated the highest R^2 values. This observation suggests that both isotherms provide the most accurate description of the adsorption mechanism of the Betamethasone drug on copper in a sulfuric acid medium. Therefore, the Langmuir and Frumkin isotherms are considered appropriate for evaluating the parameters of adsorption.

Table 2: R^2 values for the various adsorption isotherms considered.

T (K)	Langmuir	Freundlich	Frumkin	Temkin	Flory-Huggins	El-Awady
293	0.989	0.817	0.972	0.791	0.886	0.660
303	0.987	0.932	0.995	0.884	0.879	0.722
313	0.987	0.958	0.998	0.904	0.868	0.765
323	0.993	0.983	0.995	0.942	0.883	0.887
333	0.981	0.971	0.987	0.918	0.850	0.887

3.1.2. Determination of Adsorption Thermodynamic Parameters

By utilizing data obtained from the Langmuir and Frumkin isotherms, it became feasible to determine the equilibrium adsorption constant (K_{ads}) and, subsequently, the free adsorption energy (ΔG_{ads}) of the investigated inhibitor using Equation 11. Table 3 displays positive adsorption equilibrium constants, indicating the feasibility of the inhibitor's adsorption onto the metal surface (49). Furthermore, these equilibrium constants exhibit an increase with rising temperatures.

The presence of negative values for ΔG_{ads} in both Langmuir and Frumkin isotherms indicates the spontaneous nature of the inhibitor adsorption process, with these values falling below -20 kJ/mol. These lower values can be attributed to the electrostatic interaction between the composites and the metal surface (physisorption). The adsorption enthalpy and entropy were calculated using the adsorption equilibrium constant obtained from the Langmuir model and Equation 12. The positive values of ΔH_{ads} (11.13 kJ/mol) validate that the adsorption of inhibitors is an endothermic process (50). Furthermore, the positive sign of ΔS_{ads} (75.81 J/mol K) indicates an increase in the entropy of the process. This process involves both the adsorption of organic compounds (Org) and the desorption of water molecules at the electrode surface. The positive values of ΔS_{ads} suggest an augmented level of disorder among the reactant molecules on the metal electrode surface. This phenomenon serves as a significant driving force for the adsorption of inhibitor molecules onto the metal surface. Collectively, these findings underscore the substantial adsorption of the composites onto the metal surface.

Table 3: Adsorption parameters of copper corrosion in the presence of Betamethasone drug in 0.5 M H_2SO_4 medium.

T (K)	Frumkin		Langmuir	
	K_{ads}	ΔG_{ads} (kJ/mol)	K_{ads}	ΔG_{ads} (kJ/mol)
293	0.022	-0.53	1.557	-10.86
303	0.091	-4.09	2.142	-12.03
313	0.133	-5.19	2.449	-12.78
323	0.177	-6.13	2.566	-13.31
333	0.224	-6.98	2.836	-14.01

3.2. Determination of Thermodynamic Activation Parameters

Data presented in Table 4 indicate that the activation energy (ΔE_a) of the inhibited solution in this study increases with higher inhibitor concentrations, suggesting strong adsorption of inhibitor molecules onto the metal surface (7). The lower or unchanged values of ΔE_a for the inhibited systems compared to the blank test indicate a chemisorption mechanism, whereas the higher values of ΔE_a in the presence of Betamethasone drug suggest a physical adsorption mechanism (51).

Table 4: Values of activation parameters for copper in 0.5 M H_2SO_4 medium in the absence and presence of various concentrations of Betamethasone drug.

C (%,V/V)	$R^2_{(Eq.13)}$	ΔE_a (kJ/mol)	$R^2_{(Eq.14)}$	ΔH_a (kJ/mol)	$\Delta H_a=\Delta E_a$-RT (kJ/mol)	$-\Delta S_a$ (J/mol K)	$\Delta G_{a(at.313K)}$ (kJ/mol)
Blank	0.999	62.23	0.999	59.63	59.62	89.37	87.60
1	0.994	76.82	0.994	74.23	74.21	48.84	89.51
2	0.999	75.99	0.999	73.40	73.39	53.33	90.09
3	0.997	74.72	0.997	72.13	72.12	59.10	90.63
4	0.995	83.97	0.995	81.38	81.37	32.10	91.42
5	0.997	91.92	0.997	89.32	89.32	12.73	93.30

The positive values of activation enthalpy in both the absence and presence of inhibitors suggest an endothermic nature of the copper dissolution process (52). The obtained ΔH_a values are in good agreement with the calculated ΔH_a from the equation $\Delta H_a=\Delta E_a-RT$ at the average experimental temperature (T = 313K). This result suggests that the corrosion process follows an unimolecular reaction mechanism involving the evolution of hydrogen gas (51). Additionally, an increase in the activation entropy values leads to a decrease in the system's disorder due to the adsorption of Betamethasone drug molecules on the copper surface.

When comparing the ΔG_a (calculated as the average at 313K) values of the process in the presence of the inhibitor to those in its absence, higher values are observed, indicating the dominance of physisorption as the mechanism. Conversely, lower ΔG_a values are indicative of chemisorption (53).

3.3. Design of experiments study

3.3.1. Optimization of inhibition efficiency using RSM

A total of 17 experimental runs were conducted to obtain the responses (inhibition efficiency, IE) of the dependent variables (Inhibitor concentration, A; Temperature, B; and Immersion time, C) as presented in the experimental design (Table 5).

The optimal conditions that yield the highest inhibition efficiency (IE) were determined using Response Surface Methodology (RSM). For the three-factor inputs, the second-order polynomial equation is provided below (Equation 15):

$$\mathrm{IE} = 68.49 + 14.57\,A - 9.69\,B - 2.50\,C + 1.72\,A^2 + 0.79\;B^2 - 0.29\,C^2 + 4.18\,AB - 0.62\,AC + 2.89\,BC \quad (15)$$

Table 5: Responses of experimental design for inhibition process of copper in the presence of Betamethasone drug in 0.5 mol/L H_2SO_4.

Exp No	Run	Factors			Response (%)	
		A (%, v/v)	B (°C)	C (h)	IE_{Obs}	IE_{Pred}
1	15	1	20	0.5	75.14	74.81
2	6	5	20	0.5	96.23	96.84
3	3	1	60	0.5	41.06	41.26
4	5	5	60	0.5	80.15	80.05
5	12	1	20	1.5	65.23	65.26
6	13	5	20	1.5	85.06	84.78
7	10	1	60	1.5	43.98	43.29
8	2	5	60	1.5	79.31	79.57
9	14	1	40	1.0	54.89	55.65
10	11	5	40	1.0	85.31	84.80
11	8	3	20	1.0	79.04	78.98
12	7	3	60	1.0	59.30	59.60
13	17	3	40	0.5	71.12	70.71
14	9	3	40	1.5	65.04	65.70
15	4	3	40	1.0	67.93	68.49
16	16	3	40	1.0	68.37	68.49
17	1	3	40	1.0	69.71	68.49

The histograms depicting the effects of coefficients on the inhibition efficiencies (IE) of the Betamethasone drug are presented in Figure 1. The variables with the most significant impact on IE are inhibitor concentration (A), while the influences of temperature (B) and immersion time (C) are comparatively smaller. Coefficients in the model characterized by positive values denote a synergistic effect, whereas negative values indicate an antagonistic effect (54). Among the model factors, A^2, B^2, AB, and BC positively contribute to the formulation, whereas C^2 and AC exert a negative influence on the developed model.

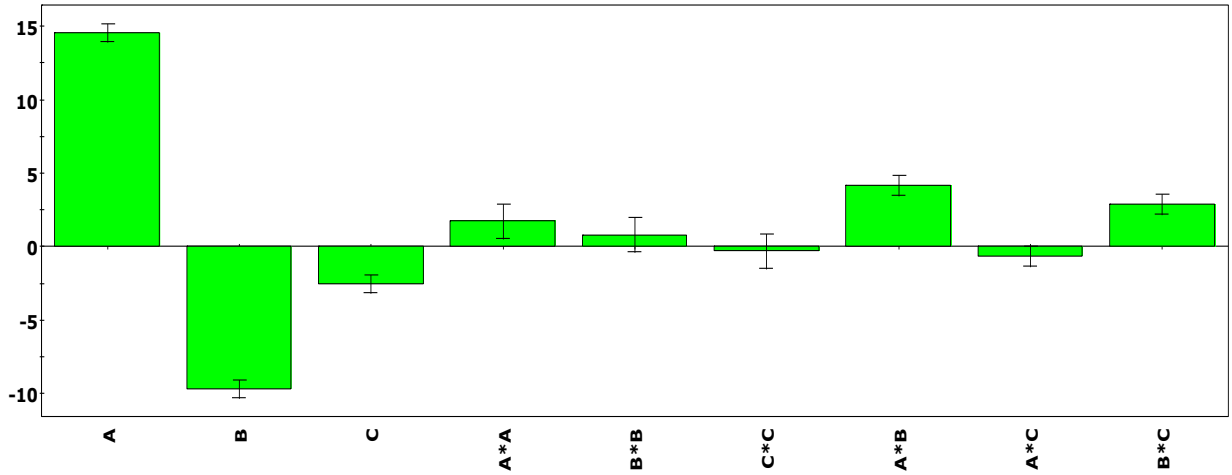

Figure 1: Coefficients plot

In Figure 2, a clear linear trend is evident in the diagnostic plots illustrating the relationship between predicted and experimental inhibition efficiency. These trends affirm the design model's capability to predict not only the inhibition efficiency of the expired drug but also the response variables within the experimental data. The findings from this study on expired medication demonstrate a very

significant inhibitory capability, exceeding 96%, both in experimental and predictive calculations. This inhibition efficiency (IE%) is considered among the best inhibitors in the literature.

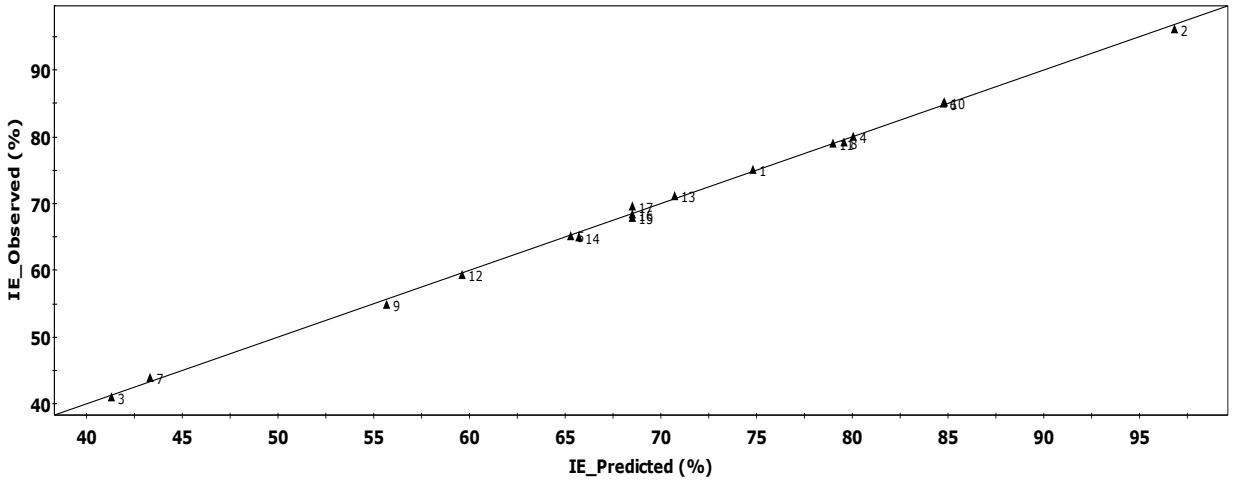

Figure 2: Diagnostic representation of predicted versus observed inhibition.

3.3.2. Main Effects

The effects of each parameter under consideration are shown in Figure 3. It is important to note that the values represented by each point correspond to the average corrosion inhibition efficiencies obtained at that specific level, regardless of other parameter variations. The overall mean is plotted across each panel. As the concentration of the Betamethasone drug increased, there was a corresponding increase in inhibitor efficiency (IE%). Conversely, the decrease in corrosion inhibition efficiency with the elevation of temperature (55), as observed in this study (Figure 3), suggests a physisorption mechanism.

The decline in inhibition efficiency over time could be attributed to the desorption or dissolution of adsorbed inhibitor molecules. Optimal efficiencies were achieved when copper was immersed in a solution containing 5% (v/v) Betamethasone drug for a duration of half an hour, at a temperature of 20°C. Conversely, the lowest IE was observed when copper was exposed to a solution with 1% (v/v) Betamethasone drug, immersed for 1.5 hours, and maintained at a temperature of 60°C.

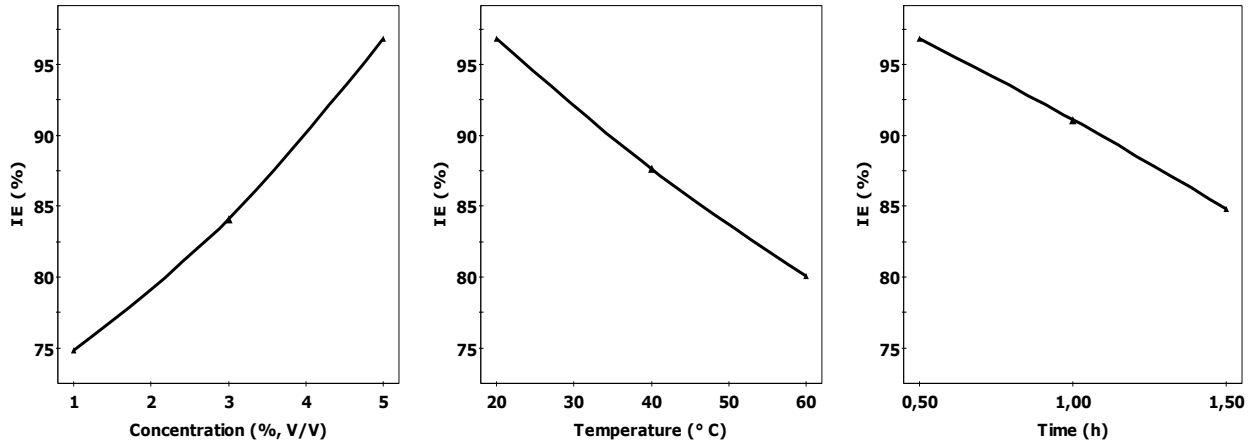

Figure 3: Weight Loss and RSM Optimization of Betamethasone Drug's Inhibition Efficiency on Copper in Sulfuric Acid.

3.3.3 Response Surface and Contour Plots

To identify the optimal zone of inhibition efficiency (IE), surface plots with contour plots have been generated, as depicted in Figures 4 and 5. Given that inhibition efficiency is influenced by various process variables, a thorough investigation becomes essential. This investigation is achieved by constructing contour plots to depict the interplay of two independent variables—working temperature and inhibitor concentration—across different immersion periods (Figure 5).

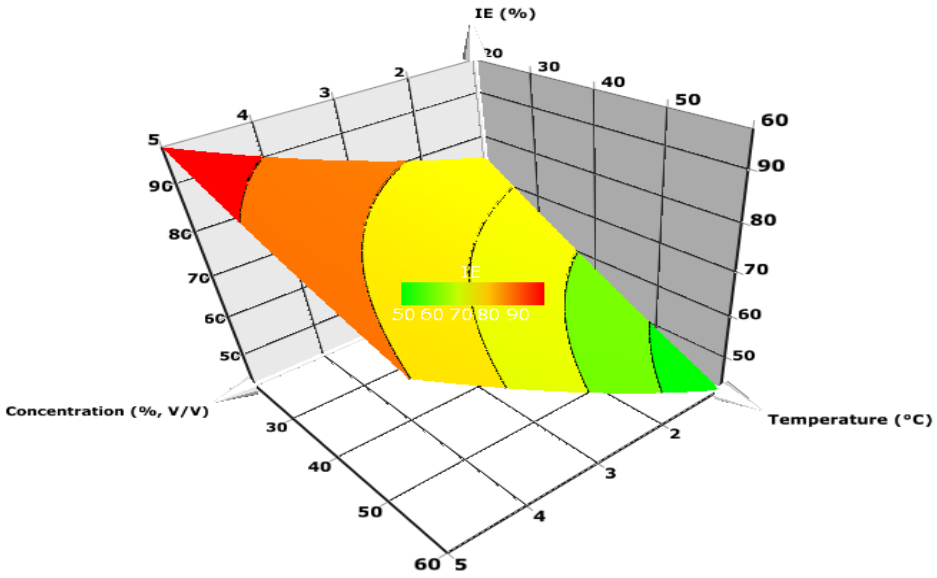

Figure 4: Response Surface Plots of the Effects of Temperature and Inhibitor Concentration on Inhibition Efficiency at Half an Hour.

As evident from both figures, the inhibition efficiency increases with decreasing temperature for a given inhibitor concentration. This decrease in IE (%) can be attributed to the desorption of the inhibitor molecule from the metal surface, leading to the process of physical adsorption.

Figure 5 reveals that as the inhibitor concentration ranges from the minimum to the maximum, IE (%) increases with decreasing temperature and shorter immersion times. For a fixed Betamethasone concentration, the IE decreases with prolonged immersion time but remains higher for higher inhibitor concentrations. The IE attains its peak value at the lowest temperature (20 °C) and shortest immersion time (0.5 h), along with the highest concentration of Betamethasone drug, as illustrated in Figure 5. These results align with findings reported in the literature (56).

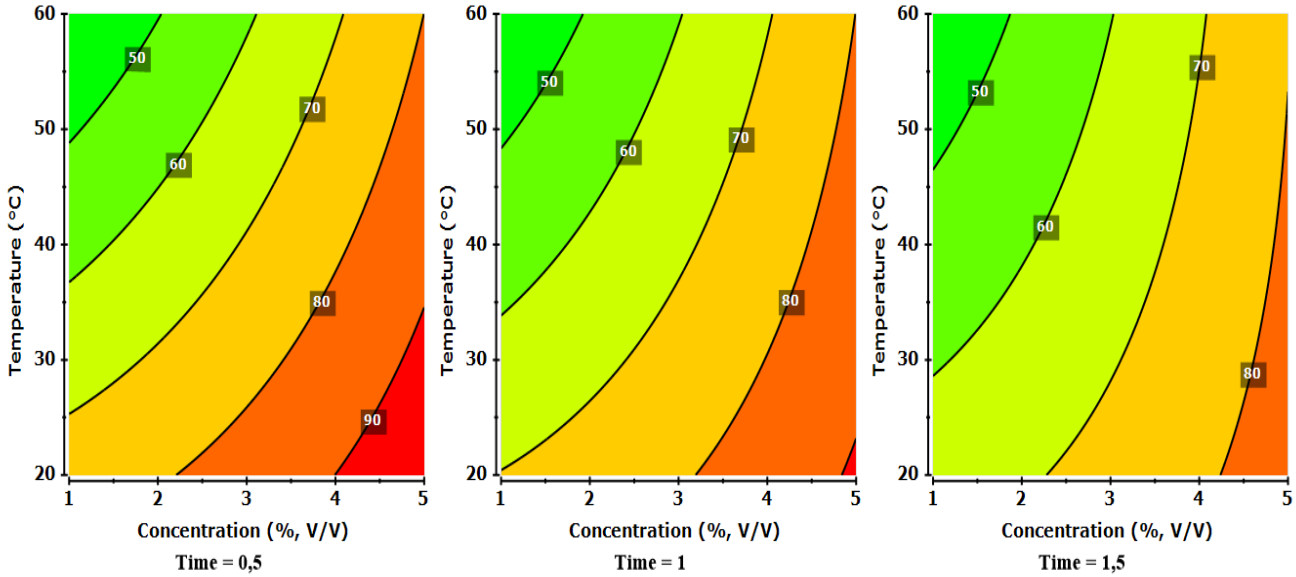

Figure 5: 4D-Contour Plots Showing the Effect of Temperature and Concentration on Inhibition Efficiency at Various Times.

3.1. Statistical test and analysis of models

The quadratic model was developed and applied to the dataset, with the findings presented in the fit plot summary (Figure 6). This comprehensive overview provides valuable insights into the model's robustness and efficacy, encompassing critical parameters such as Model Validity (0.911), Reproducibility (0.996), R^2 (0.999), and Q^2 (0.989).

The current model's prediction of more than 99.9% response variability is shown by the determination coefficient (R^2) value of 0.999. A model is classified as excellent when its Q2 value exceeds 0.9 (56). Furthermore, in this study, a reliable model typically exhibits a difference between R^2 and Q^2 of less than 0.3; here, the difference is merely 0.01. A Model Validity bar exceeding 0.25 indicates the absence of Lack of Fit in the model. In this study, a value of 0.996 is nearly equivalent to unity, signifying a high level of reproducibility.

Analysis variance (ANOVA), which is shown in Table 6, ensured the accuracy of the statistical analysis calculation. P-values and F-values serve as valuable metrics in the context of ANOVA, used to assess the significance of models, specific experimental variables, and their interactions (57). When a model's P-value is below 0.050 and its F-value is significant, it is considered highly significant in statistics.Moreover, with model terms, a P-value less than 0.050 indicates the significance of the corresponding terms, while a value exceeding 0.100 suggests that the terms are not deemed significant (58). A strong significance of the regression model was found utilizing analyses employing an F-value of (581.28) with a low probability "P" value (P= 0.000) at the 95% confidence level. The predicted-R2 value for the model and the corresponding adjusted-R2 value were in good agreement because their difference was less than 0.20 (59). It was determined that the model was highly significant, and values for R^2 and R^2 Adj exceeding 0.99 demonstrated an exceptional agreement between predicted and experimental inhibition efficiency in the drug betamethasone (36). A robust model with a low RSD value closely fits the observed results with the expected values (56).

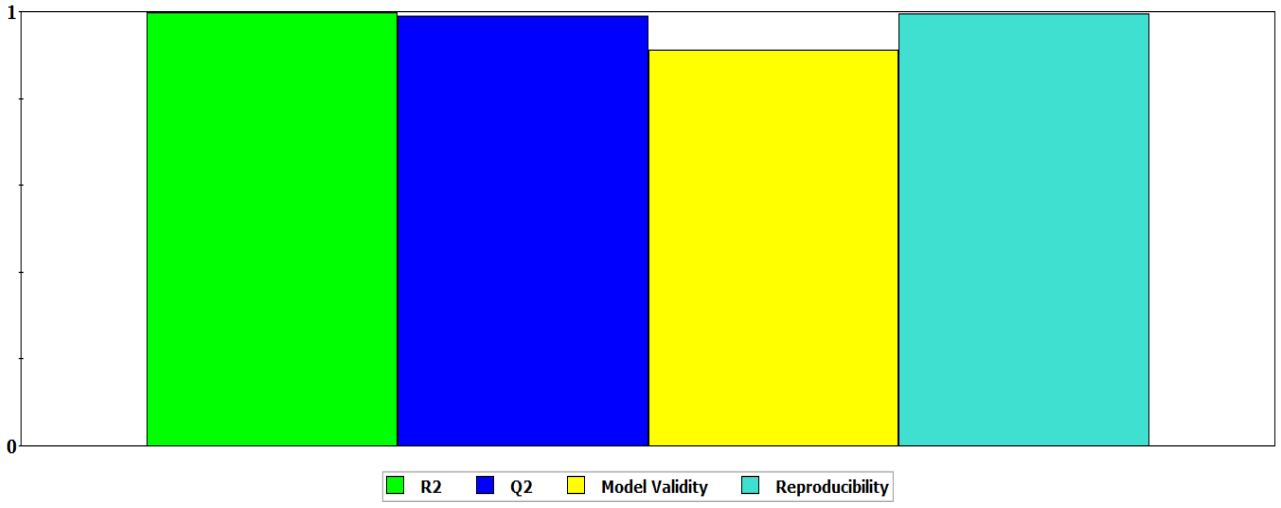

Figure 6: Summary of fit plot showing model fit (R^2), predictability (Q^2), model validity, and reproducibility.

Table 6: Analysis of Variance for the Quadratic Model of Inhibition Efficiency.

	DF	Sum of Squares	Mean Square	F	p	SD
Total	17	86221.9	5071.87			
Constant	1	82862.4	82862.4			
Total Corrected	16	3359.49	209.968			14.4903
Regression	9	3355	372.778	581.28	0.000	19.3075
Residual	7	4.48914	0.641306			0.800816

	Q^2 =0.989	Cond. no.=4.438
	R^2 =0.999	RSD=0.8008
	R^2 Adj.= 0.997	Conf. lev.=0.95

4. CONCLUSION

In conclusion, Expired Betamethasone drug proved to be a highly effective corrosion inhibitor for copper in an H_2SO_4 solution, ranking among the best inhibitors in the literature. It demonstrated an impressive inhibitory capability, exceeding 96%, in both experimental and predictive calculations.

The adsorption behavior of this inhibitor on copper in a sulfuric acid solution was investigated using Langmuir and Frumkin adsorption isotherms, along with the consideration of Gibbs' free energy. The negative ΔG_{ads} indicates spontaneous adsorption, suggesting a physical adsorption mechanism on the copper surface.

Our corrosion inhibition efficiency (IE) model, developed through response surface methodology (RSM), exhibited an excellent fit, with Q^2 values exceeding 0.989, indicating exceptional model performance. Additionally, the utilization of R^2 statistics, appropriate precision, and diagnostic plots served as pivotal measures to validate the accuracy and comprehensiveness of the IE models.

5. ACKNOWLEDGMENTS

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