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Response Optimisation and Modelling of Experimental Data on the Performance of *Lasienthera africanum* Leaves Extract as a Corrosion Inhibitor on Mild Steel in Hydrochloric-Induced Environment

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Abstract. In this study, the CCD response surface methodology was used to model and optimise the performance of *Lasienthera africanum* leaves extract (LALE) as a corrosion inhibitor on mild steel. The experimental parameters were assessed at different immersion time and inhibitor concentration to determine the optimum conditions for corrosion mitigation. Using experimental results of the corrosion characteristics such as the weight loss, corrosion rate, and inhibition efficiency of LALE, new models were developed, the significance of which was tested using variance analysis. The developed RSM models of WL, CR, and IE were accurate and reliable, and their P-values were 0.0001, which is less than 0.05. Likewise, the R^2-statistics (R^2, adjusted-R^2, and predicted-R^2), adequate precision, and diagnostic plots were also used as a means to ascertain the degree of accuracy and adequacy of the WL, CR, and IE models. In addition, optimization of the corrosion inhibition process for LALE revealed that the optimum conditions for maximum IE, minimum WL, and CR were achieved at a concentration of 93.93 ppm and an immersion time of 228 hrs. Under these settings, the inhibition efficiency, weight loss, and corrosion rate were 93.85%, 0.294g and 3.267 mm/y, respectively. Therefore, the models are considered ideal for prediction with a confidence level of 95%, and the optimal combination is suitable for the corrosion inhibition process design. Hence these models can be recommended for applications such as oil well acidizing and pickling pipelines.

1. Introduction

Hydrochloric acids are frequently employed in various industrial applications such as oil well cleaning, pickling, acid descaling, and acidification. However, it is important to note that these acids exhibit a high level of corrosiveness towards mild steels [1]. The mitigation of corrosion in steel holds significant importance in several industrial applications. One effective method for alleviating the challenges posed by corrosion is the use of corrosion inhibitors [2]. Corrosion inhibitors are available in a diverse range of types [3-6], encompassing inorganic salts, rare earth compounds, organic molecules, and plant-derived natural substances. Natural compounds formed from vegetable and plant components possess numerous advantages in comparison to synthetic chemicals. These advantages include low cost, biodegradability, abundance, and eco-friendliness [6]. The development of chemical corrosion inhibitors has resulted in increased costs, adverse environmental impacts, and potential risks to human health [7].

In the oil and gas industry, mild steel is widely used in constructions and applications such as upstream platforms, transportation pipelines, processing facilities, and fuel storage facilities. Mild steel is widely used because of its affordability, durability, and versatility [8]. Nevertheless, an increase in pH levels in the environment in use, would result in an increased rate of precipitation and the formation of deposits, eventually leading to under deposits corrosion. The key factor contributing to corrosion in mild steel inside a moist environment is a reduction in pH value, whereas conversely, an increase in pH value would result in a mitigating impact. Hence, mild steel continues to be the preferred material for a significant majority of applications, although the existence of other corrosion-resistant materials manufactured by contemporary industry. Nevertheless, corrosion-resistant materials lack the economic viability to completely replace mild steel as the preferred material.

One of the most common precautionary measures against corrosion is the use of an inhibitor [9–10]. It is common knowledge that one way to shield metal from the corrosive effects of its surrounding environment is to take preventative measures against the corrosion process [11]. It has been postulated that organic molecules containing oxygen, nitrogen, and phosphorus are especially efficient at militating against corrosion related effects on metals when exposed to an acidic environment [12]. Extensive research has been conducted to investigate the anticorrosion capabilities of plant extracts derived from a wide range of different plant sources. The utilisation of plant extracts for corrosion control has demonstrated efficacy due to the presence of phytochemical constituents [13–19]. Scientists are continually investigating the potential benefits of plant species for their ability to serve as environmentally benign metal inhibitors in both alkaline and acidic environments [20–21].

Several plants have been shown to be effective inhibitors in corrosion control and mitigation. Organic inhibitors have been extracted from plants such as *Eucalyptus camaldulensis* [22], *Ricinus communis* [23], *Artemisia herba alba* [24], Ginko leaves *[25], Thyme* leaves [26], C*arica papaya* [27], I*rvingia gabonensis* [28], and C*offee senna* [29]. All of them were shown to have components whose interactions enhance inhibition on the surface of mild steel.

Lasienthera africanum ("Editan") is a member of the order Celestrales, which consists of thirteen fundamental tree and shrub families. It belongs to the Icacinaceae family. These specific plants and shrubs have both medicinal and edible potential. It is consumed as a vegetable in the southern part of Nigeria [30]. However,there has been no investigation into whether the plant's essential leaves can be utilised to control and minimize the corrosion rate of mild steel in hydrochloric solution. Various researchers have explored the use *Lasienthera africanum extract* (LAE) for corrosion control under diverse conditions. Akinyemi [31] investigated LAE as an organic inhibitor for aluminium and mild steel in HCl medium. Their study revealed impressive corrosion inhibition efficiencies of 99.56% for aluminium and 94.93% for mild steel at an extract concentration of 0.6g/l, employing the Weight Loss method. Okuma et al. [19] also explored LAE's inhibitive effect on HCl medium and found a substantial 98.6% inhibition efficiency for mild steel. Fayomi et al. [32] delved into the impact of temperature variation on LAE's inhibitive absorption in 0.5M HCl, establishing inhibition efficiencies of 93.8% at 303K and 87.3% at 313K.These studies collectively highlight LAE's potential in preventing corrosion in carbon steel samples, considering various influencing parameters. Experimental design methods prove invaluable in optimizing the number of experiments, yielding more accurate results for key responses (WL, CR, and IE) and the interactions among studied variables or parameters. Consequently, the concurrent assessment of various parameters on WL, CR, and IE can be expedited through these design methods, facilitating a comprehensive understanding of LAE's performance in corrosion control.A valuable and practical approach in this context is the utilization of the Response Surface Method (RSM) [33-35] . RSM comprises a collection of statistical and mathematical techniques highly useful for simulating and assessing problems where the response variable is influenced by numerous independent parameters, with the ultimate goal of optimizing these responses [36]. A key advantage of RSM lies in its ability to significantly reduce the number of required tests when evaluating multiple variables and their interrelationships. Furthermore, RSM proves advantageous for developing predictive models for corrosion rate (CR) and inhibition efficiency (IE) associated with specific inhibitors [37,38].This review will delve into the application of RSM and Analysis of Variance (ANOVA) in the exploration of an inhibitor's effectiveness in mitigating the corrosion process.

Chung et al. [39] employed the Response Surface Method (RSM) to assess changes in corrosion current density for carbon steel samples across different media. They conducted electrochemical experiments, analysing corrosion current density at varying pH values, chloride, and sulphate

concentrations. Using experimental data, the authors constructed a mathematical model to determine corrosion current density. Their findings indicated the model's success within the studied parameter ranges, with chloride concentration identified as the primary factor influencing the corrosion process. Yamin et al. [38] delved into the inhibition efficiency (IE) of a novel organic corrosion inhibitor featuring oxygen, sulphur, and nitrogen heteroatoms in its structure for mild steel samples immersed in 1 M HCl solution, employing RSM. They leveraged laboratory data from weight loss experiments at different reagent concentrations, temperatures, and times to develop a quadratic formula for predicting corrosion prevention effectiveness. Their analysis underscored immersion time and temperature as two pivotal parameters significantly impacting the corrosion inhibitor's efficiency.
Kumari and Lavanya [40] optimized the corrosion inhibition performance of a Schiff base in HCl solution for mild steel samples through electrochemical tests and RSM. They conducted tests at varying acid concentrations, temperatures, and reagent concentrations, measuring experimental data on corrosion rate (CR) and IE. Their regression model for corrosion inhibition efficiency proved valuable for prediction, closely aligning with laboratory data. Omran et al. [34] harnessed RSM to optimize corrosion inhibition using green inhibitors for mild steel in sulfuric acid. Their approach involved electrochemical testing and modelling based on experimental data, supported by Analysis of Variance (ANOVA). The authors identified pH and reagent concentration as key parameters for corrosion inhibition, with the proposed model demonstrating high accuracy. Drawing from this literature review, it becomes evident that temperature, inhibitor concentration, and exposure time in aggressive environments significantly influence weight loss (WL), CR, and IE. Consequently, this study aims to experimentally assess these parameters' impact on LALE's IE in 0.5 M hydrochloric acid solution for mild steel samples, involving the measurement of WL, CR, and IE values. The resulting experimental data will undergo RSM analysis to formulate mathematical models for predicting WL, CR, and IE across a wide range of influencing factors. This work introduces novelty by developing a new model for predicting the effectiveness of LALE corrosion inhibition, considering time and inhibitor concentration simultaneously. While LALE has received substantial attention in the literature, a predictive model for its inhibitory effectiveness has not yet been established, making this study a significant contribution to the field.

2. Materials and Methods

2.1 Data collection

The data utilised for the analysis and development of the design was derived from experimentally generated data. Gravimetric methods were employed to acquire the experimental corrosion data [41]. The anti-corrosion efficiency of *Lasienthera africanum* was evaluated by subjecting it to 0.5M hydrochloric acid (HCl) solutions at room temperature. The concentrations of the solutions were varied at 20, 40, 60, 80, and 100 parts per million (ppm). The experiments were conducted at a temperature of 25°C. In order to assess weight loss, test coupons made of mild steel with dimensions of 9 mm by 18 mm by 3 mm were prepared. These specimens were measured and afterwards submerged in a 200-ml beaker containing a test media. The immersion durations were set at 48, 96, 144, 192, 240, and 288 hours. The test media was used both with and without the inclusion of *Lasienthera africanum* extract. Following the designated duration, they were retrieved. The corrosion products were removed with the application of distilled water, acetone, and a subsequent air-drying procedure. The specimens underwent additional weighing procedures to ascertain their mass reduction. Subsequently, the weight loss of the specimen was recorded and calculated at each predetermined time interval. The experimental data were collected and analysed using equations (1) to (3) as derived from previous research [41].

$$\text{Î''}W = w_i\text{â\`'}w_a \quad (1)$$

$$\text{CR} = \frac{W_{bl}\text{â\`'}W_{in\text{â„Ž}}}{Area(m^2)\text{Ã—}Time(day)} \quad (2)$$

$$\text{IE\%} = \frac{W_{bl}\text{â˜}W_{in\text{â„Ž}}}{W_{bl}} \times \frac{100}{1} \qquad (3)$$

W_i and W_a represent the coupon's initial and final weights, respectively. w_{bl} and w_{inh} represent, respectively, the weight loss values for the blank and inhibited conditions.

2.2 Corrosion inhibitor

In this study, *Lasienthera africanum* leaf extract (LALE) was used to study corrosion rate and inhibition effectiveness in a 0.5M HCl solution at various values of exposure time, and inhibitor concentration. The Phytochemicals organics compounds of LALE is presented in Table 1. As shown in the Table, the inhibitor contains alkaloids, tannins, flavonoids and saponins, which can provide high inhibition performance [19,22,28]. The application of LALE inhibitor for corrosion control by various researchers was reviewed in the Introduction section.

Table 1 Phytochemicals present in LALE inhibitor [19]

Phytochemical	Occurrence
Alkaloids	++
Tannins	++
Flavonoids	++
Saponins	++

++ = Present in appreciable quantity

2.3 Optimization Study with Response Surface Methodology

The application of the Response Surface Methodology (RSM) in conjunction with central composite design (CCD) tool of Design Expert (DOE) software version 11 facilitated the process of modelling and improved the inhibitory efficiency (IE) as well as other experimental corrosion metrics. The study employed a quadratic layout model. The independent factors in this study were the concentrations of inhibitors (20, 40, 60, 80, and 100 ppm) and the duration of immersion time (48, 96, 144, 192, and 240 hrs). The dependent variables measured were weight loss (WL), corrosion rate (CR), and inhibition efficiency (IE). A total of 30 independent experiments were done in order to gather data pertaining to the dependent variable. The factors levels is presented in Table 2.

Table 2 Variables level of independent parameter for central composite Design (CCD)

Independent Parameters	Low level (-1)	High level (+)
Immersion time, (hours)	48	288
Inhibitor Concentration (ppm)	20	100

3 Results and Discussion

3.1 Response Surface Analysis

The Response surface analysis of mild steel in the induced acid corrosion is presented in Table 3. A total of 30 experimental runs were analysed from the design tool.

Table 3 Experimental results design layout

		Factor 1	Factor 2	Response 1	Response 2	Response 3
Std	Run	A:Immersion time	B:Inhibitor Concentration	WL	CR	IE
		hours	ppm	g	mm/yr	%
14	1	48	20	0.0493	2.547	57.4
3	2	48	40	0.0438	2.2628	62.18
6	3	48	60	0.0312	1.6119	73.1
24	4	48	80	0.0285	1.4723	97.4
15	5	48	100	0.0221	1.1418	98.6
8	6	96	20	0.0822	2.7547	86.8
16	7	96	40	0.0974	2.516	84.3
1	8	96	60	0.0898	2.3197	85.6
29	9	96	80	0.0815	2.1053	95.8
22	10	96	100	0.0695	1.7952	96.8
20	11	144	20	0.1313	2.2611	87.2
26	12	144	40	0.1389	2.392	86.5
11	13	144	60	0.1149	1.9786	88.8
5	14	144	80	0.1382	2.3799	94.7
28	15	144	100	0.1732	2.9827	95.1
4	16	192	20	0.2676	3.4563	76.3
19	17	192	40	0.3861	4.9867	65.8
13	18	192	60	0.3641	4.7026	67.8
21	19	192	80	0.2561	3.3077	92.1
25	20	192	100	0.2712	3.5027	90.1
27	21	240	20	0.4783	4.9421	57.8
2	22	240	40	0.4326	4.214	61.8
30	23	240	60	0.4526	4.6755	60.1
18	24	240	80	0.3131	3.2351	92.6
9	25	240	100	0.3131	3.1318	93.3
17	26	288	20	0.4997	4.3027	57.68
23	27	288	40	0.4894	4.2139	58.6
12	28	288	60	0.4954	4.2657	58
7	29	288	80	0.3752	3.2307	92.4
10	30	288	100	0.3612	3.1101	93.1

3.2 Statistical Analysis of Variance (ANOVA)

Table 4 showcase the output of the analysis of variance (ANOVA), which indicates that quadratic model is adequate for analysing experimental data. Statistically, the model is significant, with an F-value of 11.17. This "model F-value" has a possibility occurrence probability of 0.01%. Additionally, model terms are significant if their "Prob > F" values are less than 0.0500. In this instance, the letters A, B, AB, A^2, B^2, and are significant model terms. If a model term's value is greater than 0. 1000.This reported model shows that the signal is strong enough to move around the design space [42–43]. This model can also predict the corrosion inhibition efficiency of mild steel in a hydrochloric acid environment when treated with *Lasienthera Africanum* leaf extract (LALE) This indicates that the findings can be relied upon statistically. The model equation is represented by Equation (4) in terms of the coded values of the process variables.

$$IE = 82.8676 - 1.11516\,A + 13.8205B + 1.88464AB - 5.65262A^2 + 6.16095B^2 \quad (4)$$

Table 4 ANOVA results for inhibition efficiency on mild steel in 0.5M HCl with LALE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	4451.09	5	890.22	9.5	< 0.0001	significant
A-Immersion time	17.87	1	17.87	0.1907	0.6663	
B-Inhibitor Concentration	2526.68	1	2526.68	26.96	< 0.0001	
AB	44.2	1	44.2	0.4717	0.4988	
A^2	482.57	1	482.57	5.15	0.0325	
B^2	199.28	1	199.28	2.13	0.1577	
Residual	2248.99	24	93.71			
Cor Total	6700.08	29				
Std. Dev.	9.68		**R^2**	0.6643		
Mean	80.26		**Adjusted R^2**	0.5944		
C.V. %	12.06		**Predicted R^2**	0.441		
			Adeq Precision	11.1727		

Likewise, from Table 5, the p-value for the mathematical model for corrosion rate is less than 0.05 (0.0001), so it is a significant model. The F-value of 9.5 also indicate the significance of this model. This revealed that the input factors such as immersion time, and extract concentration have a significant effect on the corrosion rate. The second-order polynomial model obtained for corrosion rate is expressed in Eq. (5).

$$CR = 3.01171 + 1.06208 A - 0.43751B - 0.0928307AB - 0.234745A^2 - 0.169905B^2 \quad (5)$$

Table 5 ANOVA results for corrosion rate of mild steel in 0.5 HCl with LALE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	24.79	5	4.96	12.83	< 0.0001	significant
A-Immersion time	16.21	1	16.21	41.92	< 0.0001	
B-Inhibitor Concentration	2.53	1	2.53	6.55	0.0172	
AB	0.1072	1	0.1072	0.2774	0.6033	
A^2	0.8322	1	0.8322	2.15	0.1553	
B^2	0.1516	1	0.1516	0.392	0.5372	
Residual	9.28	24	0.3866			
Cor Total	34.07	29				
Std. Dev.	0.6218		**R^2**	0.7277		
Mean	3.06		**Adjusted R^2**	0.6709		
C.V. %	20.32		**Predicted R^2**	0.5979		
			Adeq Precision	12.0539		

Table 6 shows the ANOVA results on the response of weight loss to the process variable at the 95% confidence level and 5% significance level. As indicated, the probability for the linear model is 0.0001, which is less than 0.05. It is evident from this that the variables directly influencing weight loss are significant. In addition, the F-value of 12.83 indicates that the model is significant, since noise can only account for 0.01% of such a high F-value. The second-order polynomial model obtained for WL is expressed in Eq. (6).

$$WL = 0.183563 + 0.164098A - 0.0222057B - 0.0325629AB + 0.00756487A^2 - 0.0209238B^2 \quad (6)$$

Tables 4, 5, and 6 **predict R^2** values that are in agreement with the **adjusted R^2** values. As their variances are less than 0.2 and the **R^2** nears 1, the fitted model considered ideal for the process [44]. The signal-to-noise ratio is measured by **Adeq Precision**. .It is considered acceptable and desirable to have a ratio of 4 or higher. The ratios of 11.1727,12.0539, and 24.9089 indicate adequate signals in Tables 4, 5, and 6. The design space can therefore be navigated successfully using these models [45].

Table 6 ANOVA results for weight loss of mild steel in 1.0 HCl with LALE

Source	Sum of Squares	df	Mean Square	F-value	p-value	
Model	0.7448	5	0.149	63.89	< 0.0001	significant
A-Immersion time	0.3869	1	0.3869	165.93	< 0.0001	
B-Inhibitor Concentration	0.0065	1	0.0065	2.8	0.1074	
AB	0.0132	1	0.0132	5.66	0.0257	
A^2	0.0009	1	0.0009	0.3707	0.5483	
B^2	0.0023	1	0.0023	0.9859	0.3307	
Residual	0.056	24	0.0023			
Cor Total	0.8007	29				
Std. Dev.	0.0483		**R^2**	0.9301		
Mean	0.2349		**Adjusted R^2**	0.9156		
C.V. %	20.55		**Predicted R^2**	0.8942		
			Adeq Precision	24.9089		

3.3 Diagnostic fitness plots

The diagnostic fitness plot presented in Fig 1(a-c) are the normal distribution plots for inhibition efficiency, corrosion rate and weight loss. In the depicted Figures, it can be observed that the plots points are clustered around the line of best fit. This showed that fitted models can accurately be used to represent the data for each of the responses [46].

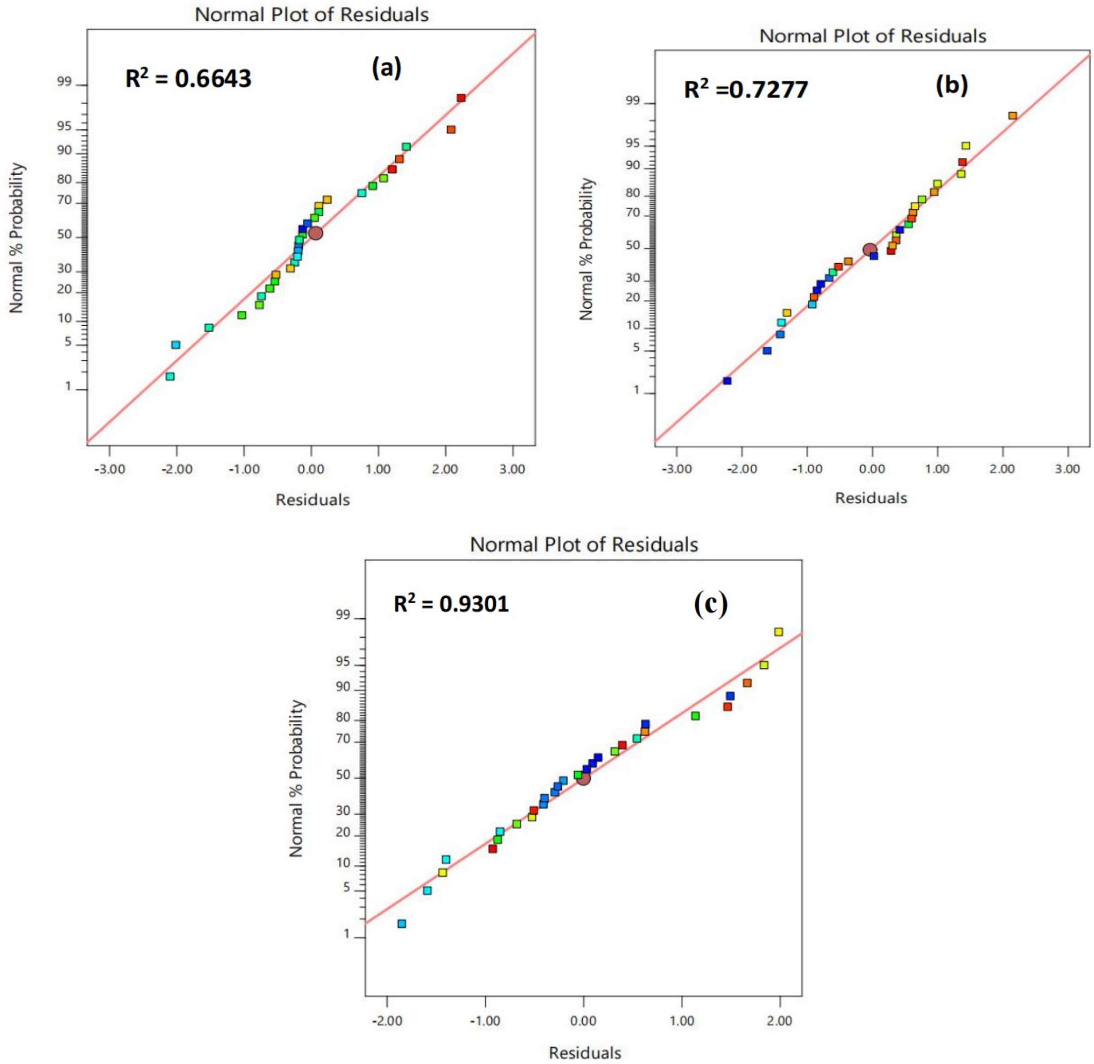

Fig.1. Normal distribution plots for responses (a) inhibition efficiency (b) corrosion rate (c) weight loss

The fitness model is illustrated in Fig. 2(a–c), which show the interaction between the actual and predicted results of inhibition efficiency, corrosion rate, and weight loss of mild steel in 0.5M HCl with LALE. The fitness model showed the level of fit between the model's predicted and experimental values. From the figures, it revealed a good fit result was obtained from the data points as the plot randomly clustered around the points of intersection for all responses [47]. These trends show that the achieved design model is adequate to predict the studied corrosion characteristics of mild steel in the LALE inhibited environment. There is also a strong correlation between the predicted and actual values of the IE, CR, and WL.

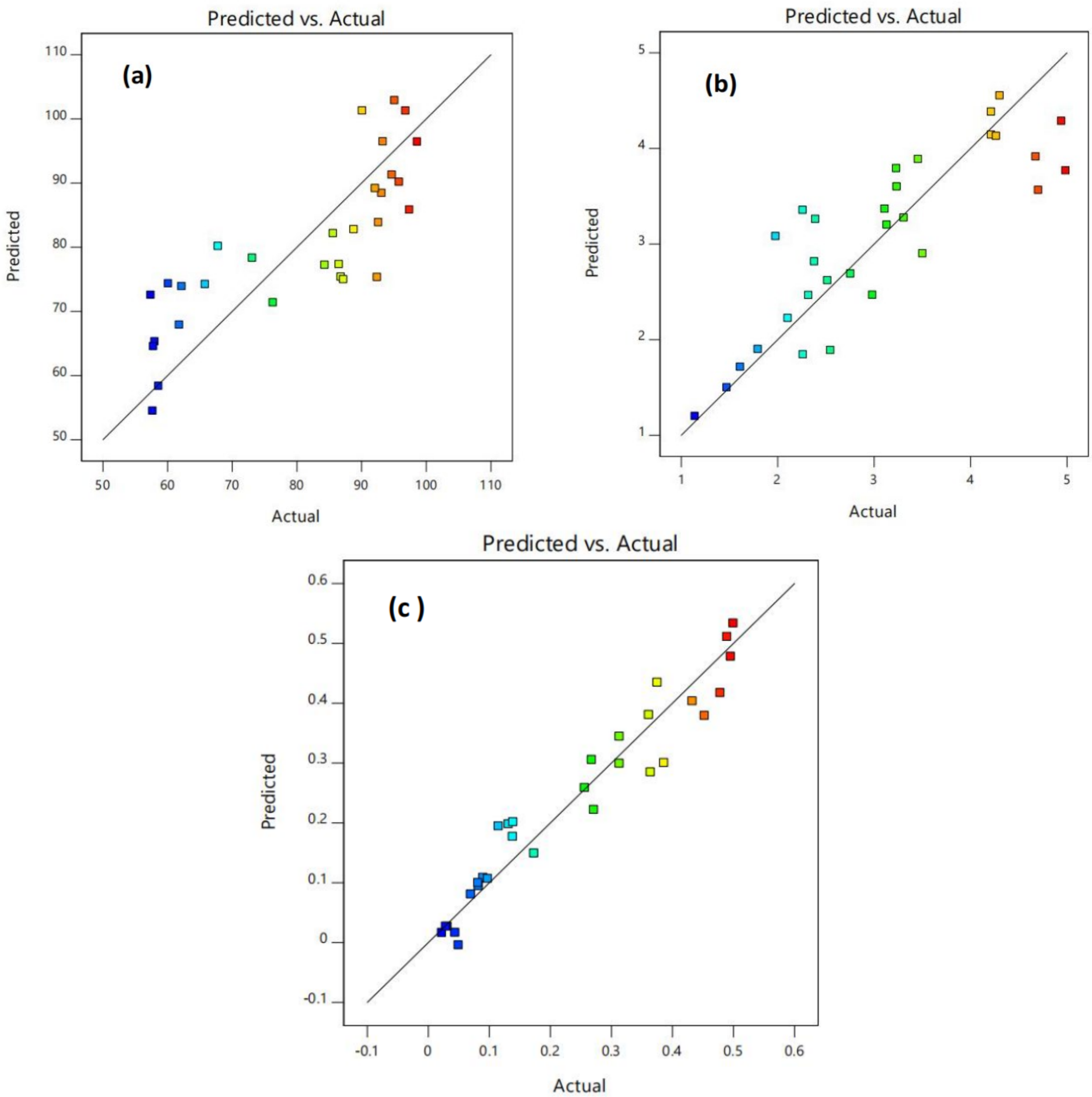

Fig. 2. Model graph of predicted *versus* actual for (a) inhibition efficiency; (b) corrosion rate (c) weight loss

Figures 3(a–c) highlight a three-dimensional (3D) surface plot that display the surface interaction between the dependent responses (inhibition efficiency, corrosion rate and weight loss) and some of the independent factors (immersion time and inhibition concentration). It can be observed from the figures that the responses are affected by the independent variables. The surface plots further depict that increasing both the extract concentration of LALE and immersion time enhances the inhibition efficiency reduces the weight loss and corrosion rate, and, also has a significant effect on the expected response due to the increase in environmental conditions. Thus, electrochemical reaction would readily occur when the average atmospheric temperature rises [45]. The model surface 3D results were discovered to be consistent with the experimental results, suggesting LALE is a suitable plant extract for surface treatment of mild steel in aggressive environments.

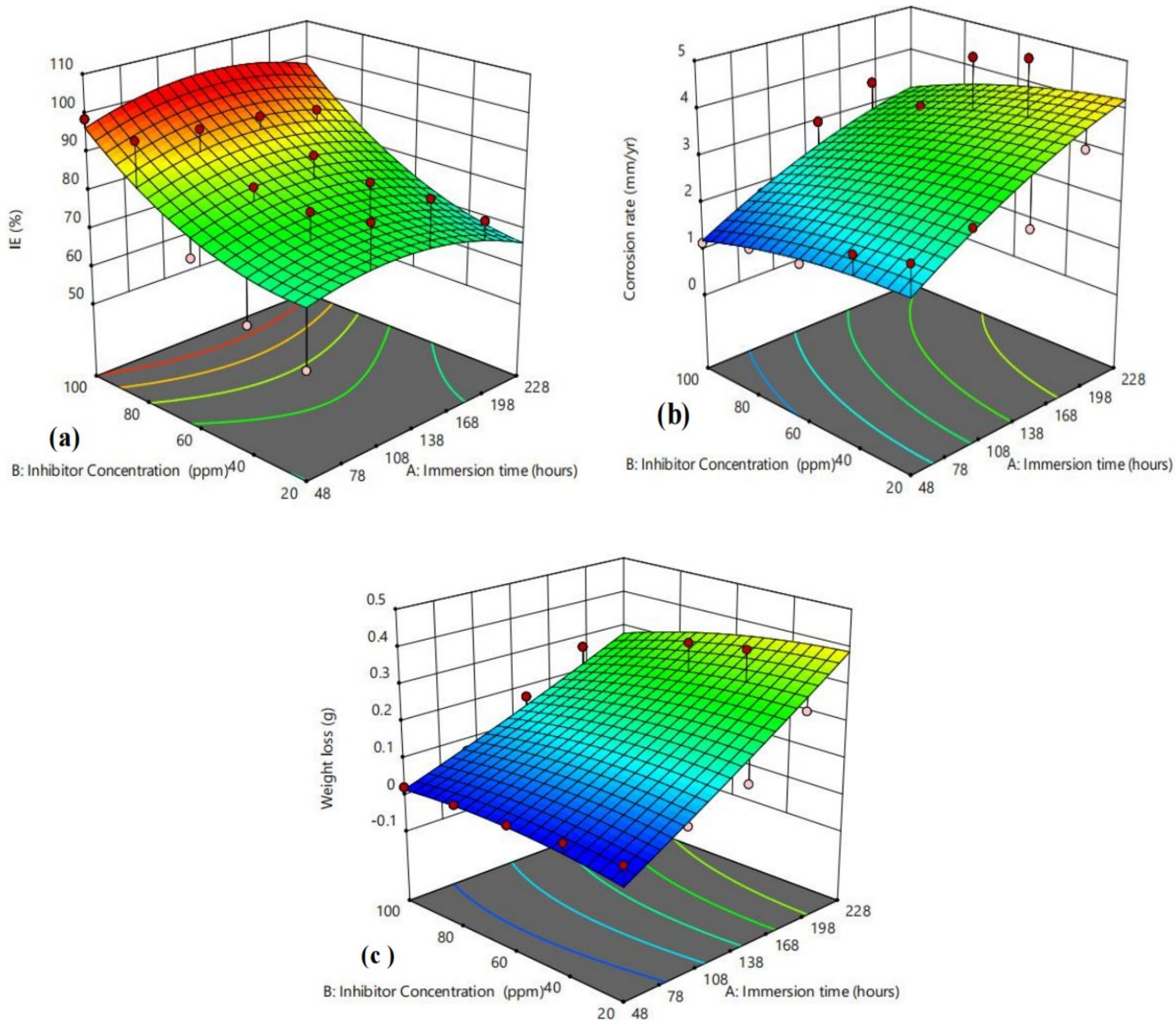

Fig.3. Three-dimensional surface interaction plots for (a) Inhibition efficiency (b) Corrosion rate; (c) weight loss

3.4 Optimization of the Corrosion Inhibition process

In the study, the main focus was to obtain the optimum conditions of parameters that the maximum corrosion control of mild carbon steel in the evaluated environment can be achieved. For this reason, optimization of the process was completed using **Design-Expert-Software** based on the established IE, CR and WL models [46]. The main objectives (optimization criteria) of the present work here to minimize CR, WL and maximize IE at the same time. The characteristics and pre-set optimization goals are presented in Table 6. From the report shown in Fig. 4, it was depicted that out of 9 solutions generated from the procedure with a near desirability value of 0.653, the numerical optimal solution for the independent factors (immersion time, and inhibition concentration) was 228 hrs, and 93.93ppm respectively. The optimal responses of the corrosion characteristics are 0.294g, 3.27mm/yr, and 93.85% for weight loss, corrosion rate, and inhibition efficiency under the same desirability. The optimum conditions are reliable in determining the significance of individual responses. Also, this optimization solution was chosen and presented in the overlay plot after meeting the given conditions (Fig. 5). Figure 7 highlight the optimization desirability chart that shows the degree of desirability for each optimal solution for the factor response variables. The best factor conditions are presented by a red bar, while the best response predictions value is described with a blue bar [43]. The chart revealed how well each parameters satisfied the conditions with values near to unity being accepted as satisfactory [47].

Table 7 Pre-set optimisation goals for desirability

Name	Goal	Lower Limit	Upper Limit	Lower Weight	Upper Weight	Importance
A: Immersion time	is in range	48	228	1	1	3
B: Inhibitor Concentration	is in range	20	100	1	1	3
WL	is in range	0.0221	0.4997	1	1	3
CR	maximize	1.1418	4.9867	1	1	3
IE	maximize	57.4	98.6	1	1	3

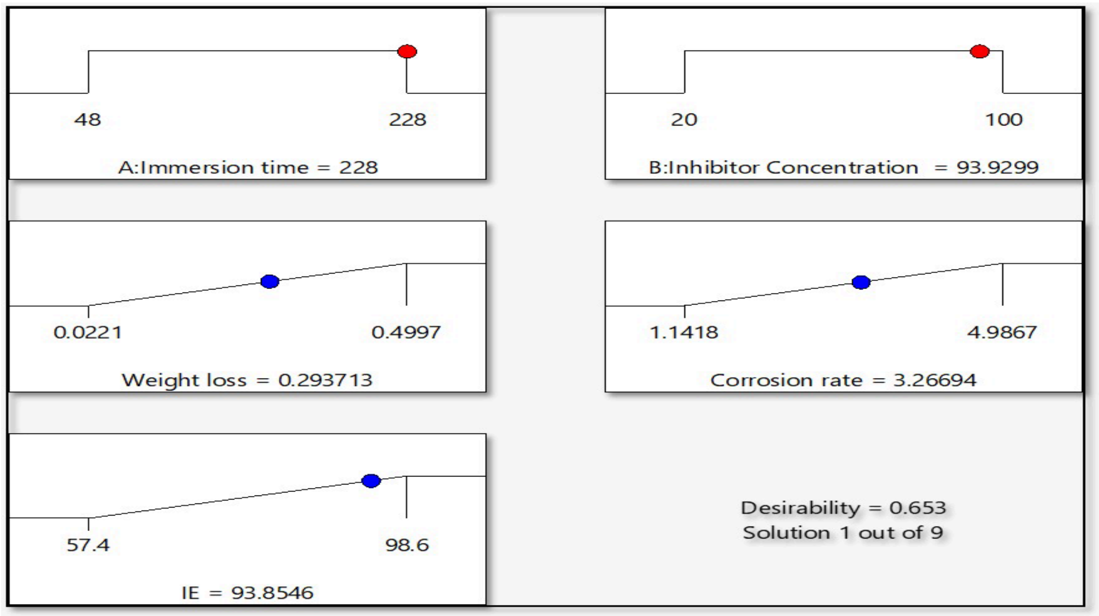

Fig.4. Optimization Ramp

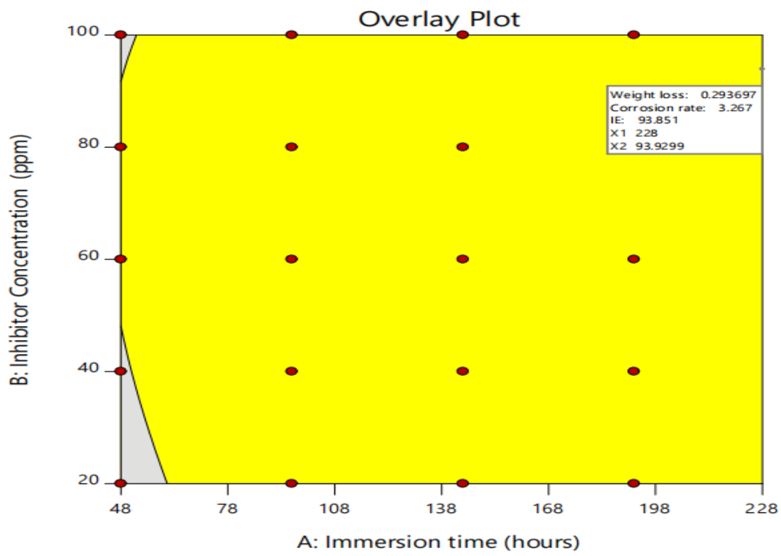

Fig. 5. Optimization Overlay

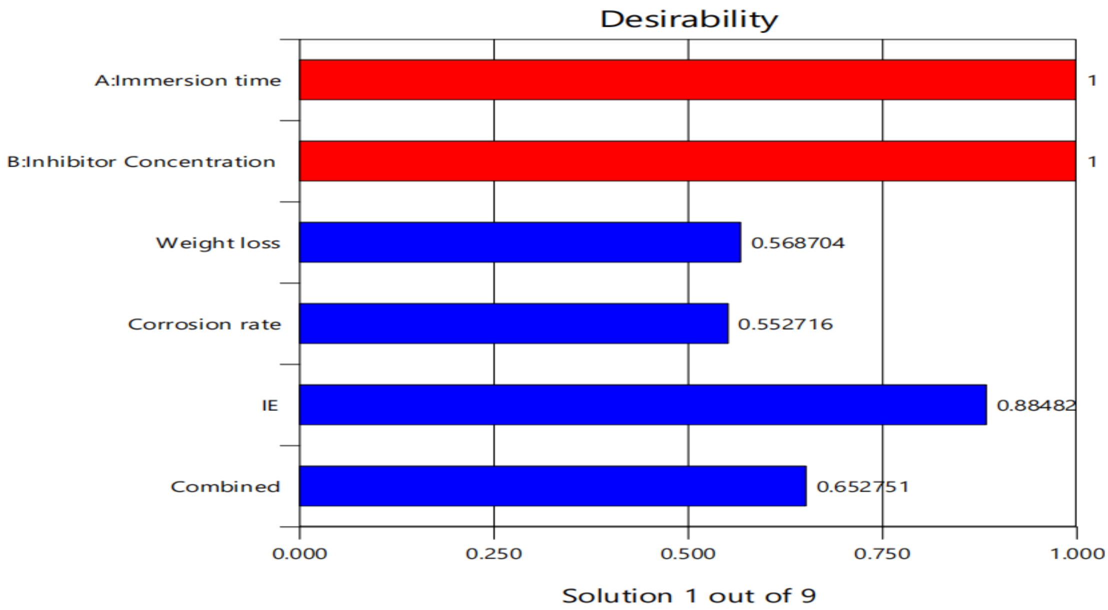

Fig.6. Optimization desirability values chart for factors, responses and combined

3.5 Validation of Predicted Models

An additional experiment to validate the model's prediction was done with the predicted optimum conditions. Duplicate samples of mild steel were machined for each test, and the mean result obtained was recorded. The results are shown in Table 8. As presented in this table, the predicted and experimental values are close to each other, and the uncertainty errors between them are 0.02, 0.085, and 0.27% for WL, CR, and IE, respectively. Therefore, we establish that the models are statistically fit in the prediction of the corrosion parameters responses. Hence these models can be recommended for applications such as oil well acidizing and pickling pipelines.

Table 8 Comparative validation of predicted and experimental values of LALE corrosion parameters

Parameters	Inhibitor Concentration	Immersion time	Predicted values	Experimental Values	Uncertainty error
	ppm	hours			%
	93.93	228			
WL			0.29	0.31	0.02
CR			3.271	3.356	0.085
IE			93.85	94.12	0.27

Conclusions

The central composite design (CCD) of response surface methodology was adopted in analysing and optimization of the LALE corrosion inhibitor performance on mild steel in hydrochloric induced environment. The main findings from the study are as follows:

1. Response surface methodology (RSM) via variance analysis in three significance regression models were developed to predict WL, CR and IE. The coefficient of determination and RSM diagnostic plots were also use to assess the accuracy and adequacy of the models. The results showed that the models were significant and suitable to navigate the design space.
2. The model developed for each corrosion characteristics response was reaffirmed to be statistically significant and ideal for predicting the responses. Also, the interaction between each response is dependent on the factors as shown from the three-dimensional plots.

3. The optimal optimization of the corrosion characteristic process for LALE showed that the optimum settings for maximum IE (93.85%), minimum WL (0.294g) and CR (3.267mm/yr) were obtained at a concentration of 93.93ppm and immersion time of 228 hours.
4. The validation experiment done at the optimal conditions established 94.12% for IE, 3.356 for CR and 0.31 for WL respectively. Since the uncertainty error is less than 5%, the models are therefore validated to be statistically fit for the prediction of corrosion characteristic responses.

Declaration of Conflicting Interests

The authors confirm that there is no potential conflict of interest involved in the research, the authoring, or the publication of this article.

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