Original Article

Analysis of Garcinia indica Choisy extract as eco-friendly corrosion inhibitor for aluminum in phosphoric acid using the design of experiment

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ABSTRACT

The inhibiting performance of Garcinia indica Choisy extract was studied on Al in phosphoric acid solution via electrochemical impedance spectroscopy technique and by using response surface methodology (RSM) of the design of experiment. The surface analysis was carried out using scanning electron microscopy (SEM) and Energy dispersive X-ray spectroscopy (EDX) to affirm the adsorption of inhibitor on the surface of metal. In the study, the influence of three process variables (extract concentration, acid concentration, and temperature) are considered on the inhibition efficiency of Al in acid. The process variables considered for the study were taken in 3 levels: temperature (X₁) at 30 °C, 40 °C, and 50 °C, extract concentration (X₂) at 0.1, 0.3 and 0.5 gL⁻¹ and acid concentration (X₃) at 0.5, 1.25 and 2 M. A full quadratic regression model was established and authenticated before the variables were optimized for the highest inhibition efficiency. From the results, it was inferred that the extract concentration has the maximum effect on the inhibition efficiency followed by temperature and concentration of the acid. It was also observed that the data predicted by regression analysis had a good agreement with the data obtained from the experiments with the values of R² = 0.9946 and Adj-R² = 0.9898 for inhibition efficiency. The optimum settings for the studied parameters were found to be at temperature (50 °C), extract concentration (0.5 gL⁻¹), and acid concentration (0.5 M) to achieve the maximum inhibition efficiency of 86.19%.

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1. Introduction

In a study made by NACE International in 2016, it was mentioned that annually US$ 2.5 trillion is the global cost of corrosion accounting 3.4% of the global GDP. It was also reported that 15–35% of the cost of damage could be saved globally by implementing the best practices of corrosion prevention [1–3]. In spite of the significant technological advancements, still very critical cases of corrosion have persistent to appear [4]. Metal dissolution is a very common phenomenon as acid solutions are extensively used in industrial scrubbing and descaling processes [5–8]. In order to extend the lifecycle, to improve its feasibility, and to decrease the high cost of manufacture, concrete steps need to be taken to prevent metal corrosion. Failure to do this can result in metal damages, loss of manufacture time, permeable vessels, and unnecessary cleaning costs.

Aluminum (Al) is one of the most commonly employed metal for ample engineering applications as it is cheap and having outstanding functional features. The 2nd most extensively used metal after iron is aluminum [3]. It has been perceived that to prevent high corrosion, this metal is reliant on the presence of a thin layer of surface oxide. Then again, it was additionally seen that antacid arrangements play a critical role in diminishing the oxide film. The investigation of aluminum corrosion marvels is getting particular, particularly in acidic media, as a result of the more mechanical utilization of corrosive arrangements [9]. Much research was indicated to think about the corrosion of aluminum and its amalgams in different fluid and acid arrangements by means of natural and inorganic inhibitors [3,10–13]. Something else, acids advance the pace of metal disintegration and are liable for material disappointment in a roundabout way. In this manner, inserting a corrosion inhibitor is a critical strategy to decrease metal disintegration in that arrangement. Most of the corrosive inhibitors are natural mixes, including nitrogen, sulfur, and oxygen, yet the most considerable piece of the applied natural inhibitors is environment friendly and non-toxic [8,14–16]. In this manner, it is important to progress eco-accommodating corrosion inhibitors for aluminum in acidic mediums [17,18]. There has been few work on phosphoric acid being a medium of study with aluminum and its alloys [19–22].

The majority of research works in the area of corrosion control concentrated on the mechanism of corrosion, type, and execution of inhibitor, energy ponders, and so forth. Advancement, measurable, and numerical examinations got less consideration. In science, the advancement system (optimization) is a champion among the most notable applications [7,23–26]. The chief objective of streamlining is to choose the degrees of free factors that brief a base (or the most extreme) estimation of a result [26].

Accordingly, the point of this examination is to explore the viability of Garcinia indica Choisy (GIE) extract as an eco-friendly green corrosion inhibitor for aluminum in phosphoric acid. GIE contains several natural compounds. The primary dynamic segments of the fluid concentrate are Garcinol, Curcumin and Isogarcinol. The pace of corrosion was surveyed utilizing the electrochemical impedance spectroscopy (EIS) method. Furthermore, the collaboration impacts of extract concentration, concentration of acid, and temperature variation on the corrosion inhibition were surveyed utilizing response surface methodology and analyzed with relevant statistical tools.

2. Experimental methods

2.1. Preparation of corrosive medium and inhibitor

Analytical grades (Merck) of phosphoric acid (85%) and double distilled water were used for preparing the test solutions (0.5 M, 1.25 M, 2 M). A stock solution of higher strength was prepared, standardize, and used. Analyses were completed utilizing a thermostat at temperatures 30°C, 40°C, 50°C (+0.1°C).

Garcinia indica Choisy belongs to Clusiaceae family. The ripe fruit is dark purple in red and contains around 5–8 seeds [27]. Seeds are embedded to the pulp with rind by tissue. The seed is removed from fruits and then dried for about 8 days. Seeds were dried in an oven at 40°C for 2 h. Then the dried seeds were powdered and refluxed in water for 3 h and filtered. Filtres were warmed gradually on a water bath to evacuate water substance. After drying, the powder was then finely ground and protected in a desiccator.

2.2. Preparation of metals specimen

The commercially obtained sample of aluminum was used for the study. The sample contains aluminum (99.61%) with small amount of iron (0.27%) and silicon (0.12%). The circular test coupon was fixed with acrylic gum material so that the zone presented to the medium was 1.0 cm². The specimen was cleaned with various then polished with emery papers of different grades and further washed with disc polishing machine utilizing alumina paste till we get a mirror-like surface finish on the specimen. It was then dried and transferred to a desiccator to maintain a strategic distance from dampness before being utilized for studies on corrosion.

2.3. EIS technique

EIS studies were carried out using CH instrument (CH600D-series). The electrochemical cell consist of counter electrode (platinum), reference electrode (SCE) and working electrode (aluminum). Impedance-contemlates were done at unfaltering state OCP. A little adequacy (10 mV) sinusoidal ac voltage, in the broad recurrence run (100 kHz to 0.01 Hz) was applied over the framework. A diagram was acquired by plotting genuine impedance (Z’ vs. non nonexistent impedance (Z”) [10]. For each situation, at least 3 trails were taken, and the normal of the best three concurring qualities was accounted for.

2.4. Surface morphology examination: SEM and EDX analysis

Surface characterization of aluminum immersed in phosphoric acid solution containing 0.50 g L⁻¹ of inhibitor was studied by recording the SEM and EDX of the samples using EVO MA18
with Oxford EDS (X-act). The immersion time for the metal in contact with 0.5 M phosphoric acid and inhibitor of 0.5 gL⁻¹ was 3 h.

3. Methodology

3.1. Experimental design

Typically, composite design is an examination technique that includes some unequivocal preliminaries on the basis of regression design points. Therefore, it can substantially diminish the number of trials. The process variables studied were temperature (X₁) and extract concentration (X₂) and acid concentration (X₃). These three variables were considered at three levels. The settings and the levels of each of the parameters are as shown in Table 1. The Minitab 19 programming was utilized for the exploratory runs and displaying of trial information.

3.2. The Regression model

As described above, the temperature and concentration of inhibitor have substantial effects on inhibition efficiency. In this examination, the full quadratic model is received to build up the connection between the inhibitor effectiveness and the process parameters. The impacts of different process parameters on the inhibition efficiency are precisely analyzed by Eq. 1.

\[
Y = b_0 + \sum_{i=1}^{k} b_i X_i + \sum_{j=1}^{k-1} \sum_{i=j+1}^{k} b_{ij} X_i X_j + \sum_{i=1}^{k} b_{ii} X_i^2
\]  

(1)

For three factor inputs of X₁, X₂ and X₃, the quadratic response is shown in Eq. 2 below;

\[
Y = b_0 + b_1 X_1 + b_2 X_2 + b_3 X_3 + b_{12} X_1 X_2 + b_{13} X_1 X_3 + b_{23} X_2 X_3 + b_{11} X_1^2 + b_{22} X_2^2 + b_{33} X_3^2
\]  

(2)

Y: Predicted values of inhibition efficiency.  
X₁, X₂, and X₃: autonomous parameters were signifying the temperature, extract concentration, and concentration of acid.  
b₀: constant. b₁, b₂, and b₃: constants were reflecting the influence of parameters X₁, X₂, and X₃.  
b₁₂, b₁₃, b₂₃: constants were reflecting the interaction between the two parameters X₁X₂, X₁X₃, X₂X₃.  
b₁₁, b₂₂, and b₃₃: constants were reflecting the effect of quadratic X₁, X₂, and X₃.

Table 1 – Levels of experimental parameters selected for the CCD.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Symbol</th>
<th>Unit</th>
<th>Low (-1)</th>
<th>Center (0)</th>
<th>High (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Temperature</td>
<td>X₁</td>
<td></td>
<td>30</td>
<td>40</td>
<td>50</td>
</tr>
<tr>
<td>Extract concentration</td>
<td>X₂</td>
<td>gL⁻¹</td>
<td>0.1</td>
<td>0.3</td>
<td>0.5</td>
</tr>
<tr>
<td>Acid concentration</td>
<td>X₃</td>
<td>M</td>
<td>0.5</td>
<td>1.25</td>
<td>2.0</td>
</tr>
</tbody>
</table>

Fig. 1 – Nyquist plots for the corrosion of Al in 1.25 M H₃PO₄ containing GIE at 30°.

![Fig. 1](image1.png)

Fig. 2 – A comparable circuit used to fit the test EIS information.

![Fig. 2](image2.png)

The study aims to identify the optimum parameter setting to acquire the maximum inhibition efficiency. While, as a general rule, it is tough to find out optimum processing variables. Henceforth, the RSM approach is used to examine the impacts of the different process parameters on the response. Then the combination of the process variables that can accomplish an optimum anticipated value can be acquired.

4. Results and discussion

The Nyquist plots for Al in 1.25 M H₃PO₄ containing the GIE inhibitor at 30° are given in Fig. 1. The enormous high recurrence capacitive circle shows that the charge move process chiefly constrains corrosion because of the oxide film, which

Table 2 – Actual and anticipated estimations of polarization resistance and inhibition efficiency values acquired from the EIS and the central composite design.

<table>
<thead>
<tr>
<th>Run order</th>
<th>Actual level of parameter</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
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</thead>
<tbody>
<tr>
<td></td>
<td>X₁</td>
<td>X₂</td>
<td>X₃</td>
<td>Rₚ(oh)</td>
<td>IE (%)</td>
<td>Residual</td>
<td>IE% error</td>
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<td></td>
<td>20</td>
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<td>0.3</td>
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<td>59.13</td>
<td>59.80</td>
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<td>24</td>
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<td>0.3</td>
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<td>72.07</td>
<td>70.27</td>
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<tr>
<td></td>
<td>30</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
<td>218.92</td>
<td>60.81</td>
<td>60.63</td>
</tr>
<tr>
<td></td>
<td>36</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
<td>579.87</td>
<td>85.34</td>
<td>86.17</td>
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<tr>
<td></td>
<td>42</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
<td>165.96</td>
<td>81.2</td>
<td>81.03</td>
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<td></td>
<td>48</td>
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<td>0.3</td>
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<td>0.3</td>
<td>2</td>
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<td>63.56</td>
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<td>0.3</td>
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<td>38.99</td>
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<td>0.3</td>
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<td>712.02</td>
<td>66.11</td>
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<td>0.3</td>
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<td>73.72</td>
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<td>0.3</td>
<td>2</td>
<td>218.92</td>
<td>60.81</td>
<td>60.63</td>
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<td>0.3</td>
<td>2</td>
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<td>52.11</td>
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<td>0.3</td>
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<td>218.92</td>
<td>60.81</td>
<td>60.63</td>
</tr>
<tr>
<td></td>
<td>96</td>
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<td>0.3</td>
<td>2</td>
<td>291.01</td>
<td>46.29</td>
<td>48.59</td>
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<td>102</td>
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<td>0.3</td>
<td>2</td>
<td>218.92</td>
<td>60.81</td>
<td>60.63</td>
</tr>
<tr>
<td></td>
<td>108</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
<td>287.39</td>
<td>62.32</td>
<td>61.94</td>
</tr>
<tr>
<td></td>
<td>114</td>
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<td>0.3</td>
<td>2</td>
<td>218.92</td>
<td>60.81</td>
<td>60.63</td>
</tr>
<tr>
<td></td>
<td>120</td>
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<td>0.3</td>
<td>2</td>
<td>79.01</td>
<td>60.51</td>
<td>61.33</td>
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<tr>
<td></td>
<td>126</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
<td>245.64</td>
<td>65.4</td>
<td>65.63</td>
</tr>
<tr>
<td></td>
<td>132</td>
<td>0.3</td>
<td>0.3</td>
<td>2</td>
<td>218.92</td>
<td>60.81</td>
<td>60.63</td>
</tr>
</tbody>
</table>

Table 3 – Analysis of variance for inhibition efficiency.

<table>
<thead>
<tr>
<th>Source</th>
<th>DF</th>
<th>Adj SS</th>
<th>Adj MS</th>
<th>F</th>
<th>P</th>
<th>% Contribution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Model</td>
<td>9</td>
<td>2429.60</td>
<td>269.96</td>
<td>206.00</td>
<td>0.000</td>
<td>48.18</td>
</tr>
<tr>
<td>Linear</td>
<td>3</td>
<td>2394.32</td>
<td>798.11</td>
<td>609.03</td>
<td>0.000</td>
<td>48.39</td>
</tr>
<tr>
<td>Temperature</td>
<td>1</td>
<td>1177.01</td>
<td>1177.01</td>
<td>898.17</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Extract concentration</td>
<td>1</td>
<td>1182.00</td>
<td>1182.00</td>
<td>901.98</td>
<td>0.000</td>
<td></td>
</tr>
<tr>
<td>Acid concentration</td>
<td>1</td>
<td>35.31</td>
<td>35.31</td>
<td>26.94</td>
<td>0.000</td>
<td>1.44</td>
</tr>
<tr>
<td>Square</td>
<td>3</td>
<td>27.79</td>
<td>9.26</td>
<td>7.07</td>
<td>0.008</td>
<td></td>
</tr>
<tr>
<td>Temperature*temperature</td>
<td>1</td>
<td>3.95</td>
<td>3.95</td>
<td>3.95</td>
<td>0.113</td>
<td>0.16</td>
</tr>
<tr>
<td>Extract concentration*extract concentration</td>
<td>1</td>
<td>13.52</td>
<td>13.52</td>
<td>10.32</td>
<td>0.009</td>
<td>0.55</td>
</tr>
<tr>
<td>Acid concentration*acid concentration</td>
<td>1</td>
<td>3.05</td>
<td>3.05</td>
<td>3.05</td>
<td>0.158</td>
<td>0.12</td>
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<tr>
<td>2-way interaction</td>
<td>3</td>
<td>7.50</td>
<td>2.50</td>
<td>2.50</td>
<td>0.193</td>
<td></td>
</tr>
<tr>
<td>Temperature*extract concentration</td>
<td>1</td>
<td>5.27</td>
<td>5.27</td>
<td>4.02</td>
<td>0.073</td>
<td>0.21</td>
</tr>
<tr>
<td>Temperature*acid concentration</td>
<td>1</td>
<td>1.87</td>
<td>1.87</td>
<td>1.43</td>
<td>0.260</td>
<td>0.07</td>
</tr>
<tr>
<td>Extract concentration*acid concentration</td>
<td>1</td>
<td>0.35</td>
<td>0.35</td>
<td>0.27</td>
<td>0.617</td>
<td>0.01</td>
</tr>
<tr>
<td>Error</td>
<td>10</td>
<td>13.10</td>
<td>1.31</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Lack-of-fit</td>
<td>5</td>
<td>13.10</td>
<td>2.62</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Pure error</td>
<td>5</td>
<td>0.00</td>
<td>0.00</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td>19</td>
<td>2442.70</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

S | R-sq | R-sq (adj) | R-sq (pred) |
---|------|------------|-------------|
1.14475 | 99.46% | 98.98% | 95.12% |

DF: degrees of freedom, Seq SS: sequential sum of squares, Adj MS: adjusted mean of squares, P: probability.

carries on as a parallel circuit of a resistor and capacitor as a result of ionic conduction [28]. At medium repeat area, an inductive circle was watched in perspective superficially loosening up of species in the oxide film [29]. A little capacitive circle was seen at low repeat is identified with the breaking down of Al₂O₃ [29]. Discouraged capacitive circles are a result of the roughness and inhomogeneity of anode surface, exhibiting deviation from impeccable capacitive conduct.

Fig. 2 address indistinguishable circuit which is fit for the plots, including solution resistance (Rₛ), charge transfer resistance (Rₜ), inductive resistance (Rᵢ), inductance (L), constant phase element (Q), R₁ and R₂ = protections that is identified with the high repeat capacitive circle, capacitors (C₁, C₂). The polarization resistance (Rₚ) and twofold layer capacitance (Cₛ) is resolved from condition (3) and (4) [30]:

\[ Rₚ = Rₛ + Rₜ + R₁ + R₂ \]  
\[ Cₛ = Q + C₁ + C₂ \]

Screening experiments demonstrated that temperature and centralization of inhibitor and acid concentration had a remarkable impact on the polarization resistance \( Rₚ(\text{inh}) \).

Hence, they were picked as test parameters in this examination. The impacts of temperature ($X_1$) and extract concentration of GIE inhibitor ($X_3$) and concentration of acid ($X_3$) was explored by methods for a Central Composite Design (CCD) [31]. The tests were performed haphazardly to keep away from correct mistakes, and the outcomes were analyzed utilizing Minitab-19 programming [32]. All the real and coded estimations of parameters have appeared in Table 1. The experimental plan of design and the levels dependent on the CCD of distinct parameters are given in Table 2 as actual values alongside the experimental response (polarization resistance $R_p^{(inh)}$). It is seen that the polarization resistance increased with an increase in the extract concentration of the GIE inhibitor. The inhibition efficiency (IE) were additionally acquired by using the following Eq. (5):

$$IE(\%) = \left( \frac{R_p^{(inh)} - R_p}{R_p^{(inh)}} \right) \times 100$$

where $R_p$ and $R_p^{(inh)}$ are the polarization resistances in the absence and presence of the inhibitor.
From Table 2, it has been witnessed that the largest efficiency is obtained in the experiment with an extract of 0.5 g L⁻¹ GIE, the acid concentration of 0.5 M, and with a working temperature of 50 °C. To find out the right combination for achieving the highest polarization resistance with the highest efficiency of the three parameters of this study, RSM is used for the optimization analysis. At that point, the regression equation between the process variables and the inhibition efficiency was set up. The regression model, as far as coded factors for inhibition efficiency, could be stated utilizing Eq. 6 shown below:

\[
IE = -15.8 + 2.245 \times X_1 + 39.1 \times X_2 - 4.18 \times X_3 - 0.01198 \\
\times X_1 \times X_1 + 55.4 \times X_2 \times X_2 + 1.87 \times X_1 \times X_3 \\
- 0.406 \times X_1 \times X_2 - 0.0645 \times X_1 \times X_3 - 1.39 \times X_2 \times X_3
\]

ANOVA was then utilized utilizing the "quadratic model". The methods for determined qualities were examined with a significance level of 95%. Table 3 demonstrates the ANOVA results. The value of P indicates whether the impact for that term is significant or not [7]. The degree of essentialness, α, was picked to be 0.05, which is a generally utilized level. As per the information in Table 3, the value of P is less than the selected level for the linear and square effect. The outcomes from the ANOVA demonstrated that the concentration of the GIE inhibitor is the parameter having a significant impact on the response, with the effect of 48.39% pursued by temperature with 48.18%.

The parameters S, R², and R² (adj) are the techniques for how well the model fits the information. These qualities may choose the model with the best fit when contrasting various models for the examination. As the value of R² and R² (adj) closer to 1, the model better fits the information. R² consistently increments with other indicators, yet the R² (adj) is an adjusted R², which is not identified with the number of indicators. As indicated by Table 3, R² (adj) is generally near 1.

Fig. 3 represents a normal plot suggests that all three process variables have a substantial effect on the inhibition efficiency. Out of the interaction effect, only the squared effect of extract concentration is having a major effect on the inhibition efficiency.

The "Main effect" graphs are the additional output received from the regression analysis. Fig. 4 demonstrates the main effect plots for the means of inhibition efficiency. A "Main impact plot" indicates how to control elements that influence the output parameter. A fundamental impact is speaking to when different degrees of a factor affect the response in an unexpected way. As per Fig. 4, among the considered factor levels, the maximum inhibition efficiency was witnessed with 0.5 g L⁻¹ extract concentration of GIE inhibitor and a temperature of 50 °C and at an acid concentration of 0.5 M. Along these lines, it was anticipated that a blend under the previously stated conditions may have high inhibition efficiency and can be an appropriate definition for the considered inhibitor blend.

The interaction between factors occurs when the response change is different for two variables. Fig. 5 shows the interaction plot for inhibition efficiency suggests that the interactions between the parameters are not very significant, except the squared effect of extract concentration. From the ANOVA analysis, it is also seen that both square and two-way interactions between the settings are not substantial because the p-value is higher than 0.05, demonstrating there is no inter-correlation between the inhibitor concentration, acid concentration and temperature.

The interactive effects of the process variables on the IE (%) were studied by plotting a three-dimensional contour and

![Interaction Plot for Inhibition Efficiency](image-url)
surface plot against two independent variables. The contour and surface plot for inhibition efficiency is shown in Fig. 6. It is showed in figure that at a given temperature, the inhibition efficiency increase with an increase in the extract concentration of inhibitor. However, an increase in temperature with an increase in extract concentration of the GIE inhibitor reported an increase in inhibition efficiency. This could be attributed to the fact that chemical adsorption of inhibitor is occurring on the surface of the aluminum and thereby reducing the corrosion rate.

4.1. Response optimization

Numerical optimization of the model in Eq. (5) was done to determine the concentration of inhibitor and temperature at which the corrosion rate of Al was at a minimum so that it will result in maximum efficiency. The desirability function approach was used to optimize the process factors for the highest possible inhibition efficiency. The following steps were taken into account before the optimization to detect the measures of numerical optimization. First, the goal factors for temperature, the concentration of inhibitor, and acid concentration were set while that of inhibition efficiency was set to maximum. The predicted optimum parameters of the phosphoric acid environment were estimated to be temperature (50°C), inhibitor concentration (0.5 g L⁻¹), and acid concentration (0.5 M). At these optimum conditions, the corresponding predicted inhibition efficiency was found to be 86.19% as shown in Fig. 7. Confirmation experiments were conducted to validate the optimum parameter settings and to verify the improvement of the inhibition efficiency. The purpose of confirmation experiments is to check the repetitiveness of the experimental results and validate the accuracy of the predictive mode.

Fig. 6 – Contour plot and a surface plot for inhibition efficiency.
4.2. Surface analysis

SEM picture of aluminum immersed in 0.5M phosphoric acid and after adding GIE (0.5 gL⁻¹) are presented in Fig. 8a and b. Within the sight of phosphoric corrosive, the surface turned out to be rough because of the deposition of corrosion product. EDX spectrum and its composition on the surface of aluminum is shown in Fig. 9. The EDX demonstrated peaks for aluminum (Al), oxygen (O) and phosphorus (P). Peak for phosphorous in the EDX spectrum can be attributed to the interaction of the metal with medium and there is high content of oxygen as Al is in the form of its oxide layer.

EDX spectrum and its composition on the surface of aluminum in 0.5M phosphoric corrosive after adding of GIE (0.5 gL⁻¹) is given in Fig. 10. There was arrangement of defensive film over the surface. Uniform surface film legitimizes the adsorption of GIE atoms on the surface of the metal. EDX spectrum examination demonstrated decline in the substance of oxygen and phosphorous. A top for carbon (C) affirms the adsorption.

5. Conclusions

Given the analysis approach utilizing RSM, it very well may be presumed that:
The GIE inhibitor was capable of reducing as well as slowdown the corrosion of aluminum caused by phosphoric acid. For experiments using different temperatures, acid concentrations, and concentrations of inhibitor, the results displayed that the highest inhibition efficiency was at 0.5 gL⁻¹ extract concentration of GIE inhibitor, 0.5 M acid concentration, and 50 °C temperature with 86.17%. Based on the data received, it was clear that as the concentration of the GIE inhibitor increases, it provides a protecting layer that aids in reducing or slow down the corrosion of aluminum.

Similarly, the rise in temperature binds the inhibitor layer due to chemisorption and thereby reducing the corrosion process on the aluminum. The relation between the concentration of inhibitor, acid concentration, and temperature, the inhibition efficiency was investigated by using the response surface methodology approach. By doing so, a regression equation for the inhibition efficiency was developed in relation to process parameters. The accomplishment of the fitting model was tried with fundamental statistical arguments, ANOVA, R, and R² values. It was demonstrated that this equation could adequately explain the data which was obtained from experiments, in a 95% certainty level.

The adsorption of GIE on the metal surface was confirmed with the help of SEM and EDX analysis. There was a uniform defensive layer of inhibitor formed on the aluminum surface after the addition of GIE and the compositions of the surface is the evidence for the following mechanism.

REFERENCES


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