

# Evaluating the Influence of Temperature on the Efficacy of Capparis Decidua Extract as a Corrosion Inhibitor for Aluminium in Acidic Media

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## Abstract

The study investigates the anti-corrosive properties of the ethanolic extract of *Capparis decidua* fruit on aluminum corrosion in a 2N HCl acid solution, using a weight loss technique at temperatures ranging from 303 to 343 K. At a concentration of 0.45%, the inhibition efficiency ( $\eta\%$ ) is notably high, reaching 63.15% at 303 K. The inhibitor's adsorption behavior on the aluminum surface is consistent with the Langmuir adsorption isotherm, suggesting that the process is exothermic, physical, and spontaneous. Along with kinetic parameters including activation energy ( $E_a$ ), enthalpy of activation ( $\Delta H_{act}$ ), and entropy of activation ( $\Delta S_{act}$ ), thermodynamic parameters were also evaluated. These included the free energy of adsorption ( $\Delta G_{ads}^0$ ), enthalpy of adsorption ( $\Delta H_{ads}^0$ ), and entropy of adsorption ( $\Delta S_{ads}^0$ ). These properties hint to a robust interaction between the aluminum surface and the inhibitor molecules. The significant anti-corrosive effect is attributed to the phytochemical constituents present in the *Capparis decidua* fruit extract, which enhance the formation of a protective layer on the metal surface. This study highlights the potential of *Capparis decidua* fruit extract as an effective, natural corrosion inhibitor for aluminum in acidic environments.

**Keywords:** Aluminium, acid corrosion, *capparis decidua*, langmuir adsorption isotherm, thermodynamic and kinetic parameters.

## INTRODUCTION

Aluminum is widely used in many industrial applications, either as a metal or an alloy. Numerous industrial operations, such as acid cleaning and descaling, use acid solutions. In order to slow down the rate at which the corrosive medium attacks the metal or alloy, chemicals known as corrosion inhibitors are introduced [1]. These materials may consist of inorganic or organic components [2–4].

Many businesses use metal equipment in a variety of chemical conditions, from mild to harsh, which can cause corrosion on the surfaces of the equipment [5–6]. Research has demonstrated that because metals are applied in a variety of conditions, corrosion cannot be completely eliminated from metal surfaces [7].

An evergreen medicinal plant with a broad range of pharmacological and biological action is called *Capparis decidua*. Five spermidine alkaloids, such as isocodonocarpine, capparisidine, capparisine, capparisinine, and N-acetyl capparisine, as well as

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$\beta$ -sitosterol,  $\beta$ -Carotene, stachydrine, rutin, terpenoids, steroids (bile acids and sterols), flavonoids, phenolic compounds, and fatty acids, are the main chemical components of *Capparis decidua* fruit. These phytochemical components found in the extract are responsible for the inhibitory tendency [8–10].

Because the extract from the fruits of *Capparis decidua* is non-toxic and biodegradable, its usage could potentially lower the financial burden of corrosion monitoring while also lessening the ensuing environmental risks.

Numerous scientific investigations have been conducted about the deterioration of aluminum and the use of natural items, such as *Tamarindus indica* [11], *Piper nigrum* [12], *Acacia nilotica* [13], and *Azadirachta indica* [14], as corrosion inhibitors for aluminum in acidic media.

In the current study, a 24-hour immersion period was used to analyze the impact of temperature elevation on the inhibitive propensity of *Capparis decidua* fruit for acid corrosion of aluminum.

## EXPERIMENTAL

### Preparation of Test Coupons

A 0.18-cm-thick, locally produced aluminum sheet was physically cut into  $2.54 \times 1.52 \text{ cm}^2$  coupons with a 0.12-mm-diameter hole near the upper edge so that it could be hung in the test solution. Emery paper was used to polish coupons to a mirror shine.

### Test Solutions & Experimentation

Bi-distilled water was used to prepare the HCl electrolytic solutions. Every chemical used was of the Analar grade. The dried fruits of *Capparis decidua* were refluxed in a soxhlet extractor to obtain the ethanolic extraction (EECd F). Every specimen was suspended using a glass hook and submerged in a beaker that held 50 milliliters of the test solution and various inhibitor concentrations (EECd F). The research was conducted between 303K and 343K, which are different raised temperatures. Test specimens were rinsed under running water after predetermined exposure times, and they were allowed to dry by hanging them in desiccators for an adequate amount of time [15].

## RESULTS AND DISCUSSION

### Weight Loss Studies

Over the course of a 24-hour immersion period at various elevated temperatures in the range of 303–343k, Table 1 displays values for inhibition efficiency ( $\eta\%$ ), fractional surface coverage ( $\theta$ ), corrosion rate ( $\rho_{\text{corr}}$ ), and adsorption equilibrium constant ( $K_{\text{ads}}$ ) at various inhibitor concentrations in 2N HCl acid solution.

The inhibition efficiency ( $\eta\%$ ) was computed using the following formula, based on the mass loss value ( $\Delta M$ ).

$$\eta\% = [(\Delta M_u - \Delta M_i) / \Delta M_u] \times 100$$

When weight loss with inhibitor ( $\Delta M_i$ ) and mass loss ( $\Delta M_u$ ) are expressed respectively.

The following equation [15] can be used to calculate the corrosion rate ( $\rho_{\text{corr}}$ ) in millimeter penetration per year (mppy).

$$\rho_{\text{corr}} = (\Delta M \times 87.6) / \text{area} \times \text{time} \times \text{metal density}$$

where the metal density is expressed in  $\text{gm/cm}^3$ , the time of exposure is expressed in hours, the area of exposed metal surface is expressed in  $\text{cm}^2$ , and the weight loss in mg is expressed as  $\Delta M$ .

The Table 1 results showed that the corrosion rate ( $\rho_{\text{corr}}$ ) had decreased after the inhibitor was added to the acid. In a 2N HCl acid solution, the inhibition efficiency ( $\eta\%$ ) rose as the inhibitor concentration increased and fell as the temperature rose from 303 K to 343 K.

**Table 1.** Gravimetric parameters for iron in 2N HCl with and without different amounts of the fruit extract (ethanolic extract) of *Capparis decidua* measured during a 24-hour immersion period at high temperatures.

Effective area of specimen 7.72 cm<sup>2</sup> Immersion time 24 hrs

| Temperature (K) | EECd F Conc. (%) | Weight Loss $\Delta M$ (mg) | Corrosion Rate ( $\rho_{\text{corr}}$ ) (mmpy) | Fractional Surface Coverage ( $\theta$ ) | Adsorption Equilibrium Constant ( $K_{\text{ads}}$ ) |
|-----------------|------------------|-----------------------------|--|--|--|
| 303 ± 1         | Blank            | 420.2                       | 73.58  | -  | -  |
|                 | 0.09             | 314.6                       | 55.08  | 0.2513                                   | 3.7288   |
|                 | 0.18             | 280.4                       | 49.10  | 0.3326                                   | 2.7683   |
|                 | 0.27             | 261.2                       | 45.73  | 0.3783                                   | 2.2533   |
|                 | 0.36             | 234.6                       | 41.08  | 0.4416                                   | 2.1966   |
|                 | 0.45             | 211.7                       | 37.07  | 0.4961                                   | 2.1877   |
| 313 ± 1         | Blank            | 480.4                       | 84.12  | -  | -  |
|                 | 0.09             | 364.5                       | 63.82  | 0.2412                                   | 3.5311   |
|                 | 0.18             | 332.0                       | 58.13  | 0.3089                                   | 2.4827   |
|                 | 0.27             | 316.6                       | 55.43  | 0.3409                                   | 1.9155   |
|                 | 0.36             | 287.4                       | 50.32  | 0.4017                                   | 1.8650   |
|                 | 0.45             | 261.7                       | 45.83  | 0.4552                                   | 1.8566   |
| 323 ± 1         | Blank            | 520.6                       | 91.16  | -  | -  |
|                 | 0.09             | 398.5                       | 69.78  | 0.2345                                   | 3.4033   |
|                 | 0.18             | 376.4                       | 65.91  | 0.2769                                   | 2.1272   |
|                 | 0.27             | 365.0                       | 63.91  | 0.2988                                   | 1.5781   |
|                 | 0.36             | 319.7                       | 55.98  | 0.3859                                   | 1.7452   |
|                 | 0.45             | 289.8                       | 50.74  | 0.4433                                   | 1.7693   |
| 333 ± 1         | Blank            | 560.8                       | 98.20  | -  | -  |
|                 | 0.09             | 460.0                       | 80.55  | 0.1797                                   | 2.4333   |
|                 | 0.18             | 432.6                       | 75.75  | 0.2286                                   | 1.6461   |
|                 | 0.27             | 412.4                       | 72.21  | 0.2646                                   | 1.3325   |
|                 | 0.36             | 380.5                       | 66.62  | 0.3215                                   | 1.3161   |
|                 | 0.45             | 349.3                       | 61.16  | 0.3771                                   | 1.3451   |
| 343 ± 1         | Blank            | 600.0                       | 105.06   | -  | -  |
|                 | 0.09             | 530.4                       | 92.87  | 0.1160                                   | 1.4577   |
|                 | 0.18             | 515.8                       | 90.32  | 0.1403                                   | 0.9061   |
|                 | 0.27             | 476.5                       | 83.44  | 0.2058                                   | 0.9596   |
|                 | 0.36             | 448.2                       | 78.48  | 0.2530                                   | 0.9405   |
|                 | 0.45             | 415.6                       | 72.77  | 0.3073                                   | 0.9857   |

### Adsorption Isotherm

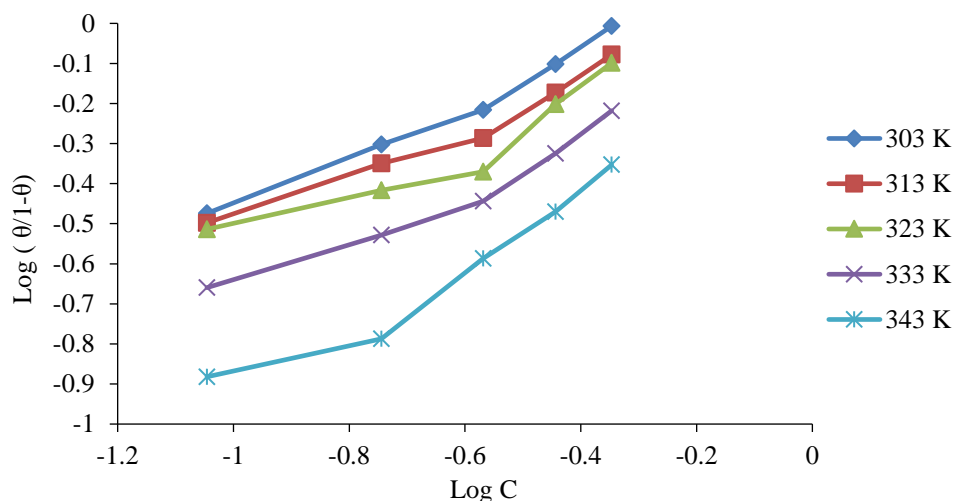
Langmuir adsorption isotherm graph was plotted between  $\log(\theta/1-\theta)$  and  $\log C$ .  $\log\left(\frac{\theta}{1-\theta}\right) = \log K_{\text{ads}} + \log C$

The standard free energy of adsorption is correlated with the  $K_{\text{ads}}$  value, which may be obtained from the intercept line on the  $\log(\theta/1-\theta)$  axis, where  $K_{\text{ads}}$  is the adsorption equilibrium constant.

The equation as follows [16] can be used to evaluate the values of  $\Delta G_{\text{ads}}^0$  for all tested temperatures.

$$\Delta G_{\text{ads}}^0 = -2.303 RT \log (55.5 K_{\text{ads}})$$

The molar concentration of water in the solution is given by 55.5, the temperature in Kelvin is given by T, and the universal gas constant is given by R = 0.008314 KJ/mol. The  $K_{\text{ads}}$  and  $\Delta G_{\text{ads}}^0$  values for the Capparis decidua fruit extract are shown in Table 2, Figure 1



**Figure 1.** The Langmuir adsorption isotherm curve for aluminum in 2N HCl at varying high temperatures throughout a 24-hour immersion period was obtained using Capparis decidua fruit extract.

**Table 2.** The correlation coefficient ( $R^2$ ), slopes, Gibbs free energy ( $\Delta G_{\text{ads}}^0$ ), and Adsorption equilibrium constant ( $K_{\text{ads}}$ ) were obtained from the Langmuir adsorption isotherm in 2N HCl with Capparis decidua fruit extract at several temperatures.

| Temperature (K) | Slope  | $R^2$  | $K_{\text{ads}}$ | $\Delta G_{\text{ads}}^0$ (KJ/mol) |
|-----------------|--------|--------|------------------|------------------------------------|
| 303             | 0.6491 | 0.9812 | 1.5439           | -11.2138                           |
| 313             | 0.5753 | 0.9648 | 1.2173           | -10.9654                           |
| 323             | 0.5685 | 0.8768 | 1.0907           | -11.0202                           |
| 333             | 0.6089 | 0.9536 | 0.8885           | -10.7939                           |
| 343             | 0.7670 | 0.9364 | 0.7365           | -10.5828                           |

### Treatment of Weight Reduction by Kinetic and Thermodynamic Methods

The phenomenon of corrosion is significantly impacted by temperature increases. The relationship between temperature and corrosion rate can be expressed using the Arrhenius equation.

$$\log \rho_{\text{corr.}} = \log A - \left( \frac{E_a}{2.303RT} \right)$$

where A is the frequency factor, R is the universal molar gas constant,  $E_a$  is the apparent activation of energy,  $\rho_{\text{corr}}$  is the corrosion rate, and T is the absolute temperature in kelvin.

The plot of  $\log \rho_{\text{corr.}}$  versus  $1/T$  is shown on a linear graph in Figure 2 for Capparis decidua. Values of activation energy The slopes of  $\log \rho_{\text{corr.}}$  versus  $1/T$  were used to estimate  $E_a$ . Arrhenius curve slope is equal to  $-E_a/2.303 R$ .

The positive readings for both  $E_a$  and  $\Delta H_{\text{act}}$  imply that the corrosion process or phenomenon is endothermic.

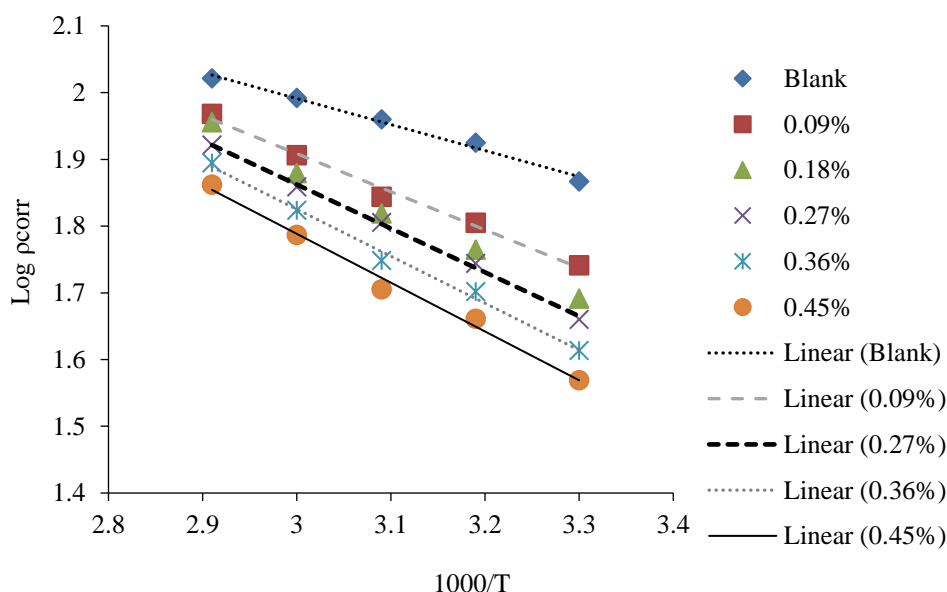
The transition state equation provided the other kinetic parameters of the corrosion reaction and allowed for the determination of the enthalpy ( $\Delta H$ ) and entropy ( $\Delta S$ ) of the activation transition state [17].

$$\rho_{\text{corr}} = \left(\frac{RT}{Nh}\right) e^{\left(\frac{\Delta S_{\text{act}}}{R}\right)} e^{\left(\frac{-\Delta H_{\text{act}}}{RT}\right)}$$

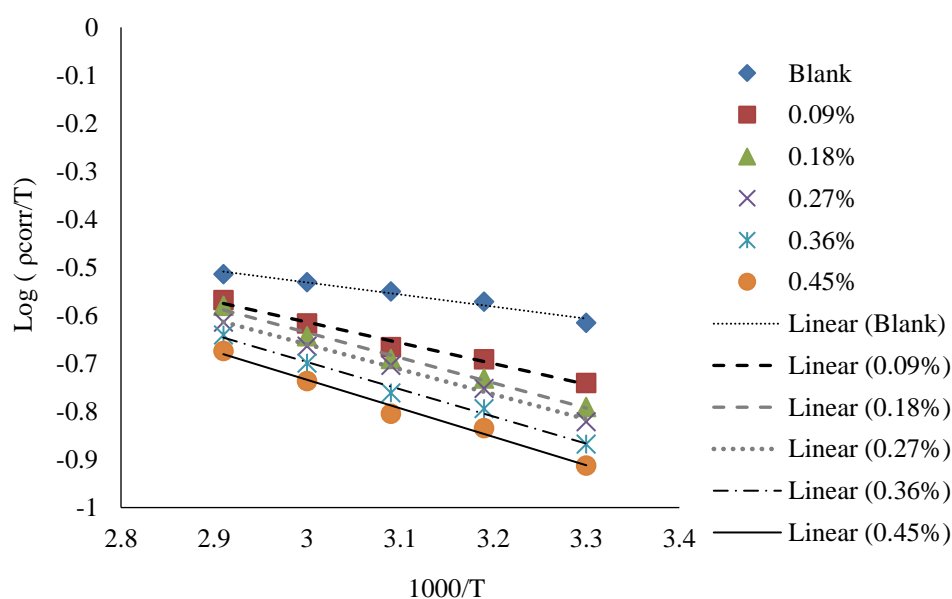
$$\log\left(\frac{\rho_{\text{corr}}}{T}\right) = \left[\log\left(\frac{R}{Nh}\right) + \left(\frac{\Delta S_{\text{act}}}{2.303R}\right)\right] - \left(\frac{\Delta H_{\text{act}}}{2.303RT}\right)$$

where T is the absolute temperature, R is the universal gas constant, N is the Avogadro's number, h is the plank's constant, and  $\rho_{\text{corr}}$  is the corrosion rate.

A straight line is produced when  $\log(\rho_{\text{corr}}/T)$  is plotted against  $1/T$ . The linear plot in Figure 3 was found to have a slope of  $(-\Delta H_{\text{act}}/2.303 R)$  and an intercept of  $[\log(R/Nh) + (\Delta S_{\text{act}}/2.303 R)]$ . Based on these values, the values of  $\Delta H_{\text{act}}$  and  $\Delta S_{\text{act}}$  were determined. Table 3 shows the calculated values of  $E_a$ ,  $\Delta H_{\text{act}}$ , and  $\Delta S_{\text{act}}$  for aluminum in 2N HCl.



**Figure 2.** Arrhenius plots for aluminium corrosion in 2N HCl with fruit extract of *Capparis decidua* at 24 hrs immersion period.



**Figure 3.** Plots showing the transition states for aluminum corrosion in 2N HCl using *Capparis decidua* fruit extract after a 24-hour immersion.

**Table 3.** Kinetic and thermodynamic parameters of aluminum corrosion in 2N HCl with and without *Capparis decidua* fruit extract at different concentrations over a 24-hour immersion period.

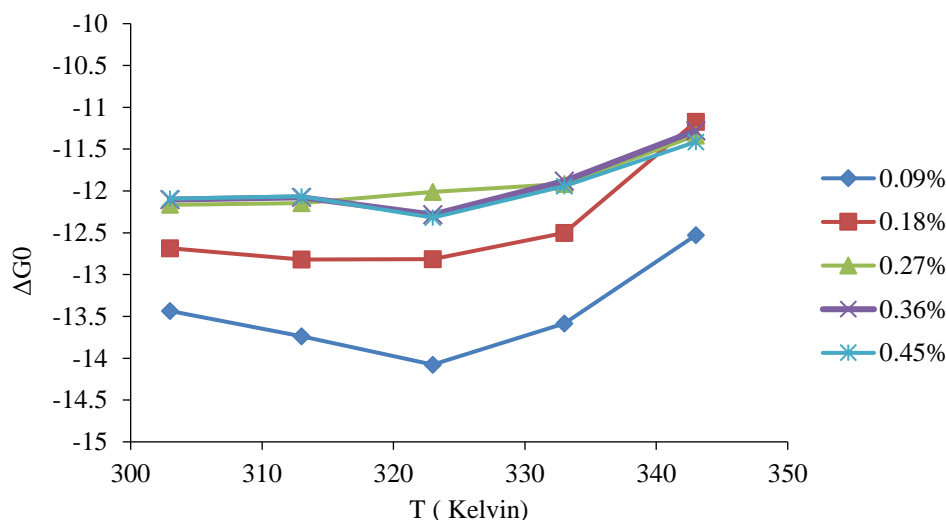
| Concentration of Inhibitor (%) | Activation Energy $E_a$ (kJ/mol) | Enthalpy $\Delta H_{act}$ (kJ/mol) | Entropy $\Delta S_{act}$ (J/mol/K) | Heat of adsorption $Q_{ads}$ (kJ/mol) |
|--------------------------------|----------------------------------|------------------------------------|------------------------------------|---------------------------------------|
| Blank                          | 7.46                             | 4.80                               | -193.29                            | -                                     |
| 0.09                           | 10.91                            | 8.26                               | -184.50                            | -18.8848                              |
| 0.18                           | 12.69                            | 10.03                              | -179.61                            | -22.3140                              |
| 0.27                           | 12.59                            | 9.94                               | -180.36                            | -17.6268                              |
| 0.36                           | 13.48                            | 10.84                              | -178.38                            | -17.3281                              |
| 0.45                           | 14.00                            | 11.35                              | -177.54                            | -16.2444                              |

### Thermodynamic Parameters

The enthalpy of adsorption ( $\Delta H_{ads}^0$ ) and the entropy of adsorption ( $\Delta S_{ads}^0$ ), two thermodynamic adsorption parameters, were also estimated using the experimental data. The formula for producing  $\Delta H_{ads}^0$  and  $\Delta S_{ads}^0$  is as follows.

$$\Delta G_{ads}^0 = \Delta H_{ads}^0 - T \Delta S_{ads}^0$$

The slope yielded the values of  $\Delta S_{ads}^0$ , while the intercept produces  $\Delta H_{ads}^0$  (Table 4). The corrosion process is entropically advantageous, as confirmed by the nearly universally positive entropy ( $\Delta S_{ads}^0$ ) values Figure 4.

**Figure 4.** Plot of  $\Delta G^0$  vs T (K) for various concentration of *Capparis decidua* fruit extract in 2N HCl at 24 hrs immersion period.**Table 4.** Thermodynamic characteristics for aluminum corrosion in 2N HCl with and without different *Capparis decidua* fruit extract concentrations at high temperatures (303–343 K) and during a 24-hour immersion period.

| Inhibitor Concentration (%) | $\Delta G_{ads}^0$ |        |        |        |        | $\Delta H_{ads}^0$ | $\Delta S_{ads}^0$ |
|-----------------------------|--------------------|--------|--------|--------|--------|--------------------|--------------------|
|                             | 303 K              | 313 K  | 323 K  | 333 K  | 343 K  |                    |                    |
| Blank                       | -                  | -      | -      | -      | -      | -                  | -                  |
| 0.09                        | -13.43             | -13.73 | -14.07 | -13.58 | -12.52 | -19.81             | -0.0196            |
| 0.18                        | -12.68             | -12.82 | -12.81 | -12.50 | -11.17 | -23.19             | -0.0334            |
| 0.27                        | -12.16             | -12.14 | -12.01 | -11.91 | -11.33 | -18.01             | -0.0189            |
| 0.36                        | -12.10             | -12.07 | -12.28 | -11.88 | -11.28 | -17.85             | -0.0184            |
| 0.45                        | -12.09             | -12.06 | -12.31 | -11.94 | -11.41 | -16.73             | -0.0148            |

## CONCLUSIONS

Based on the findings of the investigation into how temperature changes affect the ability of *Capparis decidua* fruit extract to prevent acid corrosion of aluminum in 2N HCl, the following conclusions may be made.

- Fruit from *Capparis decidua* may effectively prevent mild steel from corroding in acid in 2N HCl at 303 K, with a maximum inhibition efficacy of 63.15% at 0.45% concentration.
- There was an increase in the rate of corrosion at high temperatures, but the addition caused a discernible drop in the rate of corrosion.
- When compared to inhibited test solutions, the activation energy  $E_{act}$  in the aggressive medium alone (blank) was shown to be much lower. The  $E_{act}$  of EECdF was discovered to be between 13.11 and 22.39 KJ/mol.
- At higher temperatures, the extract's adsorption on the mild steel occurred spontaneously and followed the Langmuir adsorption isotherm.
- As EECdF increases, the entropy of adsorption decreases, indicating the interaction of inhibitor molecules.
- Overall, it is possible to utilize *Capparis decidua* fruit extract as a green inhibitor in place of hazardous chemicals that are now utilized to prevent aluminum corrosion in 2N HCl at temperatures as high as 343 K.

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