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An interesting and efficient green corrosion inhibitor for aluminium from extracts of *Chlomolaena odorata* L. in acidic solution

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Abstract The leaf extracts of *Chromolaena odorata* L. (LECO) has been studied as a possible source of green inhibitor for corrosion of aluminium in 2 M HCl using gasometric and thermometric techniques at 30 and 60 °C. Results obtained showed that the LECO functioned as an excellent corrosion inhibitor for aluminium in the acidic environment. Inhibition efficiency increased with extract concentration but decreased with temperature. The adsorption of LECO on Al surface is in accord with Langmuir adsorption isotherm. Both kinetic and thermodynamic parameters governing the adsorption process were calculated and discussed. From the experimental results obtained, it can be concluded that LECO which are biodegradable, environmentally benign, and are obtained from a renewable resource with minimal health and safety concerns have the potential to be a cost effective alternative to synthetic corrosion inhibitors. This present study provides new information on the inhibiting characteristics of LECO extract under specified conditions. The environmentally friendly inhibitor could find possible applications in metal surface anodizing and surface coating in industries.

Keywords *Chromolaena odorata* L. · Aluminium · Hydrochloric acid · Langmuir isotherm · Plant extracts · Corrosion inhibition

1 Introduction

Corrosion inhibitors are compounds that are added in small quantities to an environment to prevent corrosion of metals [1]. Most of the efficient acid inhibitors are organic compounds containing nitrogen, sulphur and/or oxygen atoms in their molecule [2–5].

Several reports have documented the use of many synthetic organic compounds, such as benzylaminopurine [6], S-triazole-triazole derivatives, [7], azoles [8], Schiff base [9], pyridine derivatives [10], pyrazole derivatives [11], bipyrazole derivatives [12], pyrimidine derivatives [13], and benzimidazole derivatives [14–16] as effective corrosion inhibitors in acidic media.

Nevertheless, the known hazardous effects of these synthetic organic inhibitors and the need to develop cheap, non-toxic and ecofriendly processes have now made researchers to focus on the use of natural product [17–23]. Recent literatures from our laboratory and other authors have shown that naturally occurring materials such as *Gum Arabic* [24], *Raphia hookeri* [25], *Ipomoea invulcrata* [26], *Vigna unguiculata* [27], *Pachylobus edulis* [28], *Ginseng root* [29], *Dacroydes edulis* [30], *Zenthoxylum alatum* [31], *Hibiscus sabdariffa* [32], *Datura stramonium* [33], limonene [34], *Prosopis cineraria* [1], to mention but a few have been found to be very efficient corrosion inhibitors for metal in acidic/alkaline media. A detailed review of natural products as corrosion inhibitors can be found in [35]. Perusals of literatures however, reveal that *Chromolaena odorota* has not been tested as corrosion inhibitor for metals in acidic medium to the best of our knowledge.

Chromolaena odorota (L.) R.M. King & H. Robinson (synonym: *Eupatorium odoratum* L.), is a perennial scadent or semi-woody shrub belonging to the Asteraceae family. This plant species is native to Central and South

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America and it is now distributed throughout Africa and tropical Asia [36]. *C. odorata* L. is an aggressive competitor that occupies different types of lands where it forms dense strands that prevents the establishment of the flora. It is a menace in plantations and other ecosystems. It suppresses young plantations, agricultural crops and smothers vegetation as it possesses allelopathic potentialities growth inhibitors [37]. The economic value of *C. odorata* L. is low. The plant can be poisonous to livestock as it has exceptional high level of nitrate (5 to 6 times above the toxic level) [38]. Despite the negative sides of the plant, it still has patronage to the practitioners of traditional medicine. It has been reported to have anti-diarrheal, astringent, anti-spasmodic, anti-hypertensive, anti-inflammatory and diuretic properties [39]. In the Southern part of Nigeria, the leaves are used for wound dressing, skin infection and to stop bleeding.

The present work therefore, has been designed to evaluate the effect of the leaf extracts of *Chromolaena odorota* (L.) on the corrosion inhibition of aluminium in 2 M HCl solution with a view to contributing to the search for beneficial uses of this invasive plant which is a menace to farmers. Gasometric and thermometric techniques were used at 30 and 60 °C for the investigation. Activation and thermodynamic parameters were effectively used to characterize the inhibition mechanism of the adsorption process.

2 Experimental details

2.1 Materials preparation

The sheets of aluminium, AA 1060 type and purity of 98.5% used for this study were obtained from Sky Aluminium Ltd, Uyo, Nigeria. Each sheet was 0.3 cm in thickness and were mechanically pressed cut into 6 × 2 cm coupons. These coupons were used as cut without further polishing. However, they were degreased in ethanol, dried in acetone and stored in moisture free desiccators before their use in corrosion studies. Coupons of the same dimension (6 × 2 × 0.3 cm) were used for both gasometric and thermometric methods.

2.2 Preparation of the leaf extracts of *Chromolaena odorata*

The procedure for the preparation of the leaf extracts is similar to that reported recently by Okafor et al. [40]. *Chromolaena odorata* L. leaves were collected from Itak, Akwa Ibom State, Nigeria. They were dried in an N53C-Genlab Laboratory oven at 50 °C, and ground to powder form. Ten gram of the powder was digested in 1 L of 2 M HCl solution. The resultant solution was kept for 24 h, filtered and stored. From the stock solution, the leaf extracts test solutions were prepared at concentration range of 10–50 v/v%.

2.3 Gasometric technique

The volume of hydrogen evolved was determined following the procedures previously described elsewhere [23, 41]. A 100 mL solution of 2 M HCl solution was introduced into the reaction vessel connected to a burette through a delivery tube. The initial volume of air in the burette was recorded. An aluminium coupon of weight 2 g was dropped into the solution of HCl and the reaction vessel quickly closed to prevent any escape of H_2 gas. However, the volume of H_2 evolved from the corrosion reaction was monitored by the depression (in mL) in the paraffin oil level. The depression in paraffin oil level was monitored every 60 s (1 min) for 840 s (14 min). The same experiment was repeated in the presence of inhibitor (LECO) having the concentration range 10–50 v/v% with a corrodent (HCl) concentration of 2 M

The inhibition efficiency (%*I*) was calculated using the equation:

$$\%I = \left(1 - \frac{V_{\mathrm{Ht}}^{1}}{V_{\mathrm{Ht}}^{\mathrm{O}}}\right) \times 100 \tag{1}$$

where V_{H}^{1} is the volume of hydrogen evolved at time “t” for inhibited solution and $V_{\mathrm{H}}^{\mathrm{O}}$ that for unhibited solution.

2.4 Thermometric method

The reaction vessel and procedure for determining the corrosion behaviour by this method has been described elsewhere by other authors [42, 43]. The volume of the test solution was kept at 100 mL. The initial temperature in all experiments was kept at 30 °C. The temperature was measured to ±0.05 °C on a calibrated thermometer (0–100 °C). This method allowed for the evaluation of the reaction number (RN). The RN is defined as:

$$\mathrm{RN}\,(^{\circ}\mathrm{C}\ \overset{-1}{\mathrm{min}}) = \frac{T_{\mathrm{m}} - T_{\mathrm{i}}}{t} \tag{2}$$

where T_{m} and T_{i} are the maximum and initial temperatures respectively and ‘*t*’ is the time (min) taken to reach the maximum temperature. The inhibition efficiency (%*I*) was evaluated from percentage reduction in the reaction number using Eq. 2.

$$\%I = \frac{\mathrm{RN}_{\mathrm{aq}} - \mathrm{RN}_{\mathrm{wi}}}{\mathrm{RN}_{\mathrm{aq}}} \times 100 \tag{3}$$

where $\mathrm{RN}_{\mathrm{aq}}$ is the reaction number in the absence of inhibitor (blank solution) and RN_{wi} is the reaction number of 2 M HCl containing studied inhibitor.

3 Results and discussion

3.1 Hydrogen evolution measurements

Experiments were undertaken using gas-volumetric technique. This technique apart from its experimental rapidity ensures a more sensitive monitoring in situ any perturbation by an inhibitor vis-à-vis gas evolution on the metal-corrodent surface. This assertion has been firmly established in earlier reports [44–47].

Figure 1a shows the effect of increasing concentrations of LECO on the relationship between the volume of hydrogen evolved during the dissolution process of aluminium (V, mL) and the reaction time (t, min) at 30 °C. A similar trend was observed at 60 °C (Fig. 1b) but with rather higher values. Inspection of Fig. 1 shows that the hydrogen evolution starts after a certain time from the immersion of the aluminium coupon in the test solution. It may be expected that this time corresponded to the period/time needed by the acid to destroy the pre-immersion oxide film and is known as incubation period [24]. It was observed that hydrogen evolution rates decreased in the presence of LECO compared to the absence of LECO (blank).

It is well known that the dissolution of Al in inhibitor-free HCl solution may occur by a simple mechanism with the formation of $AlCl_3$ [48]:

$$Al + {}^{1}\!/_{2}O_2 \leftrightarrow Al{:}O_{ads} \tag{4}$$

$$Al{:}O_{ads} + Cl^- \leftrightarrow Al{:}OCl^-_{ads} \tag{5}$$

$$Al{:}OCl^-_{ads} \overset{rds}{\leftrightarrow} Al{:}OCl_{compound} \tag{6}$$

$$Al{:}OCl_{compound} + 2Cl^- + 2H^+ \overset{fast}{\leftrightarrow} AlCl_3 + H_2O \tag{7}$$

Thus in the present study, the inhibited solutions contain Cl^- ions (from the agressive acid solution), hence the dissolution process of Al (anodic process) may had proceeded by the formation of $AlCl_3$ leading to the observed increase in corrosion rate. It is however, expected that the addition of LECO will decrease the corrosion rate.

Thus, the corrosion rate of Al in the absence and presence of the LECO were assessed from the linear portion of the hydrogen evolution plots and the corresponding values for the different systems studied are given in Table 1. The corrosion rates were seen to increase with increase in temperature and were reduced in the presence of LECO compared to the blank solution. Table 1 also shows the calculated values of inhibition efficiency (%*I*) for the

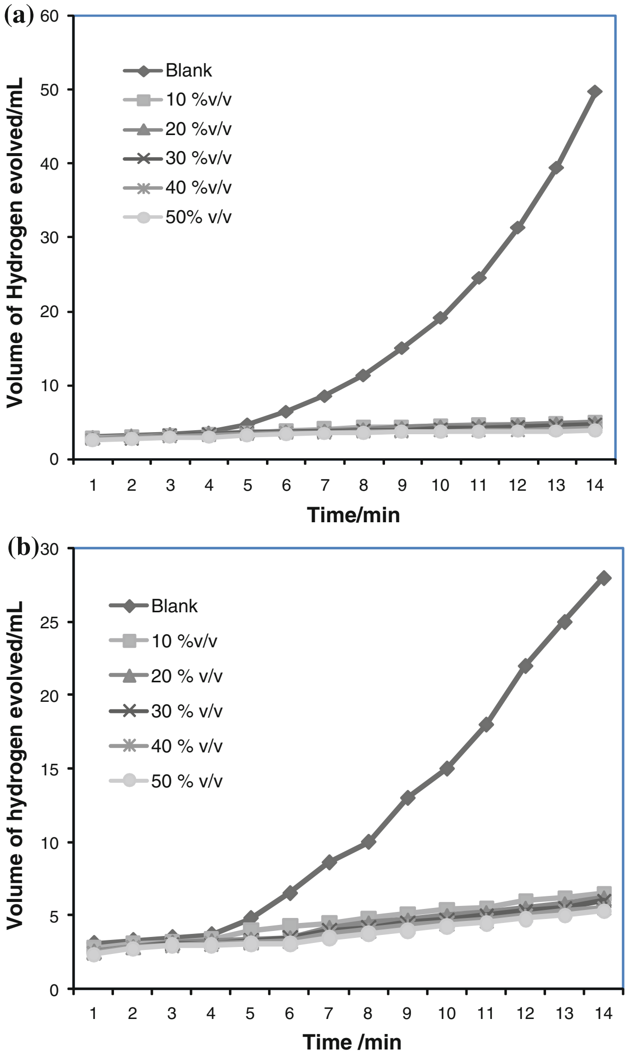

Fig. 1 Variation of volume of hydrogen evolved with time for the dissolution of Al in the absence and presence of different concentrations of LECO at **a** 30 °C and **b** 60 °C

Table 1 Calculated values of corrosion rate (mL min^{-1}), inhibition efficiency (%*I*) and the degree of surface coverage (θ) for LECO from hydrogen evolution data

Conc. (% v/v)	Corrosion rate (mL min^{-1})		Inhibition efficiency (%*I*)		Degree of Surface Coverage (θ)	
	30 °C	60 °C	30 °C	60 °C	30 °C	60 °C
Blank	17.70	80.50	–	–	–	–
10	1.82	33.80	89.75	57.97	0.897	0.579
20	1.78	30.10	89.95	62.52	0.899	0.625
30	1.71	24.10	90.36	69.97	0.904	0.699
40	1.53	22.10	91.36	72.46	0.914	0.724
50	1.39	18.10	92.16	77.43	0.922	0.774

different test solutions determined using the hydrogen evolution technique. Inhibition efficiency (%*I*) increases with an increase in extract concentration but decreases with rise in temperature. Increase in inhibiition efficiency with increase in temperature according to Oguzie [23], is attributed to high dissolution rate of aluminium at elavated temperature and the desorption of the adsorbed inhibitor due to increased solution agitation resulting from higher rates of hydrogen gas evolution which may also reduce the ability of the inhibitor to adsorbed on the metal surface.

According to Tsuru et al. [49], the inhibition of metal corrosion by organic compounds is attributed to either the adsorption of inhibitor molecule or the formation of a layer of insoluble complex of the metal on the surface which acts as a barrier between the metal surface and the corrosive medium. Since no insoluble material was observed on the metal surface, the inhibitive action of the extract may be due to its adsorption on the metal surface. In discussing corrosion inhibition by surface- active organic compounds, various factors are taken into consideration including the number and types of adsorbing groups and their electronic structure [45]. Previous investigations of the leaves of *Chlomolaena odorata* L revealed the presence of essential oils [50], steroids [51], triterpenes [52] and flavonoids [53]. This makes it difficult to assign the observed inhibiting effect to a particular constituent. The net adsorption of these organic matter on the corroding Al surface creates a barrier that isolates the metal from the corrodent. Thus, inhibition efficiency increases with an increase in the metal fraction occupied by the organic matter.

3.2 Thermometric method

The use of thermometric method as a technique in corrosion inhibition studies has been widely reported [24, 42, 43]. Results obtained from this technique is found to be comparable with well established methods such as weight loss [18] and hydrogen evolution [24].

The corrosion reaction of Al in 2 M HCl in the absence and presence of LECO was also investigated using the thermometric method. Figure 2 shows the relationship between the reaction number, RN, and the logarithm of inhibitor concentration. The curve consists of an initial decreasing portion along which the RN decreased with increasing concentration of LECO and then the rate of decrease became smaller. As the concentration of LECO increased further, the value of RN decreased with concentration. This seems to suggest that the inhibitor formed a monolayer on the surface of aluminium [24, 54].

Table 2 shows the calculated values of reaction number and percentage reduction in reaction number (inhibition efficiency) for aluminium corrosion in 2 M HCl in the absence and presence of varying concentrations of LECO.

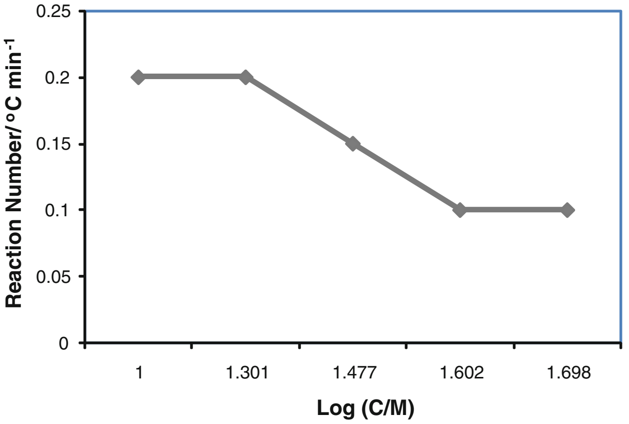

Fig. 2 Plot of RN against Log of inhibitor concentration

Table 2 Calculated values of reaction number (RN) and percentage reduction in reaction number (inhibition efficiency) in the absence and presence of different concentrations of LECO for aluminium corrosion in 2 M HCl

Conc. (% v/v)	Reaction number (RN)	Percentage reduction in RN (%*I*)
Blank (2 M HCl)	2.05	–
10	0.20	90.24
20	0.18	91.21
30	0.15	92.68
40	0.13	93.65
50	0.10	95.12

Table 3 Comparison of inhibition efficiency (%*I*) of LECO from hydrogen evolution and thermometric method at 30 °C

Conc. (% v/v)	Inhibition efficiency (%*I*)	
	Hydrogen evolution	Thermometric
10	89.75	90.24
20	89.95	91.21
30	90.36	92.68
40	91.36	93.65
50	92.16	95.12

This table reveals that the values of the reaction number were higher in the absence of the extract than in the presence of the extract. According to Umoren and Ebenso [18], a higher reaction number value reveals that the maximum temperature was attained at a very short time. In the present study, there was a decrease in the value of the reaction number on the introduction of the extract. This implies that the extract inhibit the corrosion of aluminium in the acidic medium probably by adsorption on the aluminium surface. Also inhibition efficiency increased with increasing concentration of the extract. The inhibition efficiency values obtained from the two independent methods (hydrogen evolution and thermometric) are in good agreement (Table 3). The inhibition efficiency obtained from extracts of *Chromolaena odorata* L. were higher when compared to other plant extracts like *Raphia hookeri* [25], *Ipomoea invulcrata* [26], *Vigna unguiculata* [27], *Pachylobus edulis* [28] and some well known organic inhibitors such as benzimidazole derivatives [14] and azoles [8] reported in the literature.

3.3 Effect of temperature and inhibition mechanism of inhibition process

According to Oguzie [45], organic inhibitors are known to affect the kinetics of metal corrosion by cutting back the rate of either or both the anodic and cathodic reactions. A given inhibitor functions by means of a specific mechanism, depending on the type and composition of metal and corrodent, inhibitor structure and concentration as well as temperature. Thus in examining the effect of temperature on the corrosion process, the apparent activation energies (E_a) were calculated from the Arrhenius equation [24]:

$$\log\frac{\rho_2}{\rho_1} = \frac{E_a}{2.303R}\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \tag{8}$$

where ρ_2 and ρ_1 are the corrosion rates at temperature T_1 and T_2 respectively, and R the molar gas constant. An estimate of heat of adsorption (Q_{ads}) was obtained from the trend of surface coverage with temperature as follows [45]:

$$Q_{ads} = 2.303R\left[\log\left(\frac{\theta_2}{1-\theta_2}\right) - \log\left(\frac{\theta_1}{1-\theta_1}\right)\right]\left(\frac{T_1 \times T_2}{T_2 - T_1}\right) \tag{9}$$

where θ_1 and θ_2 are the degrees of surface coverage at temperatures T_1 and T_2. θ is related to inhibition efficiency (%I) as follows:

$$\theta = \frac{\%I}{100} \tag{10}$$

The calculated values of E_a and Q_{ads} are given in Table 4. Analysis of the temperature dependence of inhibition efficiency as well as comparison of corrosion activation energies in the absence and presence of inhibitor gives some insight into the possible mechanism of inhibitor adsorption. A decrease in inhibition efficiency with rise in temperature, with analogous increase in corrosion activation energy (E_a) in the presence of inhibitor compared to its absence, is frequently interpreted as being suggestive of formation of an adsorption film of physical (electrostatic) nature. The reverse effect, corresponding to an increase in inhibition efficiency with rise in temperature and lower activation energy in the presence of inhibitor, suggests a chemisorption mechanism [24]. From the forgoing, the trend for LECO suggests physisorption of inhibiting species. The negative Q_{ads} values indicate that the degree of surface coverage decreased with rise in temperature, supporting the earlier proposed physisorption mechanism [30].

Table 4 Calculated values of activation energy, E_a (kJ mol^{-1}) and heat of adsorption, Q_{ads} (kJ mol^{-1}) for LECO for aluminium corrosion n 2 M HCl

Conc. (% v/v)	E_a (kJ mol^{-1}) 30–60 °C	Q_{ads} (kJ mol^{-1}) 30–60 °C
Blank (2 M HCl)	42.31	–
10	81.71	−56.62
20	79.06	−46.85
30	73.99	−38.83
40	74.64	−38.76
50	71.74	−39.48

Due to the complex compositions of plant extracts, the aqueous acid extracts of *Chlomolaena odorata* L. under study may exist as either protonated or molecular species, depending on the nature of the chemical changes occurring to the inhibitor. Considering the positive surface charge on a corroding aluminium specimen in acidic solution [2], protonated species are normally poorly adsorbed. Improved adsorption should however be obtained in hydrochloric acid solutions due to the tendency of chloride ions to be strongly adsorbed on the metal surface and hence facilitate physical adsorption of cation-type inhibitors [45]. Therefore the higher inhibition efficiency obtained in this study implies predominant adsorption of protonated species, which adsorb electrostatically and replaces adsorbed water molecules by possibly modifying the low stable aluminium chloro complexes to higher stable aluminium-inhibitor complex

$$\begin{aligned}&\mathrm{Al}^{3+} + m\mathrm{H_2O} + n\mathrm{Cl}^- + p(\mathrm{LECO})\\&\leftrightarrow [\mathrm{Al(LECO)}_p(\mathrm{OH})_m(\mathrm{Cl})_n]^{3-m-n} + m(\mathrm{H})^+\end{aligned} \tag{11}$$

The solubility of the formed aluminium complex depends on the molecules of inhibitor and hydroxyl groups and also determines the degree of corrosion inhibition. On increasing the concentration of LECO, inhibitor molecules replaces hydroxyl group in the complex and its solubility increases resulting in the decrease of corrosion inhibition. Similar mechanism has been documented elsewhere [55].

3.4 Adsorption and thermodynamic considerations

In order to understand the mechanism of corrosion inhibition, the adsorption behaviour of the organic material adsorbed on the aluminium surface must be known. The degree of surface coverage (θ) for the inhibitor was obtained from hydrogen evolution measurements and is presented in Table 1.

The Langmuir adsorption isotherm model has been used extensively in the literature for various metal, inhibitor and

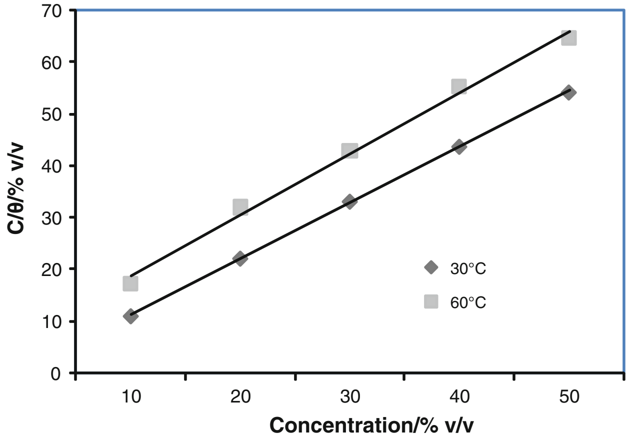

Fig. 3 Langmuir adsorption plots for aluminium in 2 M HCl containing different concentrations of LECO at 30 and 60 °C

acid solution [56–60]. The Langmuir model assumes that the adsorption occur on specific homogenous sites on the metal surface and is used succesfully in many monolayer adsorption process. It was assumed that the adsorption of LECO onto aluminium surface would follow the Langmuir isotherm. The plot of C/θ versus C (Fig. 3) yields a straight line with a strong correlation coefficient ($R^2 = 0.99$) and the slope around unity (Table 5) supporting the assumption that the adsorption of LECO from hydrochloric acid solution on the aluminium surface at the studied temperatures obeys the Langmuir adsorption isotherm, which can be represented as:

$$\frac{C}{\theta} = \frac{1}{K} + C \tag{12}$$

Moreover, the essential characteristic of Langmuir isotherm can be expressed in terms of a dimensionless separation factor, K_L [61] which describe the type of isotherm and is defined by

$$K_L = \frac{1}{1 + K_{\text{ads}}C} \tag{13}$$

If $K_L > 1$ unfavourable, $K_L = 1$ linear, $0 < K_L < 1$ favourable, $K_L = 1$ irreversible.

Table 6 gives the estimated K_L values for LECO at different concentration at 30 and 60 °C. It was found that all K_L values are less than unity confirming that the adsorption process is favourable. However, according to the mean value of K_L for each temperature, the inhibitory action of LECO is more favourable at lower temperature.

Table 6 The values of dimensionless separation factor, K_L, for LECO at various concentrations

Conc. (% v/v)	K_L	
	30 °C	60 °C
10	0.052	0.413
20	0.028	0.260
30	0.019	0.190
40	0.014	0.149
50	0.012	0.123
Mean value	0.025	0.227

The free energy of adsorption $\Delta G^{\circ}_{\text{ads}}$ of the inhibitors on aluminium surface can be determined using the following equation [30]:

$$\Delta G^{\circ}_{\text{ads}} = -RT \ln(K \times 55.5) \tag{14}$$

where $\Delta G^{\circ}_{\text{ads}}$ is the standard free energy of adsorption, K is the equilibrium constant of adsorption and the value of 55.5 is the concentration of water in solution expressed in mol L^{-1}. The calculated $\Delta G^{\circ}_{\text{ads}}$ and K results are also listed in Table 5. The negative values of $\Delta G^{\circ}_{\text{ads}}$ indicate the spontaneous adsorption of these molecules from HCl solution to the metal surface. Values of $\Delta G^{\circ}_{\text{ads}}$ around -20 kJ mol^{-1} or lower are consistent with the electrostatic interaction between charged organic molecules and the charged metal surface (physisorption); those around -40 kJ mol^{-1} or higher involve charge sharing or transfer from the organic molecules to the metal surface to form a co-ordinate type of bond (chemisorptions) [56]. The values of $\Delta G^{\circ}_{\text{ads}}$ for LECO being less than -40 kJ mol^{-1} indicates physical adsorption. Also from Table 5, it could be found that the equilibrium constant of the adsorption process K decreased with increasing temperature. It is well known that K designates the adsorption power of inhibitor onto the aluminium surface [3]. Clearly, LECO gave high values of K at lower temperatures, indicating strong adsorption of LECO onto the aluminium surface at lower temperatures. Thus, the inhibition efficiency decreased with the increase in temperature as a result of the desorption of LECO from the aluminium surface.

Considering that the values of enthalpy and entropy of the inhibition process have no distinct changes in the temperature range studied, the thermodynamic parameters

Table 5 The thermodynamic parameters for LECO in 2 M HCl on aluminium corrosion at 30 and 60 °C

T (°C)	Slope	K	ΔG_{ads} (kJ mol^{-1})	R^2	ΔH_{ads} (kJ mol^{-1})	ΔS_{ads} (J mol^{-1} K^{-1})
30	1.07	1.71	−11.47	0.99	−69.1	−192.0
60	1.17	0.14	−5.71	0.99		

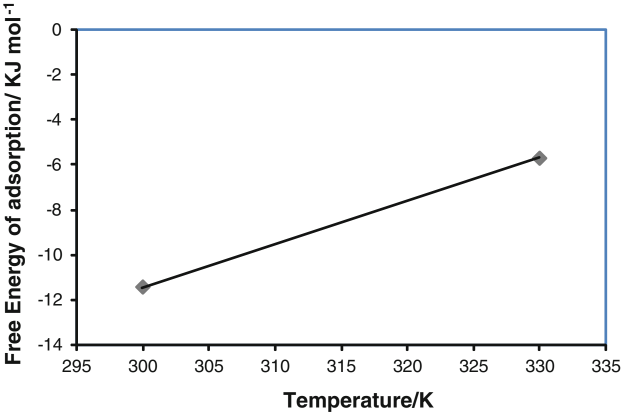

Fig. 4 The relationship between ΔG°_{ads} and T

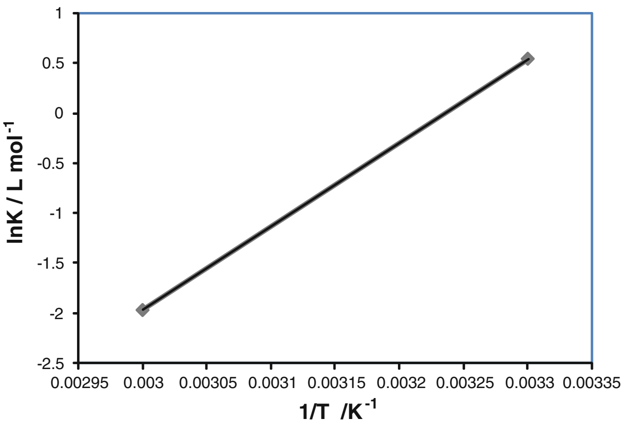

Fig. 5 The relationship between ln K and 1/T

ΔH°_{ads} and ΔS°_{ads} for the adsorption of LECO on aluminium can be calculated from the basic thermodynamic equation:

$$\Delta G^{\circ}_{ads} = \Delta H^{\circ}_{ads} - T\Delta S^{\circ}_{ads} \qquad (15)$$

where ΔH°_{ads} and ΔS°_{ads} are the variation of enthalpy and entropy of the adsorption process, respectively. The values of ΔG°_{ads} were plotted against T. This plot is shown in Fig. 4. It should be noted that the entropy change of adsorption $-\Delta S^{\circ}_{ads}$ is the slope of the straight line $\Delta G^{\circ}_{ads} - T$ according to Eq. 15. The intercept of the straight line is used to calculate the heat of adsorption ΔH°_{ads}. The calculated values are depicted in Table 5. The negative sign of ΔH°_{ads} indicates that the adsorption of inhibitor molecules is an exothermic process. Thus adsorption will be favoured at lower temperatures as obtained in this work. ΔS°_{ads} value is large and negative showing the chaotic nature of inhibitor molecule before adsorption. As adsorption progresses, the inhibitor molecules adsorbed on the aluminium surface become more orderly, resulting in a decrease in entropy [62].

On the other hand, ΔH°_{ads} can also be calculated according to Van't Hoff equation:

$$\ln K = \frac{-\Delta H^{\circ}_{ads}}{RT} + \text{const.}$$

Figure 5 shows the plot of ln K versus 1/T which gives a straight line with slopes of ($\Delta H^{\circ}_{ads}/R$) and intercept of ($\Delta S^{\circ}_{ads}/R - \ln 55.5$). The calculated ΔH°_{ads} using Van't Hoff equation is -69.3 kJ mol^{-1}, confirming the exothermic behaviour of the adsorption of LECO on the aluminium surface. Values of ΔH°_{ads} obtained by both methods are in good agreement. Moreover, the deduced ΔS°_{ads} value of -190.1 J mol^{-1}K^{-1} from Van't Hoff equation is very close to that given in Table 5.

4 Conclusion

The main conclusions are as follows:

1. Leaf extract from *Chlomolaena odorata L.*(LECO) shows good inhibitive action against the corrosion of Al in 2 M HCl.
2. The value of inhibition efficiency (*%I*) increases with increasing inhibitor concentration but decreases with increasing temperature.
3. There was good agreement between the data obtained from hydrogen evolution and thermometric methods.
4. The adsorption of LECO on Al surface obeys Langmuir adsorption isotherm.
5. The phenomenon of physical adsorption is proposed from the activation and thermodynamic parameters obtained.

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