

# Corrosion Inhibitive Action of *Euphorbia heterophylla* Leaves Extract on Mild Steel in 1M H<sub>2</sub>SO<sub>4</sub> Solution

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## Abstract

The corrosion inhibitive action of the ethanol extract of *Euphorbia heterophylla* (E.H) leaves on the corrosion of mild steel in 1M H<sub>2</sub>SO<sub>4</sub> solution was investigated using gravimetric technique (weight loss measurement). Phytochemical analysis was carried out on the extract and the effect of extract concentration, temperature, immersion time and acid concentration on the corrosion process were determined. The corrosion inhibition efficiency of the extract increased with increase in the concentration of the extract and decreased with increase in temperature. Increase in temperature also increased the corrosion rate of mild steel in 1M H<sub>2</sub>SO<sub>4</sub> in the absence and presence of different concentrations of the extract. The adsorption of the plant extract obeyed Langmuir and Freundlich adsorption isotherms. The process of physical adsorption was proposed for the extract from the trends of inhibition efficiency with temperature and from calculated values of Gibbs free energy, activation energy and enthalpy of adsorption. Gibbs free energy values for the reactions were less than 20kJ/mol, indicating physical adsorption process and were also found to be negative, indicating that the adsorption process was spontaneous. The corrosion inhibition efficiency (% IE) of the plant extract was attributed to the phytochemical constituents (alkaloids, flavonoids, tannins, saponins, phenolics, steroids and cardiac glycosides) present in them. The results showed that the extracts of E.H are good corrosion inhibitors of mild steel, reaching a corrosion inhibition efficiency (%IE) of 92.72% at 2.0g/L extract concentration.

## Keywords

*Euphorbia heterophylla*, Mild Steel, Corrosion Inhibitor, Gravimetric

## 1. Introduction

Mild steel is the main metallurgy used for various industries, especially the oil and gas industry. This is due to its availability and relatively inexpensive cost. However, corrosion has had a great impact on all the industries, which makes it a crucial obstacle that needs to be controlled and solved. In addition to selecting corrosion resistant alloys and using internally lined pipes and/or vessels, chemical inhibition is a commonly used approach to control internal corrosion reactions due to the various corrosive environments

[1]. Corrosion inhibitors have been used extensively in industry in order to reduce the corrosion rate of many metals. Thousands of articles and publications are issued about corrosion and its prevention every year. This makes one understand the importance of corrosion prevention. Corrosion inhibitors have been widely studied in many industries to reduce the corrosion rate of metal surfaces in contact with aggressive media [2, 3]. Many investigations have been conducted with a view to finding suitable corrosion inhibitors. However, most of the corrosion inhibitors are synthetic chemicals that could be difficult to synthesize, and as a result incur relatively higher

manufacturing costs. Moreover, these inhibitors can also be of a great threat to the environment and the public since they can be hazardous and toxic or carcinogenic in many cases [4]. This makes the investigation and the ongoing trend of finding safe and eco-friendly corrosion inhibitors, of crucial importance to many industries. Alternatively, plant extracts are viewed as environmental friendly and ecologically acceptable inhibitors. Plant extracts are of low-cost, readily available, and renewable. Generally, the inhibitive effect of plant extract is attributed to the adsorption of organic substances on the metal surface blocking active sites or even forming a protective barrier via physisorption and chemisorption. In recent years, natural compounds such as herbal plants are employed as inhibitors in order to develop new cleaning chemicals for green environment, and several studies have been reported in the use of natural products in different media [5-8]. In view of the continued interest on the application of plants extract for metal corrosion control, this study investigates the inhibitive effects of *Euphorbia heterophylla* leaves extract on the corrosion of mild steel in 1M sulphuric acid (H<sub>2</sub>SO<sub>4</sub>) solution.

## 2. Materials and Methods

### Collection and Preparation of Coupons

The mild steel sheet used for this work was obtained from Nkwogbe Market, Ihiala, Anambra State, Nigeria and was 0.15 cm (1.5mm) in thickness. It was mechanically cut into coupons of 3cm x 3cm (surface area 19.8 cm<sup>2</sup>). A small hole was drilled at one end of the coupons for easy hooking. The surfaces of the mild steel coupons were mechanically polished with emery paper (sand paper) to remove any corroded surface. They were washed with distilled water, degreased with ethanol, dipped into acetone, air dried and weighed using a digital weighing balance. The weights were recorded and the weighed coupons stored in moisture free desiccators before their use in corrosion studies.

### Collection and Preparation of Plants Extracts

The leaves of *Euphorbia heterophylla* were collected from a farmland in Umudimogo village, Ihiala, Anambra State, Nigeria. They were air dried under room temperature away from direct sunlight for 21 days and ground into powder using a mechanical grinder. 100g of the plant powders were extracted with ethanol using a soxhlet extractor for 24 hours. After recovering most of the solvents, the extract was heated on a water bath at 60°C until almost the entire solvent (ethanol) evaporated. Different concentrations of the extract obtained were prepared by dissolving 0.5, 1.0, 1.5 and 2.0 gramme of the extract in 1 litre (1000 ml) of 1M H<sub>2</sub>SO<sub>4</sub> respectively.

### Phytochemical Analysis

Phytochemical analysis of the ethanol extracts of the leaves of *Euphorbia heterophylla* were carried out to ascertain the presence of different phytochemicals in the leaves extracts as described in literature [9, 10].

### Gravimetric Analysis (Weight Loss Method)

Gravimetric analysis was carried out using weight loss

technique. During this analysis, the effect of immersion time, temperature and acid concentration on the corrosion process was determined.

In determining the effect of immersion time on the corrosion process the weighed mild steel coupons were each suspended and completely immersed in beakers containing 100ml of the test solutions (1M H<sub>2</sub>SO<sub>4</sub>) in the absence and presence of different concentrations of the plant extract, i.e. 0.5g/L, 1.0g/L, 1.5g/L and 2.0g/L with the help of threads and sticks for 24 hours, 72 hours, 120 hours, and 168 hours at ambient temperature and properly labeled. The coupons were retrieved as each time elapsed and then washed, scrubbed with bristle brush under fast flowing water, rinsed in ethanol to remove the corrosion product, dried using acetone and re-weighed.

In determining the effect of temperature on the corrosion process, this same procedure was repeated using a water bath at temperatures of 30°C (303K), 40°C (313K), 50°C (323K), and 60°C (333K), each maintained for 6 hours and properly labeled. For each temperature that is been determined, the mild steel coupons were retrieved after 6 hours.

In determining the effect of acid concentration on the corrosion process the weighed mild steel coupons were each suspended and completely immersed in beakers containing 100ml of different concentrations of the acid, i.e. 1M, 2M, 3M and 4M in the absence and presence of different concentrations of the plant extract, i.e. 0.5g/L, 1.0g/L, 1.5g/L and 2.0g/L at ambient temperature for 24 hours and properly labeled. For each acid concentration that is being determined the coupons were retrieved after 24 hours and then scrubbed with bristle brush under fast flowing water, rinsed in ethanol, dried using acetone and re-weighed.

The weight loss of the mild steel was evaluated in grammes as the difference in the initial and final weight of the coupons. These experiments were carried out for the *Euphorbia heterophylla* leaves extract using concentrations of 0.5g/L, 1.0g/L, 1.5g/L and 2.0g/L. From the weight loss data the corrosion rates (CR) were calculated using equation 1:

$$CR \text{ (gcm}^{-2}\text{h}^{-1}\text{)} = \frac{WL}{At} \quad (1)$$

Where WL is weight loss in gramme, A is the metal surface area and t is the time of immersion in hours.

From the corrosion rate values, the degree of surface coverage ( $\theta$ ) was got using equation 2:

$$\theta = \left[ \frac{CR_{\text{blank}} - CR_{\text{Inh}}}{CR_{\text{blank}}} \right] \quad (2)$$

The inhibition efficiencies (% IE) of the plants extracts were determined using equation 3:

$$\% \text{ IE} = \left[ \frac{CR_{\text{blank}} - CR_{\text{Inh}}}{CR_{\text{blank}}} \right] \times 100 \quad (3)$$

Where CR<sub>blank</sub> and CR<sub>Inh</sub> are the corrosion rates in the absence and presence of the plants extracts respectively.

### Thermodynamic and Adsorption Studies

The effect of temperature on the corrosion process was studied using the Arrhenius equation 4:

$$k = Ae^{-E_a/RT} \quad (4)$$

Where k is the rate constant, A is the pre-exponential factor,  $E_a$  is the activation energy, R is the universal gas constant and T is the absolute temperature.

Rate law states that:

$$\text{rate} = \frac{-d(I)}{dt} = k(I)^n \quad (5)$$

Where I is the inhibitor, (I) is the concentration of the inhibitor in mol per  $\text{dm}^3$ , t is the reaction time, k is the rate constant and n is the order of the reaction.

However, corrosion inhibition studies are done on the assumption of pseudo zero order condition [11]. Therefore:

$$\text{rate} = \frac{-d(I)}{dt} = k(I)^0 \quad (6)$$

Equation 6 becomes:

$$\text{rate} = \frac{-d(I)}{dt} = k \quad (7)$$

Hence in calculating the activation energy ( $E_a$ ) using the condensed Arrhenius equation 8, k was substituted with the corrosion rate CR.

$$E_a = 2.303R \left[ \log \left( \frac{CR_2}{CR_1} \right) \times \left( \frac{T_1 T_2}{T_2 - T_1} \right) \right] \quad (8)$$

Where  $CR_1$  and  $CR_2$  are the corrosion rates at temperatures  $T_1$  and  $T_2$  respectively, and R is the universal gas constant.

The heat of adsorption ( $Q_{\text{ads}}$ ) of the ethanol extracts of the leaves of the plants was calculated using equation 9:

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

Where  $\theta_1$  and  $\theta_2$  are the values of degree of surface coverage at temperatures  $T_1$  and  $T_2$  respectively. These values are approximately equal to change in enthalpy of adsorption ( $\Delta H_{\text{ads}}$ ) because the reactions were carried out at constant pressure.

Langmuir and Freundlich adsorption isotherms were tested to see if they fit the experimental data.

Langmuir adsorption isotherm postulates a monolayer adsorption of the adsorbate onto the adsorbent which is expected to have a coefficient of determination ( $R^2$ ) of unity [12]. The  $R^2$  value is also an indication that the plant extract's components are approximated by Langmuir adsorption isotherm and the monolayer of the extract species must have been attached to the metal surface without lateral interaction between the adsorbed species.

Langmuir adsorption isotherm is given by the expression:

$$\frac{c}{\theta} = \frac{1}{K_{\text{ads}}} + c \quad (10)$$

Where  $\theta$  is the surface coverage, c is the concentration of the inhibitor,  $K_{\text{ads}}$  is the equilibrium constant of adsorption.

$c/\theta$  was plotted against c with the value of the intercept equal to  $1/K_{\text{ads}}$ , hence  $K_{\text{ads}}$  was calculated.

Freundlich adsorption isotherm postulate a multilayer adsorption of the adsorbate onto the adsorbent which is expected to have a coefficient of determination ( $R^2$ ) of unity [13].

Freundlich adsorption isotherm is given by the expression:

$$\log \theta = \log k + 1/n \log c \quad (11)$$

Where  $\theta$  is the surface coverage, c is the concentration of the inhibitor, k and n are constants for a given adsorbate and adsorbent at a particular temperature. k is a function of energy of adsorption and temperature, and is a measure of adsorptive capacity while n determines the intensity of adsorption [14, 15].

$\log \theta$  was plotted against  $\log c$  with the value of the intercept equal to  $\log k$ , hence k was calculated.

The standard Gibbs free energy of adsorption ( $\Delta G_{\text{ads}}^\theta$ ) was obtained using equation 12:

$$\Delta G_{\text{ads}}^\theta = -2.303RT \log (55.5k_{\text{ads}}) \quad (12)$$

Where the numeral 55.5 is the molar concentration of water in solution, R is the universal gas constant ( $8.314 \text{ J mol}^{-1} \text{ K}^{-1}$ ), T is the absolute temperature and  $K_{\text{ads}}$  is the equilibrium constant of adsorption.

### 3. Results and Discussion

#### *Phytochemical Screening of Plants Extracts*

Table 1 showed the results of the phytochemical screening of the extract of E.H.

*Table 1. Results of phytochemical screening.*

Chemical Constituents	E.H
Alkaloids	+
Flavonoids	+
Tannins	+
Saponins	+
Phenols	+
Steroids	+
Cardiac Glycosides	+

Note: + = present  
E.H = Euphorbia heterophylla

It was seen from the results that the plant extract contained appreciable quantities of phytochemicals (alkaloids, flavonoids, tannins, saponins, phenols, steroids and cardiac glycosides). Therefore the inhibition efficiencies of the plant extract might be attributed to the presence of these constituents in the extract.

*Effect of Time on the Corrosion of Mild Steel in 1M H<sub>2</sub>SO<sub>4</sub> Solution*

**Table 2.** Weight loss of mild steel in 1M H<sub>2</sub>SO<sub>4</sub> solution for different times at ambient temperature.

Plant Sample	Extract Conc. (g/L)	Weight loss (g)			
		24hr	72hr	120hr	168hr
E.H	Blank	2.404	4.476	5.290	6.290
	0.5	1.182	3.253	4.208	5.086
	1.0	0.716	2.474	3.127	4.506
	1.5	0.363	1.240	2.883	3.937
	2.0	0.144	0.655	1.049	2.735

From Table 2 it was seen that the weight loss of mild steel increased with increase in time, indicating that the rate of corrosion of mild steel in acid medium increase with time. Table 2 also showed that the weight loss of mild steel decreased with increase in the concentration of the ethanol

extract of *Euphorbia heterophylla* leaves showing that the corrosion of mild steel in the acid medium was retarded as the concentration of the inhibitor (extract) was increased [16].

*Effect of Temperature on the Corrosion of Mild Steel in 1M H<sub>2</sub>SO<sub>4</sub> Solution*

**Table 3.** Weight loss of mild steel in 1M H<sub>2</sub>SO<sub>4</sub> solution at different temperatures for 6 hours.

Plant Sample	Extract Conc. (g/L)	Weight loss (g)			
		30°C	40°C	50°C	60°C
E.H	Blank	1.798	2.467	3.857	5.755
	0.5	1.011	1.441	2.503	4.111
	1.0	0.497	0.967	1.659	3.879
	1.5	0.241	0.571	1.337	2.843
	2.0	0.127	0.302	0.916	1.971

From Table 3 it was observed that the weight loss of mild steel increased with increase in temperature, an indication that the rate of corrosion of mild steel in acid medium increased with increase in temperature. This is because the rate of a chemical reaction increases with increase in temperature, due to increase in the kinetic energy of the reactant particles, leading to an increase in the frequency of

collision.

It was also observed from Table 3 that the weight loss of mild steel decreased with increase in the concentration of the inhibitors. This showed that the inhibitors inhibited the corrosion of mild steel in H<sub>2</sub>SO<sub>4</sub> medium [17].

*Effect of Acid Concentration on the Corrosion of Mild Steel at Ambient Temperature.*

**Table 4.** Weight loss of mild steel in different concentrations of H<sub>2</sub>SO<sub>4</sub> solution for 24 hours at ambient temperature.

Plant Sample	Extract Conc. (g/L)	Weight loss (g)			
		1M	2M	3M	4M
E.H	Blank	1.543	3.793	6.599	7.305
	0.5	0.551	2.578	3.145	5.446
	1.0	0.364	1.150	2.162	4.298
	1.5	0.238	0.890	1.347	3.164
	2.0	0.132	0.606	0.816	2.019

The Table revealed that the weight loss of mild steel increased with increase in acid concentration (H<sub>2</sub>SO<sub>4</sub>). This showed that the rate of corrosion of mild steel in acid medium increased with increase in the acid concentration (H<sub>2</sub>SO<sub>4</sub>). This could be attributed to the fact that the rate of a chemical reaction increases with increase in the concentration of the active species. Table 4 also showed that

the weight loss of mild steel decreased with increase in the concentration of the ethanol extract of *Euphorbia heterophylla* leaves for each acid concentration. This showed that the corrosion of mild steel in the acid medium was retarded as the concentration of the inhibitor (extract) was increased.

*Corrosion Rate Data for Mild Steel Corrosion*

**Table 5.** Corrosion rate of mild steel in 1M H<sub>2</sub>SO<sub>4</sub> solution at different temperatures.

Plant Sample	Extract Conc. (g/L)	Corrosion rate (gcm <sup>-2</sup> hr <sup>-1</sup> )			
		30°C	40°C	50°C	60°C
E.H	Blank	0.0151	0.0208	0.0325	0.0484
	0.5	0.0085	0.0121	0.0211	0.0346
	1.0	0.0042	0.0081	0.0140	0.0327
	1.5	0.0020	0.0048	0.0113	0.0239
	2.0	0.0011	0.0025	0.0077	0.0170

It was observed from Table 5 that the corrosion rate of mild steel increased with increase in temperature. This showed that the rate of a chemical reaction increases with increase in temperature.

It was also observed from Table 5 that the corrosion rate decreased with increase in the extracts concentration. This might have resulted from the fact that adsorption and surface coverage increases with increase in extract concentration,

thus, separating the surface of the metal from the acid medium ( $H_2SO_4$ ), thereby preventing the metal from acid corrosion. This showed that the extract inhibited the

corrosion of mild steel in 1M  $H_2SO_4$  solution [18].

. Surface Coverage and Corrosion Inhibition Efficiency Data for the Extract of *Euphorbia heterophylla*

**Table 6.** Surface coverage and corrosion inhibition efficiency of E.H extract on mild steel in 1M  $H_2SO_4$  solution at different temperatures.

Plant Sample	Extract Conc. (g/L)	Inhibition Efficiency (%IE)				Surface Coverage ( $\theta$ )			
		30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C
E.H	0.5	43.71	41.82	35.08	28.51	0.4371	0.4182	0.3508	0.2851
	1.0	72.19	61.06	56.92	32.44	0.7219	0.6106	0.5692	0.3244
	1.5	86.75	76.92	65.23	50.62	0.8675	0.7692	0.6523	0.5062
	2.0	92.72	87.98	76.31	64.88	0.9272	0.8798	0.7631	0.6488

Table 6 showed that the inhibition efficiency increased with increase in extract concentrations. It reached 92.72% at 2.0g/L E.H. An increase in the concentration of the plant extract meant that the degree of surface coverage ( $\theta$ ) of the mild steel surface by the inhibitor was increased, leading to increase in adsorption of the inhibitor molecules on the mild steel surface thereby protecting the “covered” surface from further corrosive ( $H_2SO_4$ ) attack. This showed that the extracts inhibited the corrosion of mild steel in  $H_2SO_4$  solution [19]. From Table 6, it was observed that inhibition efficiency decreased with increase in temperature. The drop in inhibition efficiency could be due to solubility of the protective films on the mild steel surface as temperature increased, which increased the susceptibility of the metal to acid corrosion, as noted by [20] or due to desorption of the inhibitor as explained by [21].

As temperature increased, adsorption and the degree of surface coverage decreased since there was reduced adsorption of the extract on the metal surface, which was physical in nature. Decrease in inhibition efficiency with increase in temperature was suggestive of physical adsorption process (physisorption) [22].

*Thermodynamic Data for the Corrosion of Mild Steel in 1M  $H_2SO_4$  Solution*

**Table 7.** Thermodynamic parameters for mild steel coupons in 1M  $H_2SO_4$  solution at 30°C and 40°C.

Extract Conc. (g/L)	E.H	
	$E_a$ (kJ/mol)	$\Delta H_{ads}$ (kJ/mol)
Blank	25.26	-
0.5	27.86	-60.83
1.0	51.79	-39.75
1.5	69.04	-53.24
2.0	64.74	-43.69

Calculated values of activation energy were presented in Table 7. The values were found to increase with increase in the concentration of the extract (inhibitor), meaning that a higher protection efficiency was attained due to increase in the energy barrier for the reaction as the concentration of the extract increased. This showed that the extract (inhibitor) was physically adsorbed on the surface of the mild steel [23, 24].

Calculated values of heat of adsorption ( $Q_{ads}$ ) were presented in Table 7. These values are approximately equal to change in enthalpy of adsorption ( $\Delta H_{ads}$ ) because the reactions were carried out at constant pressure.

It was observed from Table 7 that the values of ( $\Delta H_{ads}$ ) was negative for the plant extract indicating that the adsorption of the extract of the plant was exothermic (exothermic adsorption process). Exothermic adsorption process signifies either physical or chemical adsorption, while endothermic adsorption process is attributed to chemical adsorption (chemisorption). In an exothermic adsorption process, physical adsorption is distinguished from chemical adsorption by considering the absolute value of adsorption enthalpy. Typically, enthalpy of physical adsorption process is lower than  $80\text{kJmol}^{-1}$  while the enthalpy of chemisorption process approaches  $100\text{kJmol}^{-1}$  [24].

The calculated enthalpy of adsorption ( $\Delta H_{ads}$ ) for the extract of the plant suggested physical adsorption of the inhibitor (plants extract) on the surface of the metal.

*Adsorption Data for the Corrosion of Mild Steel in 1M  $H_2SO_4$  Solution*

The experimental data was subjected to Langmuir and Freundlich adsorption isotherm equations.

**Table 8.** Data for Langmuir adsorption isotherm plots for the adsorption of E.H and extract on the surface of mild steel.

Plant Sample	Extract Conc. (g/L)	Surface Coverage ( $\theta$ )				C/ $\theta$			
		30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C
E.H	0.5	0.4371	0.4182	0.3508	0.2851	1.1439	1.1956	1.4253	1.7538
	1.0	0.7219	0.6106	0.5692	0.3244	1.3852	1.6377	1.7569	3.0826
	1.5	0.8675	0.7692	0.6523	0.5062	1.7291	1.9501	2.2996	2.9633
	2.0	0.9272	0.8798	0.7631	0.6488	2.1570	3.1964	2.6209	3.0826

**Table 9.** Data for Freundlich adsorption isotherm plots for the adsorption of E.H extract on the surface of mild steel.

Plant Sample	Extract Conc.	log C	Surface Coverage ( $\theta$ )				log $\theta$			
			30°C	40°C	50°C	60°C	30°C	40°C	50°C	60°C
E.H	0.5	-0.3010	0.4371	0.4182	0.3508	0.2851	-0.3594	-0.3786	-0.4549	-0.5450
	1.0	0.0000	0.7219	0.6106	0.5692	0.3244	-0.1415	-0.2142	-0.2447	-0.4889
	1.5	0.1761	0.8675	0.7692	0.6523	0.5062	-0.0617	-0.1140	-0.1856	-0.2957
	2.0	-0.3010	0.9272	0.8798	0.7631	0.6488	0.0328	0.0556	-0.1174	-0.1879

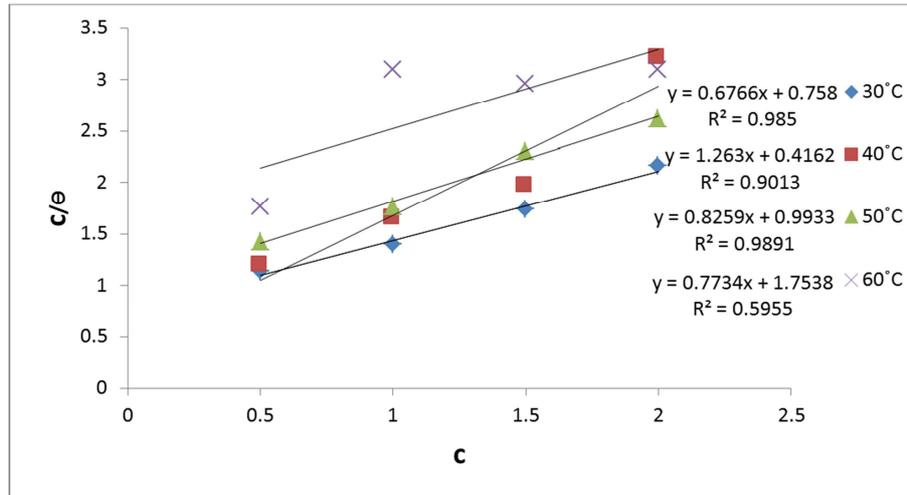


Figure 1. Langmuir plots for *Euphorbia heterophylla* at different temperatures.

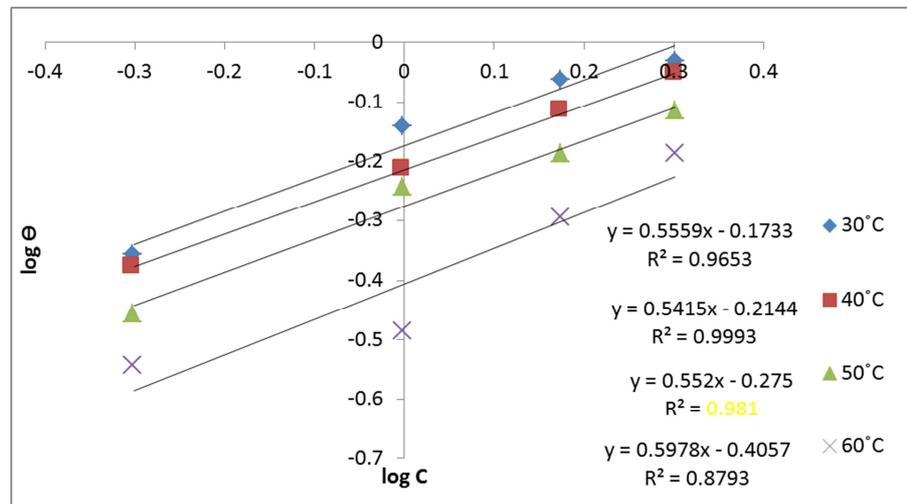


Figure 2. Freundlich plots for *Euphorbia heterophylla* at different temperatures.

Table 10. Langmuir and Freundlich adsorption isotherm parameters for the adsorption of E.H extract on the surface of mild steel.

Temperature (°C)	Langmuir		$\Delta G_{\text{ads}}^{\theta}$ (kJ/mol)	Freundlich	
	$K_{\text{ads}}$	$R^2$		K	$R^2$
30	1.319	0.985	-10.82	0.671	0.965
40	2.404	0.901	-12.74	0.611	0.999
50	1.007	0.989	-10.81	0.531	0.981
60	0.570	0.595	-9.57	0.394	0.879

Linear plots were obtained from Figures 1 and 2, with good coefficients of determination ( $R^2$ ) which were almost equal to unity (1). This showed that the adsorption of the extract (inhibitor) obeyed Langmuir and Freundlich adsorption isotherm. It was observed from Table 10 that the values of  $K_{\text{ads}}$  obtained from the intercept of the Langmuir isotherm plots decreased with increase in temperature indicating that the extract (inhibitor) was physically adsorbed on the surface of the mild steel [25]. It was also seen from Table 10 that the values of  $k$  (adsorptive capacity) calculated from the intercept of the Freundlich isotherm plots, decreased with increase in temperature indicating that the adsorption of the extract on the mild steel surface was reduced at higher temperatures, since adsorptive capacity decreased with

increase in temperature. Values of  $K_{\text{ads}}$  obtained from the Langmuir adsorption isotherm were used to calculate  $\Delta G_{\text{ads}}^{\theta}$  using equation 12. Generally, value of  $\Delta G_{\text{ads}}^{\theta}$  around  $-20\text{kJmol}^{-1}$  or lower are consistent with physisorption i.e. the electrostatic interaction between the charged molecules and the charged metal; those around  $-40\text{kJ/mol}$  or higher are consistent with chemisorption which involve charge sharing or transfer from the inhibitor molecules to the metal surface to form a coordinate type of bond [26, 27]. The  $\Delta G_{\text{ads}}^{\theta}$  values obtained showed that the adsorption mechanism of the plant extract on mild steel was by physical adsorption mechanism (physisorption), since they were less than  $-20\text{kJ/mol}$ . The negative values of  $\Delta G_{\text{ads}}^{\theta}$  showed that the adsorption process was spontaneous. Although both isotherms (Langmuir and

Freundlich) described the adsorption process very well, Freundlich adsorption isotherm for the plant extract, fitted the adsorption behaviour better with higher coefficient of determination values ( $R^2$ ) as shown in Table 10.

#### 4. Conclusion

The ethanol extract of the leaves of *Euphorbia heterophylla* is a good corrosion inhibitor of mild steel in acid medium (1M  $H_2SO_4$ ), reaching a corrosion inhibition efficiency of 92.72% at 2.0g/L extract concentration. The corrosion inhibition efficiency of the plant extract is strongly affected by temperature and extract concentration, since it increased with increase in the concentration of the extract (0.5g/L  $\rightarrow$  1.0g/L  $\rightarrow$  1.5g/L  $\rightarrow$  2.0g/L) and decreased with increase in temperature (30°C  $\rightarrow$  40°C  $\rightarrow$  50°C  $\rightarrow$  60°C). The corrosion inhibition efficiency of the plant extract could be attributed to their phytochemical constituents (alkaloids, flavonoids, tannins, saponins, phenols, steroids and cardiac glycosides) which aided their adsorption on the surface of the mild steel. The adsorption of the plant extract are consistent with the process of physical adsorption and are spontaneous, since their Gibbs free energy values ( $\Delta G_{ads}^0$ ) were less than 20kJ/mol and found to be negative. The adsorption of the ethanol extract of the leaves of *Euphorbia heterophylla* obeyed Langmuir and Freundlich adsorption isotherms, since linear plots were obtained from both isotherms with good coefficients of determination ( $R^2$ ), which were almost equal to unity (1).

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