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(Research Article)

Corrosion inhibition of ethanol extract of *Moringa oleifera* leaves on aluminium in 1m sulphuric acid solution

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Abstract

The aim of this research is to use the wet loss method to determine how well *Moringa oleifera* in H_2SO_4 inhibits aluminum corrosion. Weight loss was measured before and after corrosion on aluminum coupons with a thickness of 0.15cm, a width of 3cm, and a length of 4cm, all of which were 98 percent pure. Increases in inhibitor concentrations improve inhibition effectiveness, which ranges from 35.29 % to 47.06 % to 64.71 percent to a maximum of 82.35 %, but decreases as temperature and immersion time rise. The inhibition efficiency of the formulation consisting of 1M H_2SO_4 medium and 0.4g/L inhibition is 82.35 %. This means that the inhibitor is well-adsorbed on the surface of the aluminum metal, resulting in a significant reduction in corrosion rate. As a result, further research into corrosion inhibition should be done with this type of plant. The Langmuir adsorption isotherm (where Gads(kj/mol) is found to be -13.694 and Kads is 13.53) was followed in the adsorption of inhibitor molecules on Aluminum sheet surface. The absorption peaks corresponding to the functional groups – C=O, -C=N, C-OH, and C=C were found in the infrared spectrograph of the leaf extracts. These functional groups may have interacted with the aluminum sheet's surface, preventing oxidation. Organic compounds in the leaf extracts, such as alkaloids, saponins, tannins, and phenolics, were thought to be the source of these functional classes. Green extracts of *M. oleifera* are recommended for use as corrosion inhibitors against other inorganic compounds. It has a higher inhibitory performance, is readily available, biodegradable, less expensive, and environmentally friendly.

Keywords: Aluminium; Corrosion; Ethanolic extracts; Inhibitors; *Moringa oleifera*

1. Introduction

Corrosion of metals or alloys, defined as the degradation or disintegration of materials as a result of their reaction with the environment, has remained a hot topic in the technological world. Corrosion scientists are always on the lookout for new and better ways to combat metal/alloy corrosion [1]. Aluminium is thermodynamically reactive, and it is the only metal that has the ability to defend itself from corrosion through creating an amphoteric oxide film, which protects it from further damage when exposed to aggressive medium [1,2]. Aluminium and its alloys are commonly used in the construction of heat exchangers, radiators, and other water cooling/treatment parts. As a result of inadequate provision for corrosion prevention, such as defective design features and non-introduction of appropriate corrosion inhibitors into the system, such facilities have been observed to suffer corrosion damage from ingress of chlorides and other extraneous anions [3]. There are several ways to prevent metals from corroding, but using inhibitors is still one of the most effective [4-7]. Because of its environmentally friendly impact, practical usage, low cost, and renewable sources of materials, the use of green eco-friendly natural polymeric structures extracted from various parts of plants as corrosion inhibitors is gaining popularity and interest [8].Some natural products from plants have been evaluated as potential corrosion inhibitors for various metals [9], and this activity is due to the presence of various organic compounds such

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as alkaloids, steroids, amino acids, tannins, flavonoids, and so on. According to [4] and [10], corrosion inhibitors extracted from plant extract are biodegradable and contain no heavy metals or other hazardous substances.

The edible fruits, leaves, flowers, roots, and seed oil of the *M. oleifera*, also known as the drumstick tree or Ben tree, have been shown to be useful sources of food, medicinal goods, fuel wood, and active ingredients for synthetic drugs [11]. The polyphenols, flavonoids, carotenoids, alkaloids, quercetin, kaempferol, apigenin, and a variety of other phytoconstituents found in the leaves of *M. oleifera* provide important and disease-preventing nutrients to humans [12,13]. The presence of tannin in the chemical constituents of certain plant extracts has been shown to prevent corrosion [1,14]. Aondover *et al*. [15] investigated the corrosion rate of *M. oleifera* extract at different concentrations of 0, 0.5, 1.0, and 1.5 g/ml for 168, 336, 504, 672, and 840 hours respectively. The purpose of this study is to learn more about corrosion inhibition of *M. oleifera* on aluminum in 1.0 M sulphuric acid. Gravimetric analysis was used to link the inhibition effectiveness, degree of surface coverage, and corrosion rate.

2. Material and methods

2.1. Sample Collection

Fresh leaves of *M. oleifera* were obtained from Dorayi Quarters Gwale Local government Kano state.

2.2. Preparation of Plant Extract

The stock solution for the plant extract was made by soaking 20g of dried and grinded Moringa oleifera leaves in an ethanol solution. After 6 days, the sample was purified and the filtrate concentrated to remove the ethanol from the stock solution.

2.3. Weight Loss Determination

For weight loss measurement, twenty pieces of 0.15cm thick aluminum alloy sheet with a width of 3cm and a length of 4cm were used, each with a purity of 98 percent. The coupons were carefully weighed after being dried in the oven. Four aluminum coupons were placed in four separate 100ml beakers containing 1.0M sulphuric acid solution (Blank) and were retrieved at 1 hour intervals progressively at 313K, 323K, 333K, and 343K. Before final weighing, the aluminum coupons were brushed with a tooth brush, washed in water, rinsed in acetone, and dried inside a 250ml beaker in the oven. The weight loss was calculated in grams by dividing the initial weight before immersion by the weight after the corrosion product was removed [16].

$$\Delta W = W2 - W1$$

The experiment was replicated with four different concentrations of *M. oleifera* (0.1, 0.2, 0.3, and 0.4) at 313K, 323K, 333K, and 343K, respectively, in 1.0 M H2SO4 solution. For the corrosion studies and each set of experiments, glass beakers were used.A 100 mL beaker was used, with one metal coupon per beaker. The inhibition efficiency (percent IE) of the inhibitor, the degrees of surface coverage and the corrosion rate (CR) of the aluminum were determined from the weight loss results using equations 1, 2a and 2b below.

2.4. Determination of Corrosion Rates

In 1M H_2S0_4 values of Corrosion Rates (CR) for aluminium specimens in various concentrations of inhibitors at four different studied temperatures were calculated by following equation (1) [17].

$$\mathrm{CR} = (\Delta \mathrm{W}/\mathrm{AT}) \ldots\ldots\ldots\ldots (1)$$

2.5. Determination of Inhibition Efficiency (IE %) and surface coverage

The inhibition efficiencies for aluminum in 1M H_2SO_4solutions containing different amounts of inhibitor solutions at various temperatures were calculated using the following equation [17], which is based on the calculated corrosion rate values (CR).

$$\mathrm{IE}\ \% = \frac{\mathrm{CRblank} - \mathrm{CRinhb}}{\mathrm{CRblank}} \times 100 \ldots\ldots\ldots (2a)$$

The surface coverage can be calculated using a formula as;

$$\Theta = 1 - \frac{W1}{W2} \ldots\ldots (2b)$$

2.6. Absorption Isotherms

Adsorption is a critical factor in corrosion prevention. Inhibitors are a form of adsorbent that binds to metal surfaces and slows the dissolution process. The obtained surface coverage Θ was fitted in different adsorption isotherms such as Langmuir adsorption isotherm, Temkin adsorption isotherm, and Freudlich adsorption isotherm to better understand the essence of adsorption. Equation gives the mathematical expression for the Langmuir adsorption isotherm (3) [18].

$$\frac{Cinh}{\Theta} = \frac{1}{Kads + Cinh} \ldots\ldots (3)$$

Rearranging the above equation (3) $\frac{\theta}{1-\theta} = KadsCinh$ ……………………………… (4)

3. Results

Table 1 Different corrosion parameters for aluminium in 1M H_2SO_4 in the absence and presence of different concentration of ethanolic extract of *M. oleifera* leaves at 1hour and temperature of 303K.

Concentration (g/L)	Weight loss (g)	%IE	Degree of surface coverage (ø)	Corrosion rate (g/cm²hr)
Blank	0.017	_	_	1.417×10^{-3}
0.1	0.011	35.29	0.3529	9.167×10^{-4}
0.2	0.009	47.06	0.4706	7.512×10^{-4}
0.3	0.006	64.71	0.6471	5.480×10^{-4}
0.4	0.003	82.35	0.8235	2.532×10^{-4}

Table 2 Values of weight loss, inhibition efficiency, corrosion rate, and surface coverage for the corrosion of aluminium in 1M H_2SO_4 solution in the absence and presence of constant concentration of *M. oleifera* at a temperature of 303K.

Time (hr)	Concentration (g/L)	Weight loss (g)	%IE	Degree of surface coverage (ø)	Corrosion rate(g/cm²hr)
	Blank	0.212	_	_	_
1	0.4	0.020	90.62	0.906	1.667×10^{-3}
2	0.4	0.133	37.132	0.371	5.540×10^{-3}
3	0.4	0.152	27.952	0.279	4.224×10^{-3}
4	0.4	0.174	17.925	0.179	3.625×10^{-3}

Table 3 Values of weight loss, inhibition efficiency, corrosion rate, and surface coverage for the corrosion of aluminium in 1M H_2SO_4 solution in the absence and presence of constant concentration of *M. oleifera*

Temperature (K)	Concentration (g/L)	Weight loss (g)	%IE	Degree of surface coverage (ø)	Corrosion rate(g/cm²hr)
	Blank	0.273	_	_	_
303	0.4	0.028	89.744	0.897	2.33×10^{-3}
313	0.4	0.188	31.135	0.311	1.57×10^{-2}
323	0.4	0.197	27.839	0.278	1.64×10^{-2}
333	0.4	0.210	23.077	0.231	1.75×10^{-2}

Table 4 Thermodynamic parameters and activation energy

Concentration (g/L)	Ea(kj/mol)	$\Delta H^0_{ads(kj/mol)}$	$\Delta S^0_{ads(kj/mol)}$
Blank	18.39	7.22	-1.32
0.1	30.52	28.79	-1.25
0.2	33.78	20.71	-1.38
0.3	43.42	23.63	-1.55
0.4	48.66	19.75	-1.93

Table 5 Adsorption parameters

Isotherms	Slope	ΔGads(kj/mol)	R^2	Kads
Langmuir	0.6801	-13.694	0.9870	13.53
Temkin	0.352	-11.745	0.8951	25.57

4. Discussion

4.1. FTIR of *M. oleifera*

The Fourier Transform Infrared (FTIR) technique is commonly used to determine the type of bonding for organic inhibitors adsorbed on metal surfaces. The Graph of FTIR spectrum of *M. oleifera* ethanolic extract was shown in Figure 1. The O-H or N-H stretching is associated with broad adsorption around 3260cm[1], while C-H stretching vibration is associated with broad adsorption around 2854cm[1]. C=C and C=O stretching vibrations have a strong adsorption at 1629cm[1]. The structure vibration of aromatics was assigned to adsorption bands at 1667m1 and 1449cm[1]. Alcoholic C-O stretching causes strong adsorption at 1048cm[1]. According to these findings, O and N atoms in functional groups O-H, N-H, C=O, C=C, and aromatic rings are found in *M. oleifera*, which fulfill the corrosion inhibitor's general structural requirements.

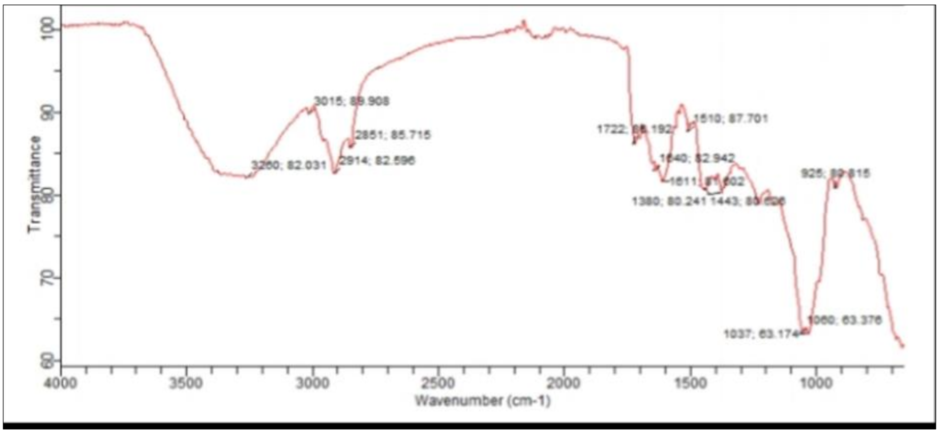

Figure 1 Fourier Transform Infrared spectrum of *M. oleifera*

4.2. Effect of Concentration

The effect of various concentrations of *M. oleifera* was revealed in Table 1, in which concentrations ranging from (0.1g/L to 0.4g/L) on the corrosion rate, weight loss, and inhibition performance of aluminum metal after 1 hour at 303K. It can be shown that adding different concentrations of the inhibitor reduces the corrosion rate; however, the corrosion rate at (Blank solution) concentration of the inhibitor was found to be significant as compared to the corrosion rate after adding different concentrations of the inhibitor. In addition, as shown in the graph Fig 2, the inhibition efficiency improves as weight loss decreases. As shown in the graph below Fig 3, increasing the concentration of the extract increases the inhibition efficiency to a maximum of 82.35 percent. A similar result was obtained by [19,20].

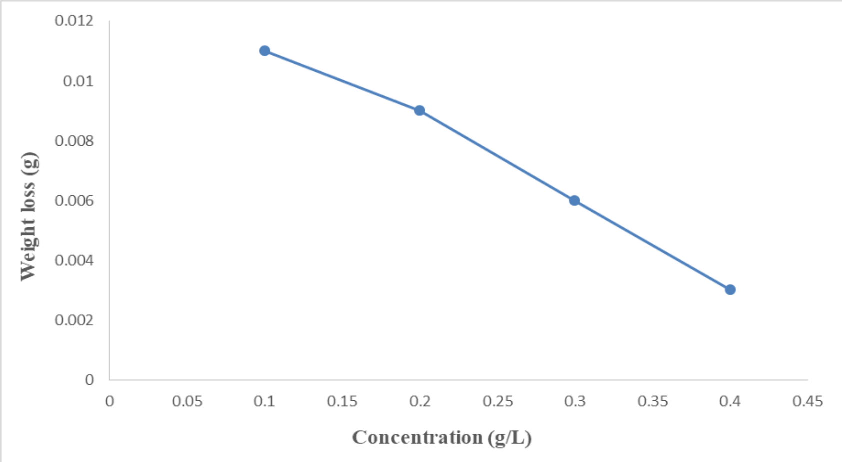

Figure 2 Variation of weight loss with various concentrations of *M. oleifera* extract for the corrosion of aluminium in 1M H_2SO_4 at 303K

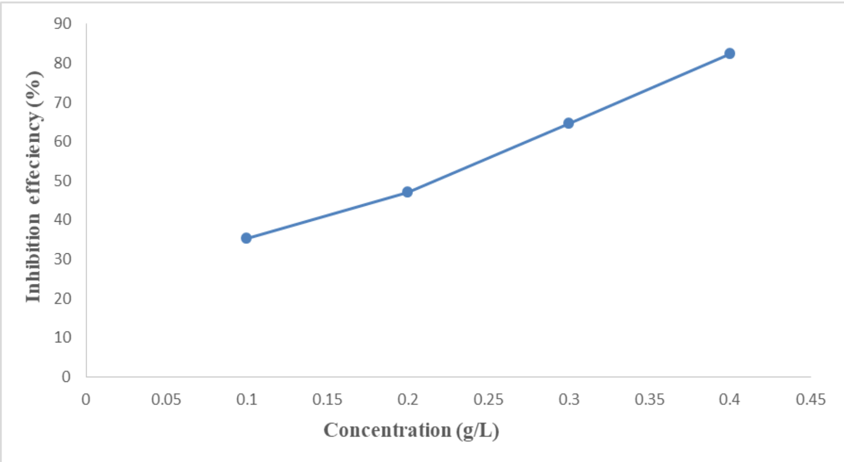

Figure 3 Variation of inhibition efficiency with various concentrations of *M. oleifera* extract for the corrosion of aluminium in 1M H_2SO_4 at 303K

4.3. Effect of Immersion Time

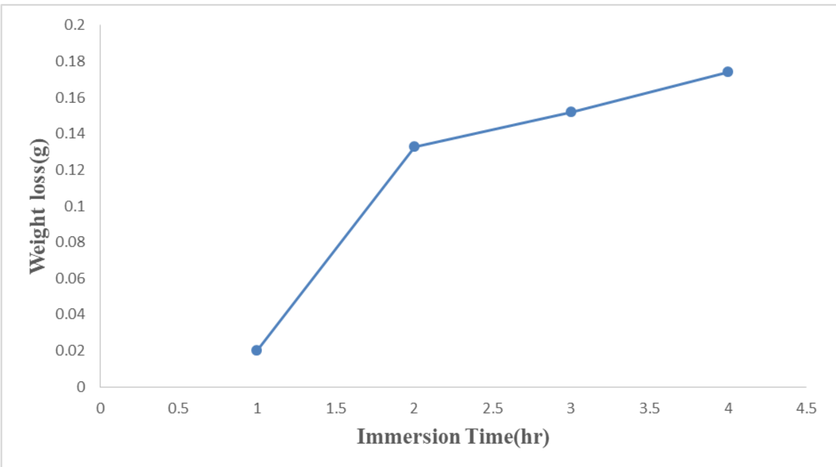

Figure 4 Variation of weight loss with immersion time for the corrosion of aluminium in 1M H_2SO_4 at 303K

Table 2 shows the impact of immersion time on aluminum weight loss in 1 M H_2SO_4solutions in the presence and absence of constant concentrations of *M. oleifera* at 303K. It can be seen from the table (1), the weight loss of aluminum in both the blank and inhibited solution increases with increasing contact time, as shown in Fig. 4, which increased slowly in comparison to those obtained for the inhibited solutions, While all other conditions remain constant, the immersion period is increased, with the inhibitor concentration (0.4g/L) of *M. oleifera* in a 1 molar of H_2SO_4, tend to significantly slow down the corrosion reaction of aluminum. In the same way as shown in Fig., the inhibitor concentration was found to decrease as contact time increased from 1 hour to 4 hours, indicating efficacy with a constant inhibitor concentration. This is due to the inhibitor molecule being adsorbed to a lesser extent on the aluminum surface, creating a protective layer that prevented further corrosion attacks from the aggressive media. Reference [21] reported similar conclusion.

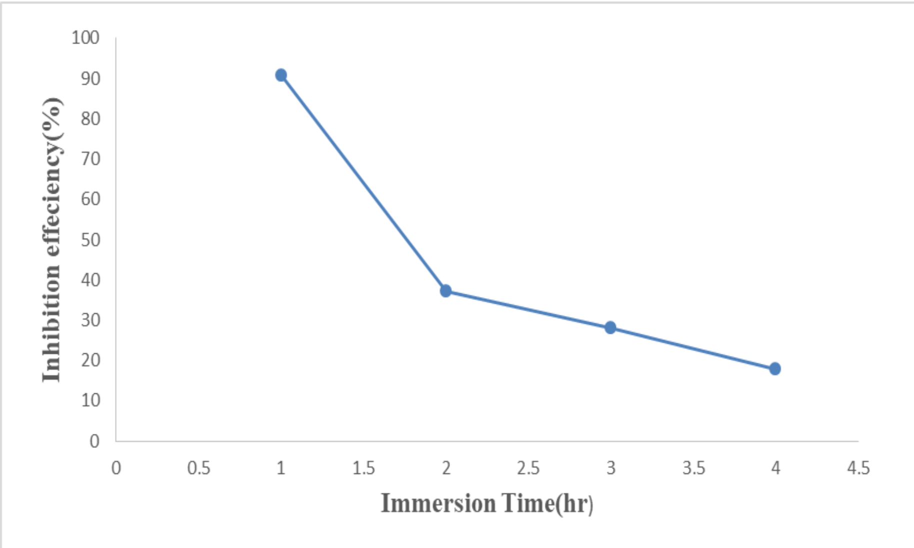

Figure 5 Variation of inhibition efficiency with immersion time for the corrosion of aluminium in 1M H_2SO_4 at 303K

4.4. Effect of Temperature

At a constant concentration of *M. oleifera* ethanolic extract (0.4g/L), the effect of temperature on inhibition efficiency is shown in Table 3. The results of the weight loss analysis, which are plotted in Fig 6, showed that in the presence of a constant concentration of *M. oleifera*(0.4g/L), decreases with increase temperature (from 89.744% at 303K to 23.077% at 333K), as shown in Table 3 and this is due to a shift in the adsorption–desorption equilibrium toward desorption of the already-adsorbed inhibitor.

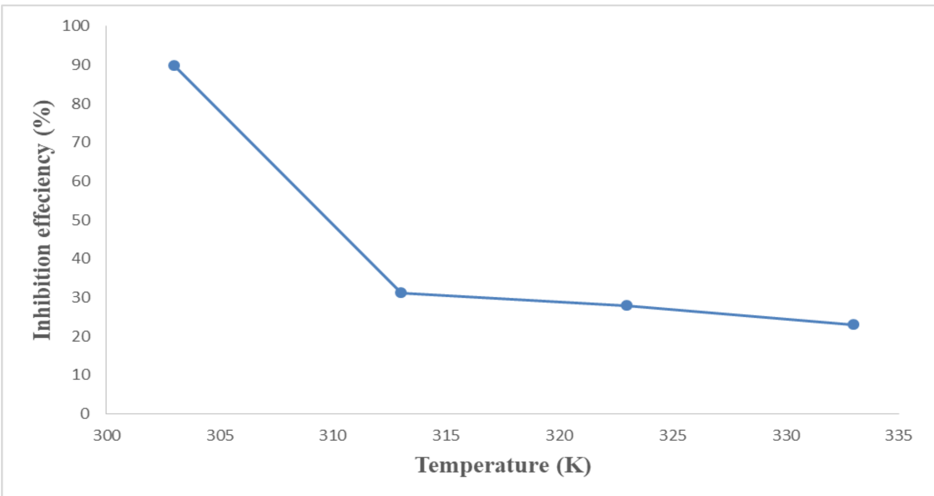

Figure 6 Variation of inhibition efficiency at various temperature range for the corrosion of aluminium at constant concentration (0.4g/L) in 1M H_2SO_4 at 303K

This drop in inhibition efficiency as temperature rises could mean that the inhibitor molecules are less stable at higher temperatures, or that the rate of dissolution of the test metal coupon is facilitated more easily at higher temperatures. As such, the weight loss of the coupon increases on increasing temperature as shown in Fig. 1. Similar finding was reported [22].

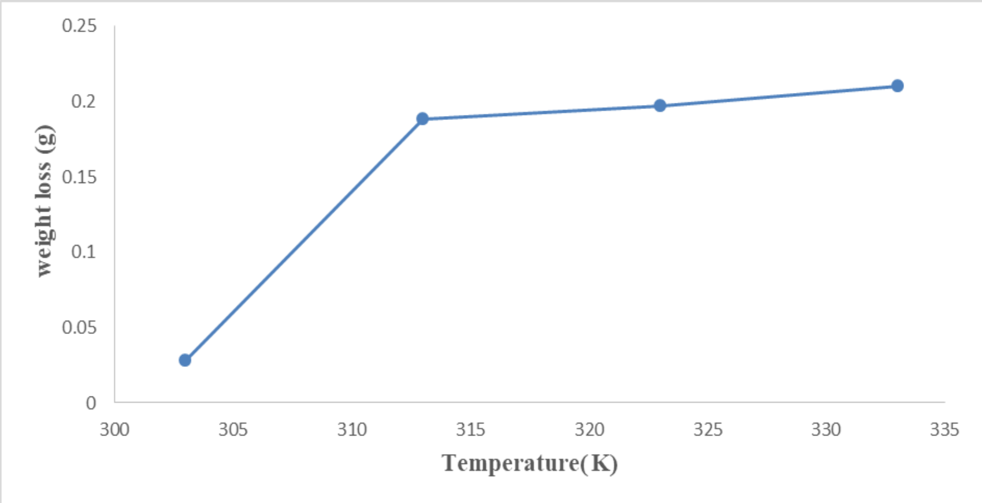

Figure 7 Variation of weight loss at various temperature range for the corrosion of aluminium at constant concentration (0.4g/L) in 1M H_2SO_4

This result indicated that *M. oleifera* extract could act as an excellent corrosion inhibitor. This is similar to the work carried out by [23]. The inhibition efficiency was found to increase with increasing inhibition concentration and the adsorption of the inhibitor molecules were consistent with the Langmuir adsorption isotherm [19].

4.5. Thermodynamic parameters obtained from adsorption isotherms in 1.0M H_2SO_4

The results of this study's experiments were analyzed to see what type of adsorption isotherm they fit into, which provided insight into the mechanism of inhibition. Physical adsorption (Physisorption) and chemical adsorption are the two types of adsorption that exist (chemisorption). The charged centers of the inhibitor and the charged metal surface interact electrostatically, resulting in physical adsorption [24].

4.6. Activation Energy

The apparent activation energy (Ea) for the corrosion phase in the absence and presence of the inhibitor was calculated using the Arrhenius equation to elucidate the inhibitor's inhibitive properties as well as the temperature dependence on corrosion rates. Table 4 lists the approximate Ea values for aluminium corrosion in the presence of *M. oleifera* extract in 1 M H_2SO_4. The activation energy was discovered to be 10.39 $KJmol^{-1}$ in the absence of the extract and to be 35.52 $KJmol^{-1}$ in the presence of the extract at 0.1g/L *M. oleifera*, as a result of the adsorbed organic matter acting as a physical barrier to alteration and mass transfer, the corrosion rate has decreased. Chemical adsorption is indicated by Ea values greater than 80 kJ/mol, while physical adsorption is indicated by Ea values less than 80 kJ/mol [23,25]. Since the Ea values are less than 80 kJ/mol, a physical adsorption mechanism is proposed in this report.

The activation energy increased with the addition of the *M. oleifera* extract, as shown in Table 4, and all values of Ea in the range of the analyzed concentrations were higher than the uninhibited solution. The increase in Ea in the presence of *M. oleifera* extract may be attributed to physical adsorption or poor chemical bonding between the inhibitor species and the aluminum surface, resulting in a decrease in the aluminum's corrosion rate. It should be noted that as the extract concentration rises, Ea rises as well, implying that the corrosion rate decreases. As a result, there was an improvement in inhibition effectiveness.

4.7. Determination of Enthalpy and Entropy

The effect of temperature was used to calculate thermodynamic parameters like enthalpy (H) and entropy (S) of corrosion activation. The equation was used to calculate the enthalpy and entropy of the corrosion activation process:

$$log\frac{CR}{T} = log\frac{R}{nh} + \frac{\Delta S}{2.303RT} - \frac{\Delta H}{2}$$

The enthalpy of activation values for *M. oleifera* was all positive, indicating that the aluminum dissolution process is endothermic. Consequently, the activation entropies were all negative, implying that the activation complex reflects association steps and that the reaction was random and feasible. These findings matched those of a previous study conducted by [25].

4.8. Free Energy of Adsorption

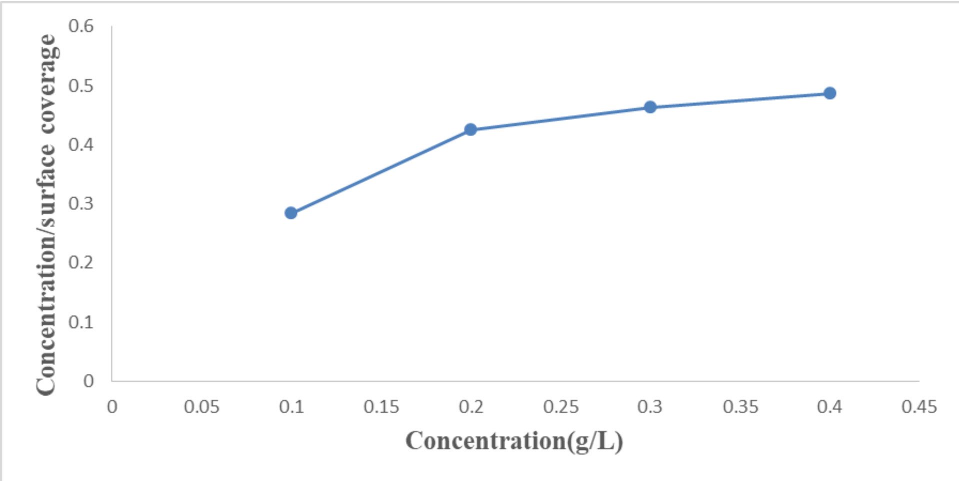

Figure 8 Langmuir isotherm for the adsorption of *M. oleifera* on aluminium surface in 1M H_2SO_4 solution

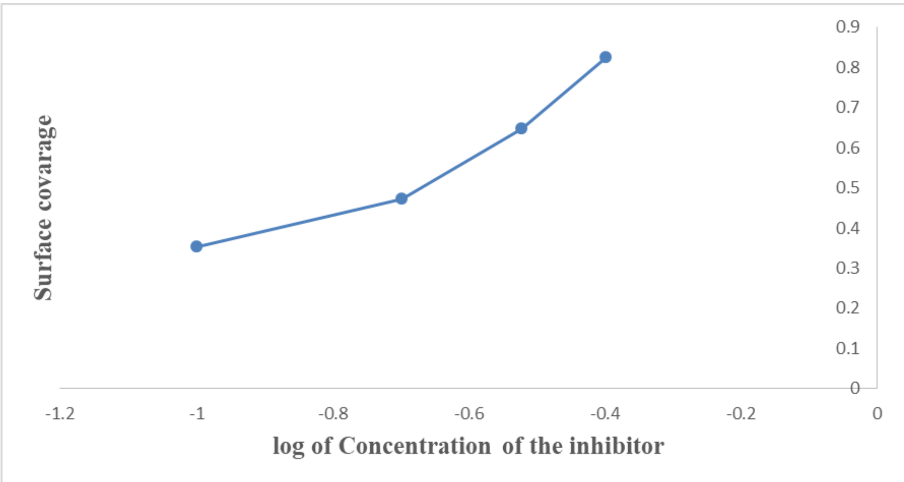

Figure 9 Temkin isotherm for the adsorption of *M. oleifera* on aluminium surface in 1M H_2SO_4 solution

The free energy of adsorption values (ΔG°ads) was obtained by using equation and the values obtained are presented in Table 5.

$$\Delta G°ads = -2.303RT \log (55.5Kads)$$

The results show that the values of ΔG°ads are all negative, indicating that the reaction is spontaneous [26] and that the physical adsorption firmly adsorbed *M. oleifera* extracts on the aluminium surface. This finding also backs up the theory that physical adsorption occurs as a result of electrostatic attraction between charged metal surfaces and charged species in the solution's bulk. All of the ΔG°ads values obtained in this analysis are negative, indicating that the procedure is feasible. ΔG values less than 50Kj/mol for different inhibitor concentrations (Table 3.4) indicated a lower rate of corrosion reaction, which is supported by other research [23].

5. Conclusion

Corrosion is the degradation of metal caused by chemical attack or interaction with its surroundings. It's a never-ending epidemic that's always impossible to eradicate entirely. The aim of this research is to investigate the corrosion inhibition of *M. oleifera* sp. on aluminum in a 1M H_2SO_4 solution. Before and after corrosion, weight loss measurements were taken on aluminum coupons with a thickness of 0.15cm, a width of 3cm, and a length of 4cm, and a purity of 98%. Increases in inhibitor concentrations result in a maximum inhibition efficiency of 82.35 %. For *M. oleifera* extract, which decreases as temperature and immersion time rise. The corrosion inhibition of *M. oleifera* against aluminum was successfully tested, and it was discovered that the plant extract has a high rate of corrosion inhibition efficiency. The formulation consisting of 1M H_2SO_4 medium, 0.4M of the inhibition provides 82.35% inhibition efficiency. Increased inhibitor concentrations result in a maximum inhibition efficiency of 82.35%, which decreases as temperature and immersion rise.

Compliance with ethical standards

Acknowledgments

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Disclosure of conflict of interest

The authors declare no conflict of interest.

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