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Examining the effectiveness of Guava leaf extract in mitigating corrosion of aluminium in potassium hydroxide solution

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Abstract

This study is on the effectiveness of guava leaf extract in mitigating corrosion of aluminium in potassium hydroxide solution. Functional groups of the extract were revealed using Fourier transform infrared spectroscopy. In addition, qualitative and quantitative analyses of the extract were carried out to ascertain the level of the phytochemicals. Effects of process variables on the effectiveness of guava leaf extract as corrosion inhibitor were determined. Then, modeling of the experimental data of inhibition efficiency of the guava leaf extract was carried using response surface methodology. In the process, modeling of the inhibition efficiency was actualized using design expert software version 11. Analysis of variance and diagnostic analysis of the model on interactive effects of inhibitor concentration, temperature and time on the inhibition efficiency were examined. Analysis of the results showed that the main functional groups of guava leaf are O-H stretch, C-H stretch, N-H bend, CH3C-H bend, C-O stretch and C-H bend. Alkaloid was found to be highly concentrated in the extract; 223.71 ±0.12 mg/100g. Tannins, flavonoids, phytates and saponins were present at moderate (concentrated) levels. Weight loss, corrosion rate, inhibition efficiency and degree of surface coverage were influenced by the inhibitor concentration, temperature and time. Quadratic model adequately described the relationship between inhibition efficiency and process variables. The predicted R^2 of 0.9311 is in reasonable agreement with the adjusted R^2 of 0.9867. Guava exhibited high inhibition efficiency. Hence, it can be used to inhibit corrosion of Al in KOH solution.

Keywords: Guava leaf; Corrosion; Aluminium; KOH solution

1. Introduction

Aluminum is an important metal for many industrial applications (Ezeugo et al, 2018). It corrodes when it has a chemical or electrochemical reaction with its surroundings. Corrosion occurs when a metal degrades due to an electrochemical reaction with its environment, hinders the effectiveness of aluminum (Onukwuli et al, 2021; Udeh et al, 2021a). It is a transformation of metallic structures into other chemical structures, most often through the intermediary of a third structure. In a broad sense, corrosion is a process of destructive alteration of a metal or an alloy by chemical reaction with any substance-solid, liquid or gas (Anadebe et al, 2018; Ramezanzadeh et al, 2019). The pattern of attack is largely governed by the combined influences of several factors relating to metal or alloy, condition of service and the chemical nature of the environment. So, corrosion might be described as an electrochemical process in which the environment reacts with metallic surfaces, resulting in the loss of the metal's material qualities (Umoren et al, 2016; Udeh et al, 2021a). Corrosion causes catastrophic damage to metallic structures. It has negative economic impact in terms of product losses, safety repair and replacement costs. Numerous industries have been adversely impacted by the corrosion problems. Corrosion should be avoided as negative phenomena because of these negative effects.

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To increase the lifespan of metallic and alloy materials, there are numerous strategies to avoid corrosion and the speeds at which it might spread. One of the accepted methods to lessen and/or avoid corrosion is the use of inhibitors for the control of corrosion of metals (steel) and alloys in harsh environments (Udeh et al, 2021a). The manufacture of inhibitors utilized in chemotechnical services through the process of corrosion inhibition uses organic or inorganic components. Controlling corrosion in metals is a crucial activity with regard to the environment, technology, economy, and aesthetics. Oxidation and reduction reactions lead to corrosion (Omyma and Shadia 2011). Corrosion inhibitors lessen or stop these responses. Adsorbed on the metal surface, corrosion inhibitors work by creating a layer or barrier that protects the metal from oxygen or moisture. On the metal surface, a passive film forms the protective layer. Inhibition of metal corrosion by organic compounds is a result of adsorption of organic molecules or ions at the metal surface forming a protective layer. This layer reduces or prevents the corrosion of the metal. The extent of adsorption depends on the nature of the metal, the metal surface condition, the mode of adsorption, the chemical structure of the inhibitor, and the type of corrosive media.

KOH solution is an example of corrosive environment. This alkaline solution is used for pickling of metallic structures. Side-effect of pickling with alkaline solution is corrosion of the metal which can be controlled by application of inhibitor. An inhibitor is a substance that, when added to a situation in a small concentration, minimizes the loss of metal. It prevents corrosion by either producing an adsorbed layer that serves as a barrier or by delaying the cathodic, anodic, or combined processes. Corrosion inhibitors are responsible for any corrosion retardation processes or the reduction in the oxidation rate of the metal induced by the addition of a chemical compound to the system (Ramezanzadeh et al, 2019). Inhibitors are frequently simple to use and provide the benefit of in-situ application without seriously interfering with the process. One of the best ways to fight corrosion is to employ corrosion inhibitors.

There are numerous studies on the use of plant extracts to prevent aluminum from corroding in corrosive environments (Omotioma and Onukwuli, 2017; Ezeugo et al, 2018). Eco-friendly inhibitors are preferred to chromates in businesses due to chromates' high toxicity and significant environmental risk. Numerous studies have looked into the outstanding anticorrosive agents (Hasimran et al, 2021; Habeeb et al, 2018; Iminabo et al 2017). Considering the phytochemical profile and beneficial effects, guava leaf is used as an ingredient in the development of functional foods and pharmaceuticals. The guava leaf is used as an antioxidant additive in food and for diabetes treatment, while the fruit pulp of guava is utilized to enhance the platelet count for treating fever. Its usage can be diversified to include using it as corrosion inhibitor.

2. Materials and Method

The equipment and materials used in this study are; guava leaf; acetone, measuring cylinder; funnel; KOH; distilled water; electronic weighing balance; stop watch; thermometer; retort stand; and aluminium. Others include emery papers; volumetric flasks; Fourier transform infrared spectrophotometer; beakers; conical flasks and water bath.

2.1. Characterization of the Inhibitors in Terms of Functional Groups

Fourier transform infrared (FTIR) spectrophotometer (Cary 630, Agilent Technologies USA) was employed to determine the functional groups of the leaf extract. In the process, Fourier transform converted raw data into actual spectrum (with various peaks). Examination of the FTIR produced peaks was done so as to identify the corresponding functional groups in accordance with procedure used by Omotioma and Onukwuli (2016).

2.2. Determination of Qualitative and Quantitative Constituents of the Extract's Phytochemicals

Standard methods used by previous research reports (Belani, and Kaur, 2018; Omotioma and Onukwuli, 2019; Haruna et al, 2019) were applied in the characterization of extract (qualitative and quantitative phytochemical analysis). That is, presence and the quantity of alkaloids, cardiac glycosides, flavonoids, phenolics, phytates and saponins were determined.

2.3. Determination of Effects of Process Variables on the Corrosion Control

The aluminium was cut into coupons; Al (3cm x 3cm). The coupons were cleaned followed by polishing with emery paper to expose shining polished surface. To remove any oil and organic impurities, the coupons were degreased with acetone and finally washed with distilled water, dried in air and then stored in desiccators. Standard method of corrosion study reported by previous researches (Udeh et al, 2021; Onukwuli et al, 2021; Anadebe et al, 2018; Omotioma and Onukwuli, 2016) was employed in this study. Considering one factor at a time, the gravimetric (weight loss) method was carried out at various inhibitor concentrations, temperatures and times. According to this method, weighed Al coupons were separately immersed in 250 ml open beakers containing 150 ml of 1 M KOH (blank).

The Al samples were separately immersed in 250 ml open beakers containing 150 ml of 1 M KOH with various concentrations of the inhibitor. Variation of weight loss was studied at various temperatures, in the absence and presence of various concentrations of the inhibitor. At regular time interval, the coupons were taken out, immersed in acetone, scrubbed with a bristle brush under running water, dried and reweighed. The weight loss (Δw), corrosion rate (CR), inhibition efficiency (IE) and degree of surface coverage were calculated using the Equations 1, 2, 3 and 4 respectively. Effects of inhibitor concentration, temperature and time on the weight loss, corrosion rate, inhibition efficiency and degree of surface coverage were determined.

$$\Delta w = w_i - w_f \quad \text{.....................(1)}$$

$$CR = \frac{w_i - w_f}{At} \quad \text{.....................(2)}$$

$$IE\% = \frac{\omega_0 - \omega_1}{\omega_0} * 100 \quad \text{................(3)}$$

$$\theta = \frac{\omega_0 - \omega_1}{\omega_0} \quad \text{..........................(4)}$$

where w_i and w_f are the initial and final weight of mild steel samples respectively; ω_1 and ω_0 are the weight loss values in presence and absence of inhibitor, respectively. A is the total area of the Al and t is the time of immersion, Θ is the degree of surface coverage.

2.4. Model of inhibition efficiency of the guava leaf extract

Modeling of the experimental data of inhibition efficiency of the guava leaf extract was carried using response surface methodology. The modeling was actualized using design expert software version 11. Analysis of variance and diagnostic analysis of the model of interactive effects of inhibitor concentration, temperature and time on the inhibition efficiency were examined.

3. Results and Discussion

3.1. Fourier transformed infrared (FTIR) spectroscopic results of the inhibitor

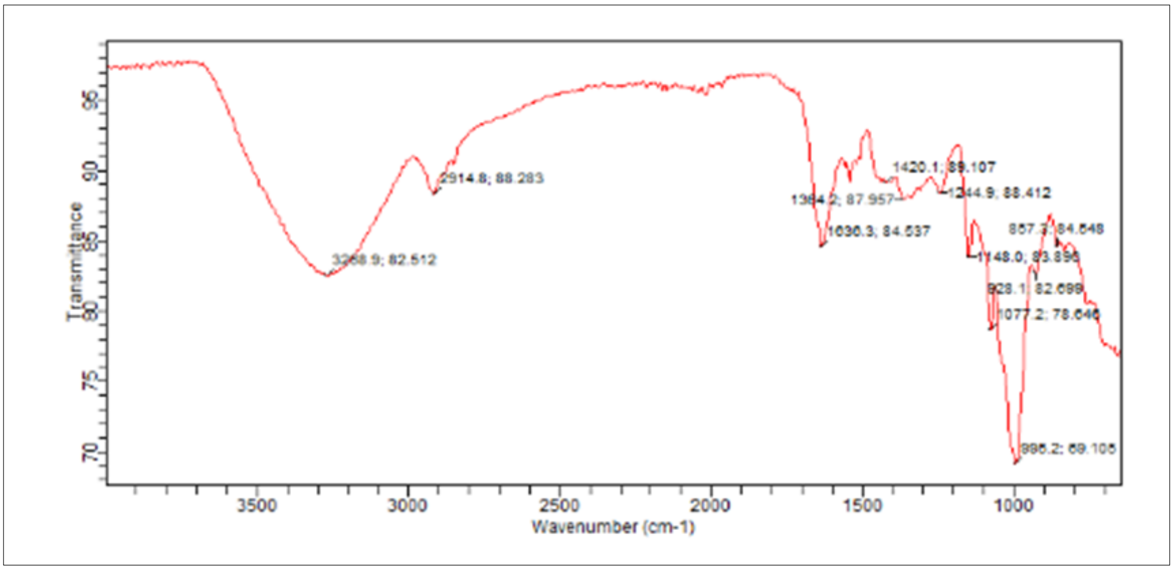

Figure 1 Spectrum of the guava leaf extract

The spectrum of the FTIR of the guava leaf (inhibitor) is shown in Figure 1. It shows the relationship between the transmission and wave number. Major functional groups of the guava leaf were identified as O-H stretch, N-H bend, CH_3C-H bend and C-O stretch. They contain polar atoms of nitrogen and oxygen. This observation is in agreement with previous reports (Udeh et al, 2021a, Omotioma and Onukwuli, 2016), which stated that polar atoms are usually present in good corrosion inhibitor. It means that guava leaf has suitable corrosion inhibitive capabilities.

3.2. Results of the phytochemical analysis of the inhibitors

Alkaloids, cardiac glycosides, flavonoids, phenolics, phytates and saponins (both qualitative and quantitative hytochemicals) of the extract of guava leaf are revealed in Table 1. The presence of these phytochemicals shows that extract is potential corrosion inhibitor (Belani, and Kaur, 2018; Omotioma and Onukwuli, 2019). Alkaloids were highly concentrated in the extract; 223.71 ±0.12 mg/100g. Tannins, flavonoids, phytates and saponins were concentrated in the guava leaf.

Table 1 Phytochemical (Qualitative and Quantitative) Analysis of the guava leaf

Phytochemicals	Qualitative results	Quantitative results
Alkaloids (mg/100g)	+++	223.71 ±0.12
Cardiac glycosides (mg/100g)	-	10.64 ±0.07
Flavonoids (mg/100g)	++	142.89 ±0.15
Phenolics (GAE/g)	+	28.67 ±0.01
Phytates (mg/100g)	++	124.08 ±0.13
Saponins (mg/100g)	++	97.40 ±0.02
Tannins (mg/100g)	++	115.31 ±0.31

–. (too little to be observed qualitatively), + (in traces), ++ (concentrated) and +++ (highly concentrated)

3.3. Effects of Process Variables on the Corrosion Inhibition of the Al in KOH

Table 2 Effect of time on corrosion control of Al in KOH medium with guava leaf

Time (hr)	ΔW_0 (g)	CR_0 (mg/cm^{2}hr)	ΔW_1 (g)	CR_1 (mg/cm^{2}hr)	IE (%)	θ
1	0.079	8.778	0.03	3.333	62.03	0.6203
2	0.115	6.389	0.034	1.889	70.43	0.7043
3	0.236	8.741	0.039	1.444	83.47	0.8347
4	0.35	9.722	0.041	1.139	88.29	0.8829
5	0.371	8.244	0.053	1.178	85.71	0.8571

ΔW_0 = loss in weight in the absence of inhibitor, ΔW_1 = loss in weigh in the presence of inhibitor, CR_0 = corrosion rate in the absence of inhibitor, CR_1 = corrosion rate in the presence of inhibitor, θ = Degree of surface coverage, IE = Inhibition efficiency.

Table 3 Effect of concentration on corrosion control of Al in KOH medium with guava leaf

Inh. Conc. (g/L)	ΔW_0 (g)	CR_0 (mg/cm^{2}hr)	ΔW_1 (g)	CR_1 (mg/cm^{2}hr)	IE (%)	θ
0.0	0.35	9.722				
0.2			0.167	4.639	52.29	0.5229
0.4			0.145	4.028	58.57	0.5857
0.6			0.068	1.889	80.57	0.8057
0.8			0.041	1.139	88.29	0.8829
1.0			0.048	1.333	86.29	0.8629

Effects of process variables (time, inhibitor concentration and temperature) on the Corrosion Inhibition of Al in KOH are presented in Tables2– 4. In Table 2, weight loss and corrosion rate increased with increase in time. In the presence of inhibitor, inhibition efficiency and degree of surface coverage increased with increase in time, but decreased with increase in temperature. Extract of guava leaf recorded maximum inhibition efficiency of 88.29%.

Table 4 Effect of temperature on corrosion control of Al in KOH medium with guava leaf

Temp. (K)	ΔW_0 (g)	CR_0 (mg/cm^2hr)	ΔW_1 (g)	CR_1 (mg/cm^2hr)	IE (%)	θ
303	0.335	9.306	0.045	1.25	86.57	0.8657
313	0.35	9.722	0.041	1.139	88.29	0.8829
323	0.434	12.06	0.083	2.306	80.88	0.8088
333	0.456	12.67	0.122	3.389	73.25	0.7325
343	0.493	13.69	0.16	4.444	67.55	0.6755

3.4. Model of inhibition efficiency of the guava leaf extract

Mathematical models (in terms of coded and actual factors) of the inhibition efficiency are presented in Equations (5) and (6) respectively.

$$\text{Inhibition efficiency} = + 89.20 + 4.19A - 4.55B + 3.84C + 1.88AB - 1.57AC - 1.41BC - 8.31A^2 - 9.01B^2 - 3.83C^2 \quad \text{.......(5)}$$

$$\text{Inhibition efficiency of guava leaf extract} = - 8786.85892 + 89.66432\text{Inhibitor concentration} + 55.75465\text{Temperature} + 84.87836\text{Time} + 0.942500\text{Inhibitor concentration} * \text{Temperature} - 7.83750\text{Inhibitor concentration} * \text{Time} - 0.141000\text{Temperature} * \text{Time} - 207.73864\text{Inhibitor concentration}^2 - 0.090095\text{Temperature}^2 - 3.82955\text{Time}^2 \quad \text{....(6)}$$

There are quadratic models because the highest power of the factors is two. The equation in terms of coded factors is used to predict the response for given levels of each factor. It is useful for classifying the relative impact of the factors by linking the factor coefficients (Udeh et al, 2021; Anadebe et al, 2018). The model F-value of 157.13 implies the model is significant (Table 5). There is only a 0.01% opportunity that an F-value this large could occur as a result of noise. P-values brlow 0.0500 show that the model terms are important. In this case A, B, C, AB, AC, BC, A^2, B^2, C^2 are important terms of the model. Predicted R^2 of 0.9311 is in rational closeness to the adjusted R^2 of 0.9867; the difference is less than 0.2. Adequate precision determine the signal to noise ratio; ratio greater than 4 is required. Thus, recorded ratio of 39.976 designates an adequate signal. This model can be used to traverse the design space. Diagnostic analyses of the model are showcased in Figures (2) and (3). Figure 2 presents the residual versus run number of the guava leaf extract, while Figure 3 show the residual versus predicted data of the guava leaf extract. The plots revealed that response surface methodology effectively modeled the relationship between inhibition efficiency and the considered factors of the corrosion inhibition process. Table 6 presents the coefficients of the model in terms of coded factors. The coefficient estimate represents the expected change in response per unit change in factor value when all remaining factors are held constant. The intercept in an orthogonal design is the overall average response of all the runs. The coefficients are adjustments around that average based on the factor settings.

Table 5 ANOVA for quadratic model of inhibition efficiency of guava leaf

Source	Sum of Squares	Df	Mean Square	F-value	p-value	
Model	2265.36	9	251.71	157.13	< 0.0001	Significant
A-Inhibitor concentration	175.31	1	175.31	109.44	< 0.0001	
B-Temperature	207.12	1	207.12	129.29	< 0.0001	
C-Time	147.38	1	147.38	92.00	< 0.0001	
AB	28.43	1	28.43	17.74	0.0018	
AC	19.66	1	19.66	12.27	0.0057	
BC	15.90	1	15.90	9.93	0.0103	

A^2	189.88	1	189.88	118.53	< 0.0001	
B^2	223.22	1	223.22	139.35	< 0.0001	
C^2	40.33	1	40.33	25.18	0.0005	
Residual	16.02	10	1.60			
Lack of Fit	16.02	5	3.20			
Pure Error	0.0000	5	0.0000			
Cor Total	2281.38	19				
Std. Dev.	1.27		R^2		0.9930	
Mean	78.62		Adjusted R^2		0.9867	
C.V. %	1.61		Predicted R^2		0.9311	
			Adeq Precision		39.9765	

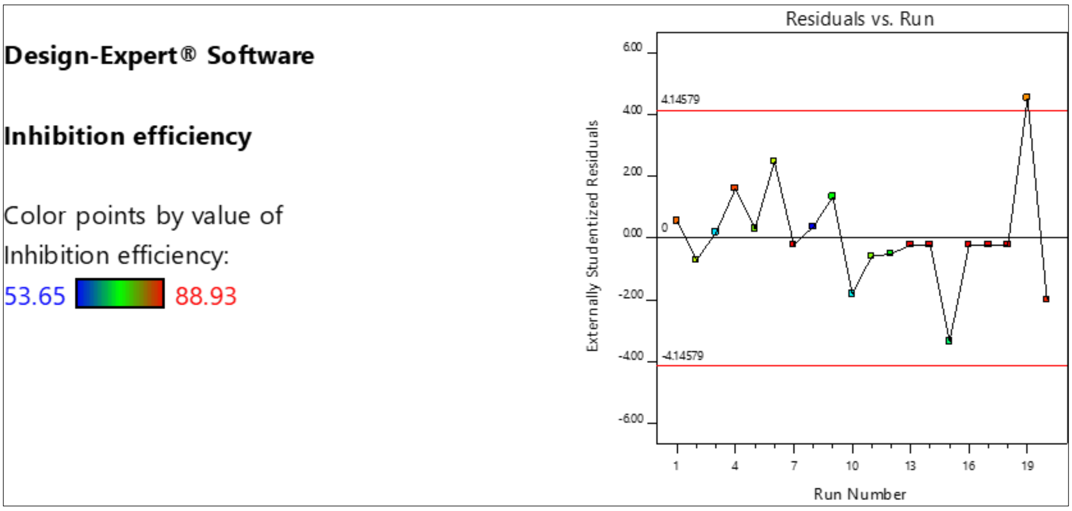

Figure 2 Residuals versus run number of the guava leaf extract

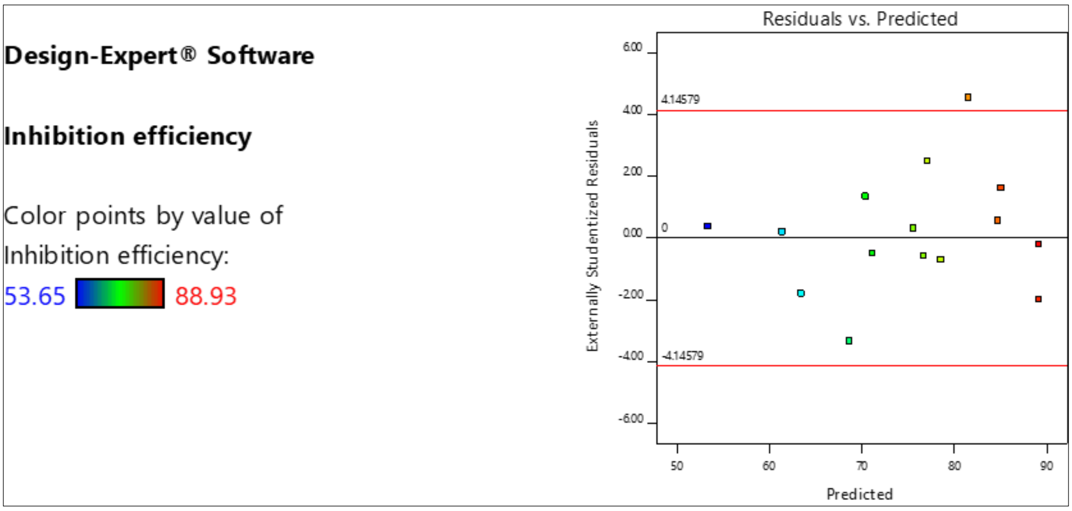

Figure 3 Residual versus predicted data of the guava leaf extract

Table 6 Coefficients of the model in Terms of Coded Factors

Factor	Coefficient Estimate	Df	Standard Error
Intercept	89.20	1	0.4351
A-Inhibitor concentration	4.19	1	0.4002
B-Temperature	-4.55	1	0.4002
C-Time	3.84	1	0.4002
AB	1.88	1	0.4475
AC	-1.57	1	0.4475
BC	-1.41	1	0.4475
A^2	-8.31	1	0.7632
B^2	-9.01	1	0.7632
C^2	-3.83	1	0.7632

4. Conclusion

From the analyses of the experimental results, the following conclusions were drawn:

- Main functional groups of the guava leaf were revealed as O-H stretch, C-H stretch, C-H stretch, N-H bend, CH_3C-H bend, C-O stretch and C-H bend. Alkaloids, cardiac glycosides, flavonoids, phenolics, phytates and saponins were found to be present in the extract at various levels.
- Weight loss, corrosion rate, inhibition efficiency and degree of surface coverage were influenced by the inhibitor. Guava exhibited high inhibition efficiency. Hence, it can be used to inhibit corrosion of Al in KOH solution.
- Quadratic model revealed the connection between inhibition efficiency and factors of inhibitor concentration, temperature, and time

Compliance with ethical standards

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Disclosure of conflict of interest

There is no conflict of interest.

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