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Journal of Civil Engineering and Environmental Sciences

ENGINEERING GROUP

ISSN: 2455-488X DOI: https://dx.doi.org/10.17352/jcees

Research Article

Evaluation of corrosion characteristics of mild steel in the acidic environment using Cocoyam and Almond leaves extracts as inhibitors

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Received: 03 July, 2023
Accepted: 06 July, 2023
Published: 07 July, 2023

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Keywords: Almond leaves; Cocoyam leaves; Extracts; Inhibition; Immersion times

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Abstract

The inhibition characteristics of Almond and Cocoyam leaves extracts on mild steel immersed in 1 M H_2SO_4 at immersion times of 24 h to 144 h have been investigated experimentally. The effects of various concentrations of the extracts on the corrosion rate and inhibition efficiency were also explored. The average corrosion rates (in mm yr^{-1}) and inhibition efficiencies (in %) were determined at each extract concentration and immersion time. Results show that both extracts demonstrated excellent inhibition characteristics for mild steel in H_2SO_4 media as the corrosion rate of the mild steel decreased from 43.0096 mm yr^{-1} to 4.7019 mm yr^{-1} and 4.9528 mm yr^{-1} after adding 8 g/L of Cocoyam and Almond leaves extracts respectively. This can be linked with the adsorption of molecules of oxidative phytochemical constituents of the extracts on the mild steel surfaces which shielded the mild steel surfaces from further attack by the acid. Within the time range of the study, the inhibition efficiency of both Cocoyam and Almond leaves extracts increased with an increase in inhibitor concentration with maximum inhibition efficiencies of 70.15% and 56.67% recorded by Almond and Cocoyam leaves extracts respectively at concentrations of 8 g/L. Conclusively, Almond leaves extracts are better mild steel corrosion inhibitors than cocoyam leaves extracts, due to the lower pH value of Cocoyam leaf extract.

Introduction

Mild steel has gained wide applications in oil, marine, and automobile industries for the fabrication of pipelines, construction of bridges, and automobile parts considering its excellent mechanical properties. But due to the corrosive nature of mild steel, it becomes pertinent to explore metallurgical means of mitigating their rate of corrosion to avoid catastrophic failure of components. This development forms the rationale for choosing mild steel for this experimental study. Corrosion inhibitors are substances that can be added to corrosive environments to reduce the rate of corrosion. Traditional corrosion inhibitors are often synthetic chemicals, but researchers have been exploring natural compounds as potential alternatives due to their eco-friendly nature and low toxicity [1]. Plant extracts contain naturally occurring compounds such as tannins, alkaloids, flavonoids, phenols, and organic acids that have been found to possess inhibitive properties against corrosion. The active compounds in plant extracts can form a protective film on the metal surface, which acts as a barrier against corrosive agents. This film can inhibit the access of oxygen, moisture, and corrosive ions to the metal surface, thus reducing the corrosion rate. The use of plant extracts as corrosion inhibitors offers a greener and more sustainable approach compared to traditional chemical inhibitors. Plant extracts are generally non-toxic, biodegradable, and readily available. The effectiveness of plant extracts as corrosion inhibitors can vary depending on factors such as concentration, pH, temperature, and the specific metal being protected [2].

The main objective of this research is to explore the potentiality of Almond and Cocoyam leaves extracts for inhibition of mild steel corrosion in a highly corrosive environment; 1 M H_2SO_4 solution. This research is quite significant as it provides information on the wider application and economic values of green plants for effective corrosion control of mild steel in industries. This development will significantly boost the economy of the country due to waste reduction, cost-effectiveness, recyclability of agricultural wastes, and effective corrosion inhibition in industries.

Recent studies explored the inhibition performances of various eco-friendly plants extracts of Rheum Ribes flower [1], Rubia tinctorum root [2], Hemigraphis colorata leaves [3], Passiflora edulis Sims peels [4], Rheum ribes leaf [5], Camellia chrysantha flower [6], Chromolaena Odorata leaf [7], garlic [8], Dysphania ambrosioïdes leaf [9], rice straw [10], Etlingera Elatior inflorescence [11], Pulicaria undulate [12], Vicia Sativa weed aerial [13], Malpighia glabra leaf [14], Cnicus Benedictus weed [15], Eruca sativa seed [16], Irvingia gabonensis and wombolu [17,18]. Kaya, et al. (2023) in their recent study of the effectiveness of Rheum Ribes flower as a potential corrosion inhibitor for mild steel in 1 M HCl solution, recorded 94.7 % and 98.4 % inhibition efficiencies at 1000 ppm concentration for 1 h and 6 h immersion times respectively. The study (Kaya, et al. 2023) revealed the extract as a mixed inhibitor. The high inhibition efficiencies are linked to the effective interaction of the molecules. Marsoul, et al, [2] explored the inhibitive characteristics of Rubia tinctorum root. And recorded optimum inhibition efficiency of 95% at 1 g/L and 298 K. Other plant extracts [3-16] demonstrated excellent inhibition performances with optimum efficiencies in the range of 65.13% - 94.9%. Irvingia gabonensis and wombolu recorded inhibition efficiencies of 93.33% and 97.87% respectively [17,18]. Green plant extracts have been revealed as a potential alternative to industrial inhibitors for a sustainable eco-friendly environment [19-40].

This study was propelled by the recent demands to expand the economic values of eco-friendly agricultural wastes in Nigeria and effectively mitigate the high rate of corrosion of mild steel in industries.

Methodology

Coupon preparation

Coupons of dimensions 3 cm x 4 cm x 0.05 cm used for this present study were prepared from a rectangular mild steel bar sourced from New Kenyatta Market Enugu, Nigeria. The coupon surfaces were ground and polished using an electric grinder (ZMAK-GA5030/2), silicon carbide papers of grit sizes; 220, 400, and 600µm, and pure aluminum powder. The polished coupons were degreased with acetone, dried using a Bosch GHG660LCD heat gun machine, and stored in moisture-free desiccators prior to use.

Sourcing and preparation of cocoyam leaf extract

The fresh Almond and cocoyam leaves used for this experimental study were sourced from Independent Layout, Enugu State, Nigeria. The Cocoyam and Almond leaves were washed properly with distilled water, sliced, and dried at 25 °C for two weeks. Subsequently, the leaves were ground using an SB-1872 electric blender. Soxhlet extraction was performed on the homogenized samples using ethanol as a solvent. The Soxhlet extraction process was carried out at 60 °C. About 1000 g samples were wrapped in a Whatman paper placed in a cellulose extraction thimble and extracted with the solvent for 6 hours at 6 cycles per hour. About 40 g of Almond and cocoyam leaf extracts were obtained out of which 2 g, 4 g, 6 g, and 8 g were measured using a BL20001 electronic compact scale and dissolved into 1.0 L of 1 M H_2SO_4 solution.

Weight loss measurement

Weight loss measurement was adopted for the measurement of the corrosion rates for each concentration of extract. The prepared coupons were immersed in 1 M H_2SO_4 solution with and without the extract. The corrosion rates of the mild steel in 1 M H_2SO_4 with and without extracts additions were measured after 24 h, 48 h, 96 h, and 144 h immersion times at a temperature of 25 °C. The pH values of the solutions with and without extract additions are presented in Table 1. The coupons were rinsed, swabbed in acetone, and dried using a Bosch GHG660LCD heat gun machine after each immersion time. The weight of the coupons before and after immersion was measured using a BL20001 electronic compact scale. The corrosion rate and inhibition efficiency of four samples per extract concentration were calculated using equations 1 and 2 respectively and average values were recorded.

$$\mathrm{Cr} = \frac{8.76\,\mathbf{x}\,10^{4}\,(\mathbf{W_i} - \mathbf{W_{11}})}{\mathbf{y}\rho\mathbf{t}} \quad (1)$$

Where Cr is the corrosion rate (in mm/yr), W_i-W_{ii} is the change in weight of the sample before and after immersion (in gram), y is the cross-sectional area of the specimen (in mm²), t is the immersion time (in h) and ρ is the density of the sample (in g/mm³).

$$\varepsilon\left(\%\right) = \frac{Cr_o - Cr_i}{Cr_o}\,x100 \quad (2)$$

Where ε is the inhibition efficiency, Cr_o is the corrosion rate without extract addition, and Cr_i is the corrosion rate with extract addition.

Results

Figures 1-4 show the results obtained from the experimental study. The corrosion rates of the mild steel with and without

Table 1: pH values of the prepared Almond and Cocoyam leaves extracts at 25°C

Concentration	pH Level of Solution The volume of extract (g/L)				
	0	2	4	8	6
No inhibitor	3.67	-	-	-	-
Almond leaves extract	-	5.67	5.83	5.98	6.14
Cocoyam leaves extract	-	5.90	5.05	5.21	5.36

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extracts additions are presented in Figures 1-3, while the inhibition efficiencies of the Almond and Cocoyam leaf extracts are presented in Figure 4.

Discussion

Figure 1 depicts the comparative analysis of the corrosion rate of mild steel immersed in 1 M H_2SO_4 with and without extract additions. From Figure 1, it can be observed that the corrosion rate of mild steel in 1 M H_2SO_4 containing no extract is higher compared with extract additions. Additions of Almond leaves and Cocoyam leaves extracts significantly decreased the rate of corrosion, with predominant effects recorded by Almond leaf extract. At each condition, it is noted that the corrosion rate decreased correspondingly with increasing immersion times. This can be linked with the adsorption of molecules of extracts in the mild steel surfaces which shielded the mild steel surfaces from further attack by the acid. Figures 2 and 3 show the effects of Almond leaves (AL) and Cocoyam leaves (CL) extract concentrations on the corrosion rate of mild steel in 1 M H_2SO_4. It is noted from Figures 2 and 3 that the corrosion rate decreased significantly with the addition of both extracts. The corrosion rate decreased correspondingly with an increase in the concentrations of the extracts. Figure 4 shows the inhibition characteristics of the Almond and Cocoyam leaves extracts at different concentrations at 24 h immersion time. Analysis of Figure 4 shows that both Almond and Cocoyam leaves extracts recorded inhibition efficiencies of 70.15% and 56.67% respectively. The maximum inhibition efficiency recorded by Almond leaf extracts can be linked with the higher pH value of the extract compared with that of Cocoyam leaf extract. From the results obtained, it is obvious that both Almond and Cocoyam leaves extracts are potential inhibitors for mild steel corrosion mitigation in 1 M H_2SO_4 solution. This development has provided information on the wider application and economic values of green plants for economic development and adequate waste reduction, cost-effectiveness, and recyclability of agricultural wastes.

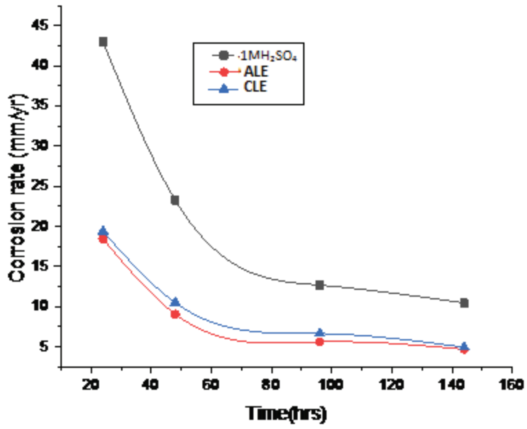

Figure 1: Corrosion rate against time (1M H_2SO_4 8g/L ALE, 8g/L CLE).

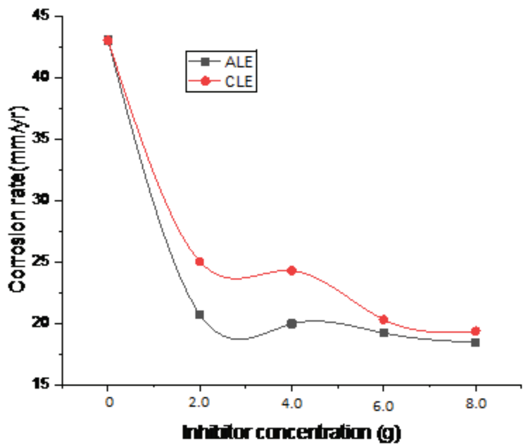

Figure 2: Corrosion rate against inhibitor concentration (ALE and CLE) 1M H_2SO_4 on mild steel immersed for 24 h.

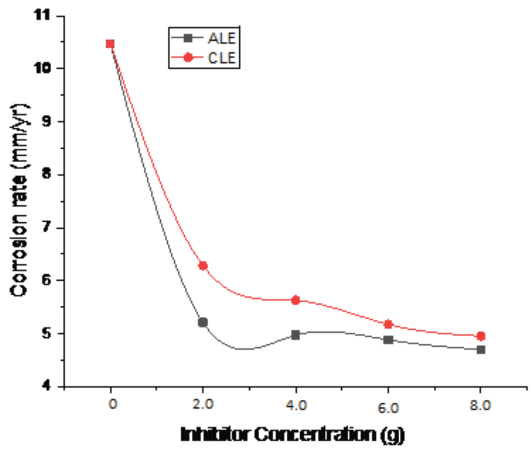

Figure 3: Corrosion rate against inhibitor concentration (ALE and CLE) in 1M H_2SO_4 on mild steel immersed for 144 h.

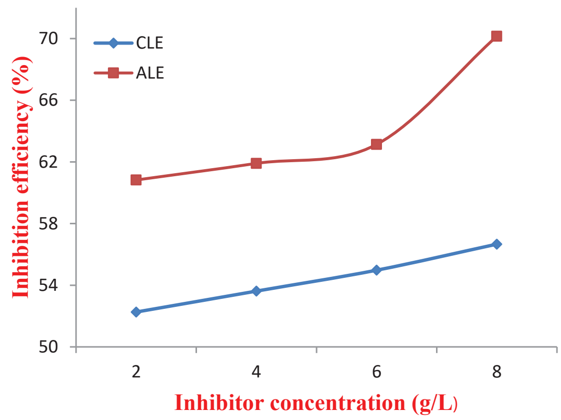

Figure 4: Inhibition efficiency against inhibitor concentration (CLE and ALE) in 1M H_2SO_4 on mild steel immersed for 144 h.

Comparative analysis of inhibition potentials of Almond and Cocoyam leaves extracts with conventional green plants inhibitors

Table 2 shows the comparative analysis of inhibition efficiencies of different green plant extracts. It is shown that the present studied green plant extracts recorded lower inhibition efficiencies compared with some earlier studied green plant extracts. Almond leaves extract recorded higher inhibition efficiency than Date palm seed extract [19].

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Table 2: Comparative analysis of inhibition potentials of the studied green plant extracts with earlier studied green plants inhibitors.

Green Plants Extracts	Environment	Inhibition Efficiency (%)	References
Almond leaves	1 M H_2SO_4	70.15	Present study
Cocoyam leaves	1 M H_2SO_4	56.67	Present study
Rheum Ribes Flower	1 M HCl	98.4	[1]
Rubia T. L. Roots	1 M HCl	95	[2]
Hemigraphis colorata (HC) leaves	1 M HCl	93.73	[3]
Chromolaena Odorata leaf	1 M HCl	83.33	[7]
Rice Straw	1.5 M H_2SO_4	85.11	[10]
Date palm seed	0.5 M CH_3COOH	64	[19]

Conclusion

The inhibition characteristics of Almond and Cocoyam leaves extracts on mild steel immersed 1 M H_2SO_4 for 24, 48, 96 and 144 h immersion times have been investigated experimentally. The effects of various concentrations of the extracts on the corrosion rate and inhibition efficiency were also explored. From the results obtained, the Almond and Cocoyam leaf extracts demonstrated excellent inhibition potential in 1 M H_2SO_4 solution at various extract concentrations and immersion times at 25 °C. Almond leaves extract recorded better corrosion resistance and inhibition efficiency compared with Cocoyam leaves extracted due to higher pH values of the extract concentration in 1 M H_2SO_4 solution. Maximum inhibition efficiencies of 70.15% and 56.77% were recorded by Almond and Cocoyam leaves extracts of 8 g/L concentrations and immersion time of 144 h at 25 °C. Conclusively, Cocoyam and Almond leaves extracts have been established as potential inhibitors for corrosion mitigation of mild steel in 1 M H_2SO_4 solution, hence can be recommended for industrial applications. Further study on the corrosion inhibition potential of both extracts at higher temperatures is recommended.

Acknowledgment

The authors are delighted and sincerely appreciate Engr. Prof. C. N. Mbah for his technical and professional input in this research work.

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