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Response of Gmelina Leave inhibitor on the corrosion of mild steel based on the pH

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ABSTRACT

Corrosion of mild steel in acidic environments poses significant challenges in industrial applications. This study investigates the effect of *Gmelina arborea* leaf extract as a green corrosion inhibitor for mild steel in acidic media with varying pH levels (1.63, 1.25, 0.74, 0.50, and 0.43). The corrosion rates of mild steel were determined both in the absence and presence of the inhibitor using weight-loss methods. In the absence of the inhibitor, the corrosion rates increased as the pH decreased, ranging from 1.013 mm/yr at pH 1.63 to 2.284 mm/yr at pH 0.43, highlighting the aggressive nature of the acidic medium. In contrast, the addition of the *Gmelina arborea* extract significantly reduced the corrosion rates, with values ranging from 0.237 mm/yr at pH 1.63 to 1.656 mm/yr at pH 0.43. The inhibition efficiency was observed to decline with decreasing pH, indicating that higher acidity levels diminish the effectiveness of the inhibitor. This behavior is attributed to the increased aggressiveness of the acidic medium, which may overcome the protective barrier formed by the inhibitor on the metal surface. The study concludes that *Gmelina arborea* leaf extract is an effective and eco-friendly inhibitor for mitigating corrosion of mild steel in acidic environments. However, its performance is pH-dependent, and optimal results are achieved at less aggressive acidic conditions. These findings support the potential application of *Gmelina arborea* as a sustainable alternative to synthetic inhibitors in industrial corrosion control.

Keywords: pH; *Gmelina arborea*; Corrosion; Mild steel; Inhibitor; Response; Leaf extract; Acidity; Performance; Weight-loss.

1. Introduction

Corrosion is a persistent problem in industries, especially where metallic materials such as mild steel are exposed to acidic environments. Acidic conditions, often encountered in cleaning, pickling, and descaling processes, accelerate the degradation of metals, resulting in economic and structural challenges. Traditional corrosion inhibitors, often synthetic and toxic, pose environmental and health hazards, prompting the search for sustainable alternatives. Green corrosion inhibitors, derived from plant extracts, have emerged as viable solutions due to their non-toxic, biodegradable, and cost-effective nature. *Gmelina arborea*, known for its rich phytochemical profile containing tannins, alkaloids, and flavonoids, has shown potential for mitigating metal corrosion through the adsorption of these compounds on metal surfaces, forming protective barriers. This study investigates the performance of *Gmelina arborea* extract as a corrosion inhibitor for mild steel across varying pH levels, contributing to the understanding of its pH-dependent efficiency in acidic media.

Sharma et al. [1] reviewed the potential of green corrosion inhibitors derived from various plant extracts. The authors emphasized the sustainability and environmental benefits of using natural inhibitors over synthetic options. Okafor et al. [2] analyzed the inhibitory effects of *Phyllanthus amarus* extract on mild steel in acidic solutions. The study demonstrated over 80% inhibition efficiency due to the presence of bioactive compounds. Ekpe et al. [3] studied *Azadirachta indica* (neem) leaves extract for corrosion inhibition in sulfuric acid. The findings revealed the potential of natural plant compounds in reducing corrosion rates. Oguzie [4] explored the effectiveness of plant extracts as corrosion inhibitors in acidic media. The study found that the phytochemicals in the extracts significantly reduced the corrosion rates of mild steel by adsorbing onto the surface and forming a protective layer. Verma et al. [5] investigated the application of henna (*Lawsonia inermis*) extract as a corrosion inhibitor for mild steel. The results showed high efficiency due to the adsorption of flavonoids and tannins on the steel surface. Umoren et al. [6] investigated the synergistic effects of natural polymers and iodide ions on corrosion inhibition. The results highlighted the role of bio-compounds in enhancing adsorption and improving inhibition efficiency. Soltani et al. [7] researched the use of green inhibitors for mild steel corrosion. The study reported that plant-based inhibitors were effective due to their eco-friendly nature and strong metal-surface interactions. Mejeha & Ebensoh [8] focused on the performance of natural plant extracts in reducing corrosion rates. The study demonstrated that plant inhibitors are cost-effective and efficient for acidic conditions. El-Etre [9] investigated the use of natural honey as a corrosion inhibitor, emphasizing its effectiveness in reducing corrosion rates and its eco-friendly properties. Abiola & Oforka [10] examined the adsorption behavior of natural compounds on mild steel in acidic environments, highlighting the importance of functional groups in enhancing inhibition. Al-Otaibi et al. [11] studied the inhibition performance of various plant extracts in acidic media. The authors highlighted the role of bioactive molecules in creating effective protective layers on metal surfaces. Ahamad et al. [12] explored the role of naturally occurring molecules, particularly tannins and alkaloids, in mitigating corrosion. The study noted the adsorption mechanism as a key factor in inhibition. Therefore this study seeks to practically examine the response of Gmelina leave inhibitor on the corrosion of mild steel based on the pH (acidity).

1.1. Study Objectives

The objectives of this study are as follows:

(1) To evaluate the corrosion behavior of mild steel in acidic environments with varying pH levels; (2) To investigate the effectiveness of *Gmelina arborea* leaf extract as a green corrosion inhibitor for mild steel in acidic media; (3) To measure and compare the corrosion rates of mild steel in the absence and presence of the *Gmelina arborea* leaf extract using weight-loss methods; (4) To determine the relationship between pH levels and the inhibition efficiency of the *Gmelina arborea* leaf extract; (5) To analyze the impact of increasing acidity on the protective barrier formed by the inhibitor on the surface of mild steel; and (6) To assess the potential of *Gmelina arborea* leaf extract as a sustainable and eco-friendly alternative to synthetic corrosion inhibitors for industrial applications.

2. Methods

The Pure and Industrial Chemistry Department Laboratory at Nnamdi Azikwe University in Awka, Anambra state, served as the site of the experiment. In order to perform this investigation, the following materials were needed: 20 x 20 x 1.5 mm specimens of mild steel (C 0.08 wt%, Si = 0.05 wt%, P = 1.00 wt%, Cu = 0.02 wt%, Pb = 0.02 wt%, and Fe = 98.83 wt%); fresh *Gmelina arborea* leaves; 16 liters of distilled water, 40 beakers, a ceramic crucible, a conical flask, filter paper, suspension threads, a pH meter, plastic sticks for thread suspension, a digital weighing scale, analytical-grade hydrochloric acid, and ethanol (absolute).

2.1. Mild Steel Specimen Preparation

The specimens were cut from a mild steel sheet and were 20 x 20 x 1.5 mm. The steel samples were cleaned, polished, and cut into the proper sizes using rough emery paper.

2.2. Preparation of Gmelina Leaves Extract

Gmelina leaves were collected in the Anambra state of Nigeria, close to Ogidi. The branches of the fresh Gmelina leaves were harvested. They were washed, dried, and crushed. After being crushed, it was steeped in an ethanol solution for a whole day, as seen in figure 1 below. The resulting solution was sieved to produce a filtrate. The filtrate was concentrated in a water bath set at 80 °C in order to remove the ethanol from the juice extract. The slurry extract was stored in a sterile bottle with a tight-fitting lid before to use.

Figure 1. Gmelina Leaves after Crushing and Soaked in Ethanol

2.3. Preparation of the Environment (Hydrochloric Acid)

HCl solutions with concentrations ranging from 0.47, to 0.10, to 1.43, to 1.91, to 2.39 were made using laboratory grade concentrated HCl and distilled water as a diluent. The beakers used in this experiment were thoroughly cleaned and washed (Emekwisia et al. [13]).

2.4. Setting Up of the Distilled Water

The distilled water was poured into the beakers after 250 milliliters had been measured out. Each beaker was then labeled with its weight, pH, acid concentration, and number of days after which it was stored.

2.5. Experimental Set-Up

Two sets of beakers were present. In the first, different initial weights of HCL were employed, while in the second, different initial weights of HCl were mixed with 6 milliliters of Gmelina extract. Two hundred hours were spent on the experiment. The pre-weighed, polished, and evenly proportioned mild steel specimens were suspended in their respective test solutions for the period.

2.6. Measurement

The pH values of the test solutions were measured and recorded before the mild steel samples were immersed in them. The pH was 1.25 before the mild steel was immersed and 0.46 after it was taken out. The beginning and final weights of the mild steel specimen were recorded. The observed weight loss was calculated after the final weight of each specimen was measured. Close attention was paid to the specimen's appearance, geometry, and changes in the surrounding environment. The specimens were removed from their different corrosive conditions, cleaned with distilled water, dried, and weighed. The corresponding weight decreases were measured and documented.

3. Results and Discussion

The weight loss results were closely examined and are discussed in the sections below.

3.1. Weight Loss

This is the difference in weight across specified time periods. The mild steel specimen's weight loss (g) in the corrosive environment for each setup is conveniently tabulated.

$$\text{Weight loss (g)} = W_i(g) - W_f(g) \quad \ldots(1)$$

Where, W_i = Initial weight of the mild steel specimen.

W_f = Final weight of the mild steel specimen.

3.2. Corrosion Rate Calculation

The corrosion rate is calculated as follows:

$$\text{Corrosion Rate, } C_R = \left(\frac{K\Delta W}{TPA}\right)(mm/yr) \quad \ldots(2)$$

Where, k = Constant = 87.6;

W = Weight loss = $W_{i(g)} - W_{f(g)}$ (Calculated below)

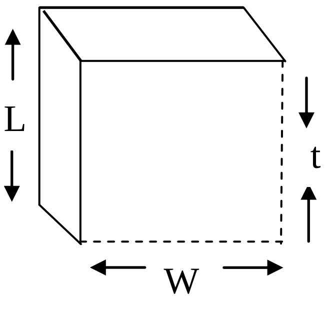
T = Time of Exposure (200 hours , (200/8760)yr. = 0.023yr.)

P = Density of mild steel = $7.85 g/cm^3$

K = Constant = 87.6

A = Surface Area of the mild steel sample exposed to corrosion = 2LW + 2Lt + 2Wt …(3)

A = 2(20 x 20) + 2(20 x 1.5) + 2(20 x 1.5) = $920 mm^2$



Where,
L = Length = 20mm
W = Width = 20mm
t = thickness = 1.5mm

Table 1. The Corrosion Rate of Mild Steel Specimen in Varied pH with Variation in Initial Weight in the Absence of *Gmelina arborea* Inhibitor

pH	Initial weight W_i (g)	Final weight W_f (g)	Weight loss W(g)	Corrosion rate (mm/yr)
1.63	21.960	20.040	1.920	1.013
1.25	21.960	19.500	2.460	1.297

0.74	21.960	18.930	3.030	1.598
0.51	21.960	18.340	3.620	1.909
0.43	21.960	17.630	4.330	2.284

Table 2. The Corrosion Rate of Mild Steel Specimen in Varied pH with Variation in Initial Weight in the Presence of *Gmelina arborea* Inhibitor

pH	Initial weight W_i (g)	Final weight W_f (g)	Weight loss W(g)	Corrosion rate (mm/yr)
1.63	21.960	21.510	0.450	0.237
1.25	21.960	21.020	0.940	0.496
0.74	21.960	20.620	1.340	0.707
0.51	21.960	19.780	2.180	1.150
0.43	21.960	18.820	3.140	1.656

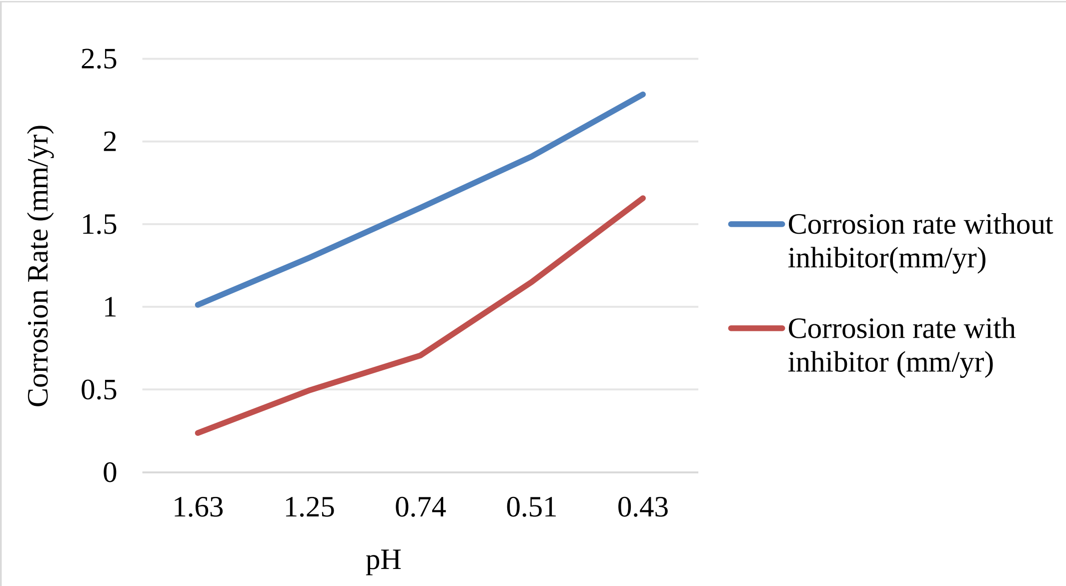


Figure 2. Graph of Corrosion Rate against pH

The results obtained in table 1 and 2, and figure 2 above showed the response of Gmelina leaf extract as a corrosion inhibitor for mild steel in an acidic medium over different pH. The study investigated the corrosion rates of mild steel in acidic environments at varying pH levels (1.63, 1.25, 0.74, 0.50, and 0.43) with and without the *Gmelina arborea* leaf extract as an inhibitor. For the corrosion rate without inhibitor, the corrosion rates increased as the pH decreased (increasing acidity). At pH 1.63, the rate was 1.013 mm/yr, escalating to 2.284 mm/yr at pH 0.43, demonstrating the severity of corrosion in highly acidic conditions. This indicates a direct correlation between acidity and corrosion aggressiveness on mild steel. Also, for the corrosion rate with inhibitor, observation showed that the corrosion rates were significantly reduced across all pH levels due to the presence of the inhibitor. At pH 1.63, the rate dropped to 0.237 mm/yr, and at pH 0.43, it was reduced to 1.656 mm/yr. This represents notable inhibition efficiencies at all pH levels. The effectiveness of *Gmelina arborea* is attributed to the adsorption of phytochemicals such as tannins, alkaloids, and flavonoids onto the metal surface, forming a protective barrier. This study therefore highlights that the inhibitor performed better in less acidic environments, with lower corrosion rates recorded at higher pH levels. Despite decreasing inhibition efficiency in more aggressive acidic environments, the inhibitor still provided substantial protection. The results demonstrate that *Gmelina arborea* extract is effective in mitigating corrosion, making it suitable for several practical applications, such as in the Petrochemical Industry, where steel equipment often encounters aggressive acids like hydrochloric acid during cleaning and descaling processes. *Gmelina arborea* extract can reduce equipment degradation, extending service life. It can also be applied in construction and civil engineering industry, automotive and Aerospace industry, Chemical Processing Plants, etc.

3.3. Microstructural Analysis

The micrograph (figure 3-6) of mild steel with the highest exposure time of 400hours in the presence of Gmelina inhibitor was observed. The result is shown below,

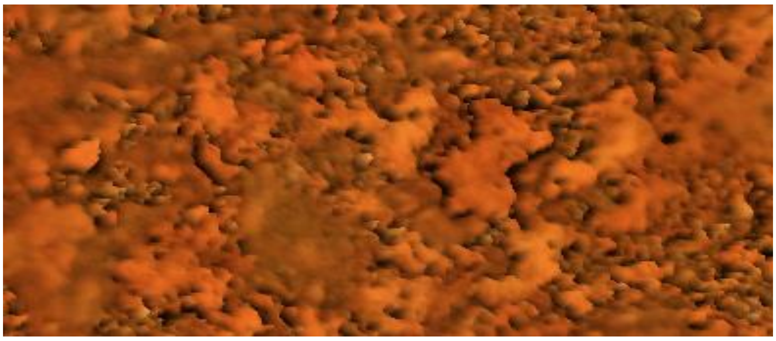


Figure 3. Mild Steel at pH of 0.43 without Inhibitor

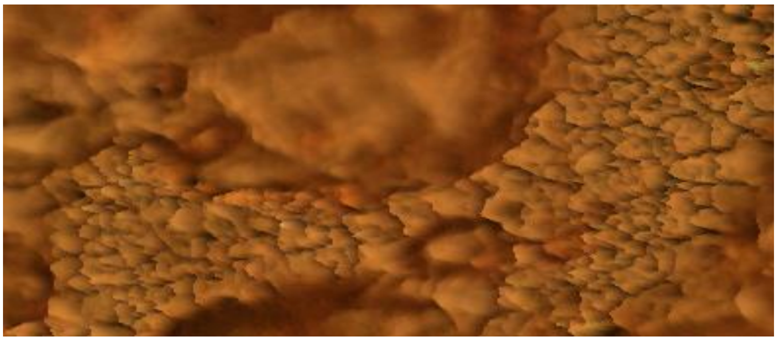


Figure 4. Mild Steel at pH of 1.63 without Inhibitor

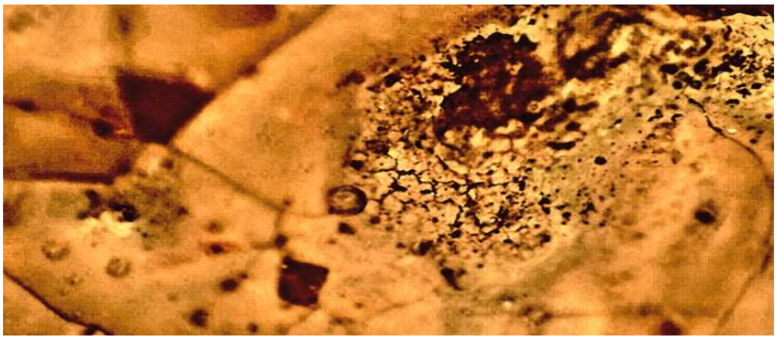


Figure 5. Mild Steel at pH of 0.43 with Inhibitor

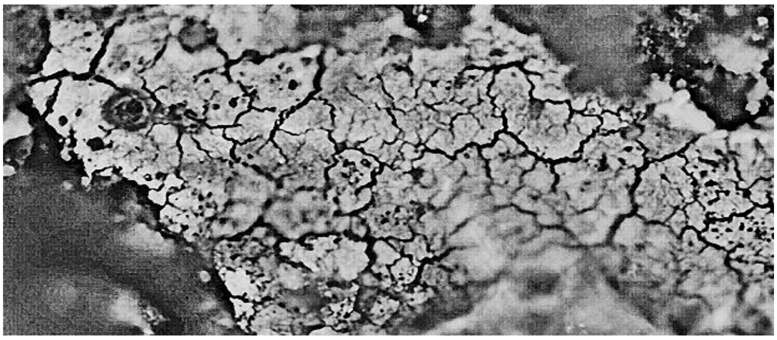


Figure 6. Mild Steel at pH of 1.63 with Inhibitor

4. Conclusion

This research highlights the response of *Gmelina arborea* leaf extract as a green corrosion inhibitor for mild steel in acidic environments. The study demonstrates that the corrosion rates of mild steel increased with acidity in the absence of the inhibitor, ranging from 1.013 mm/yr at pH 1.63 to 2.284 mm/yr at pH 0.43. However, the presence of *Gmelina arborea* extract significantly reduced these rates to 0.237 mm/yr and 1.656 mm/yr, respectively, confirming its inhibitory potential across varying acidity levels. The remarkable performance of *Gmelina arborea* extract can be attributed to the adsorption of its phytochemical constituents, such as tannins, flavonoids, and alkaloids, onto the steel surface, forming a protective barrier that minimizes corrosion. Despite the gradual decline in efficiency with increasing acidity, the inhibitor exhibited substantial protection even under highly aggressive conditions. The findings of this study support the use of *Gmelina arborea* as an eco-friendly and cost-effective alternative to synthetic inhibitors, aligning with sustainable industrial practices. Its application is particularly relevant in industries such as petrochemical processing, construction, water treatment, and any field requiring the protection of steel structures or components in acidic environments. Future research can focus on optimizing the extraction process, studying the performance of *Gmelina arborea* in different corrosive media, and exploring its synergistic effects with other natural inhibitors to enhance its overall efficiency and applicability.

5. Recommendations

Based on the above findings in this study, further works can be done to investigate the performance of *Gmelina arborea* leaf extract as a corrosion inhibitor in other acidic environments, such as sulfuric acid or phosphoric acid, to assess its versatility. The inhibitor concentration can be optimized for maximum efficiency across various pH levels. Advanced analytical techniques, such as scanning electron microscopy (SEM) or Fourier-transform infrared spectroscopy (FTIR) can be used to study the protective barrier formed by the extract on the mild steel surface. Also, the long-term stability and effectiveness of *Gmelina arborea* extract under prolonged exposure to acidic environments and fluctuating pH levels can be evaluated. Lastly, the possibility of combining *Gmelina arborea* extract with other natural or synthetic inhibitors to enhance its performance, particularly in highly aggressive acidic conditions can also be explored.

Declarations

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Competing Interests Statement

The authors declare no competing financial, professional, or personal interests.

Consent for publication

The authors declare that they consented to the publication of this study.

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