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Experimental Analysis of Gmelina Leave Inhibitor on the Corrosion Rate of Mild Steel in HCl Solutions

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Abstract

Original Research Article

Corrosion of mild steel in acidic environments poses significant challenges in various industries, leading to material failure and economic losses. This research therefore investigates the potential of Gmelina leaf extract as a sustainable and eco-friendly corrosion inhibitor for mild steel in hydrochloric acid (HCl) solutions. The aim of this research is to assess the inhibitor's effectiveness in reducing the corrosion rate of mild steel at different HCl concentrations. Results showed that without the inhibitor, the corrosion rate increased with HCl concentration, ranging from 0.754 mm/yr at 0.47 mol/dm³ to 4.667 mm/yr at 2.39 mol/dm³. However, in the presence of the Gmelina leaf inhibitor, the corrosion rate was significantly reduced, with values ranging from 0.090 mm/yr at 0.47 mol/dm³ to 0.918 mm/yr at 2.39 mol/dm³, achieving inhibition efficiencies between 80% and 88%. This research provides new insights into the high effectiveness of Gmelina leaf extract in forming a protective barrier on the steel surface, reducing corrosion even in highly acidic environments. The study highlights this leaf extract as a green, cost-effective alternative to synthetic inhibitors, with wide applications in industries requiring corrosion protection in harsh acidic conditions.

Keywords: Corrosion, Mild Steel, Gmelinas, Hydrochloric Acid.

1. INTRODUCTION

Corrosion is the degradation of materials due to their interactions with the environment, and it is inevitable for most metals (Barbara et al., 2006). It can be defined as the destructive attack of a metal through chemical or electrochemical reactions with its surroundings. Corrosion is a costly and natural process of destruction, much like natural disasters such as earthquakes (Winston et al., 2008). However, unlike these natural disasters, corrosion can be controlled or prevented with appropriate measures.

Corrosion in metals typically occurs via electrochemical mechanisms where metal atoms are removed due to electric circuits formed between the metal and the environment. Additionally, corrosion can also occur due to reactions with gases or by exposure to high temperatures, bacteria, radiation, or wear. In industrialized nations, such as the United States, corrosion costs are significant, accounting for nearly 6% of the gross domestic product (GDP). Environments, especially those containing acids, are typically corrosive to metals. Preventing or controlling corrosion is crucial for the functionality of industrial processes, reduction of energy and raw material consumption, and improving the safety and reliability of infrastructure. (Pietro, 2018)

Mild steel, a commonly used ferrous metal, is composed of iron and carbon, along with minor elements like manganese, silicon, and copper. It is affordable and widely available, with properties suitable for general engineering applications. Its high machinability, ductility, and weldability make it popular in various fields (Chuka et al., 2014). However, untreated mild steel is highly susceptible to corrosion, especially in acidic environments. Reaction between the mild steel and HCl during the corrosion process results to hydrogen evolution. Hydrogen evolution rate is directly proportional to the mild steel corrosion rate. Furthermore, inhibition efficiencies due to weight loss and hydrogen evolution were evaluated to be directly proportional and almost equal. (Nwoye et al., 2024). Corrosion resistance can therefore be enhanced through surface protection measures like primers, paints, and zinc treatments. Furthermore, mechanical processes such as grinding and chemical surface treatments like pickling can also improve the corrosion resistance of mild steel. (Manohar, et al., 2022, Al-Mamun, et al., 2021).

Organic corrosion inhibitors, containing heteroatoms such as nitrogen, sulfur, and oxygen, have been widely studied for their ability to inhibit corrosion. Several plant extracts, such as Trochodendron aralioides, Bryophyllum pinnatum, Fraxinus excelsior, Zingiber zerumbet, Artemisia capillaris, and eggshell extract, have shown promising results as eco-friendly inhibitors with inhibition efficiencies ranging from 70% to 96% (Prabakaran, et al., 2022, Berrissoul, et al., 2024, Zhuo, et al., 2023, Boudalia, et al., 2019, Bouklah, et al., 2006, Verma, et al., 2021). However, many of the conventional corrosion inhibitors are toxic, environmentally harmful, and expensive.

As a result, there is a growing interest in natural, green corrosion inhibitors that are non-toxic, readily available, and environmentally friendly. Gmelina arborea, a fast-growing deciduous tree belonging to the family Verbenaceae, is one such plant. It thrives in a variety of soil types and climates (Kijkar, 2002). Gmelina arborea contains alkaloids, carbohydrates, cardiac glycosides, tannins, and phenolic compounds, which are known to possess corrosion-inhibiting properties (Acharya et al., 2012; Nayak et al., 2012). This study therefore focuses on exploring the potential of Gmelina arborea leaf extract as a green corrosion inhibitor for mild steel in acidic environments. The aim is to provide a cost-effective, safe, and sustainable alternative to synthetic inhibitors, while investigating the efficiency of Gmelina extract in reducing corrosion rates.

2. METHODS

The experiment was carried out at the Pure and Industrial Chemistry Department Laboratory, Nnamdi Azikwe University Awka, Anambra state. The following materials were used to carry out this research: Mild steel specimens (C 0.08 wt%, Si = 0.05wt%, P =1.00wt%, Cu = 0.02wt%, Pb = 0.02wt% and Fe = 98.83wt%) with dimension of (20 x 20 x1.5)mm; Fresh Gmelina arborea leaves; Analytical grade hydrochloric acid, Ethanol (Absolute); 16 litres of distilled water; 40 Beakers; Ceramic crucible; Conical Flask; Filter paper; Suspension threads; pH meter; Plastic sticks for thread suspension; Digital weighing balance.

2.1 Preparation of Mild Steel Specimen

Mild steel specimens (C = 0.08wt%, Si = 0.05wt%, P = 1.00wt%, Cu = 0.02wt%, Pb = 0.02wt% and Fe = 98.83wt%) were cut from a mild steel sheet to a dimension of (20 x 20 x 1.5)mm. The cut steel samples were cut into sizes, cleaned and polished using rough emery paper.

2.2 Preparation of Gmelina Leaves Extract

Gmelina leaves were collected around Ogidi, in Idemili North Local Government, Anambra state. The fresh gmelina leaves were plucked from the branches. They were washed, dried and crushed. After crushing, it was soaked in an Ethanol solution for 24 hours. The resulting solution was sieved to obtain a filtrate. The filtrate was concentrated using a water bath at 80°C to remove ethanol from the juice extract and concentrate the extract. The slurry extract was stored in a clean bottle and covered properly ready to be used.

Figure 1: *Fresh Gmelina Leaves.*

Figure 2: *Gmelina leaves after crushing and soaked in ethanol.*

2.3 Preparation of the Environment (Hydrochloric Acid)

The solutions of HCl in the concentration range from 0.47 to 2.39moldm^{-3} were prepared from analytical grade concentrated HCl using distilled water as diluent. The containers(beakers) used for this experiment were thoroughly washed and rinsed.

2.4 Setting up of the Distilled Water

250ml of the distilled water were measured out and poured into the beakers. Each beaker was then kept and labeled avoiding to their number of days, pH, weight and acid concentration.

2.5 Experimental Set-Up

The beakers were set up into two groups. The first was with HCL of variation in initial weights, while the second was with HCL of different initial weights and 6ml of Gmelina extract. The time duration for the experiment was 200hours. The polished and pre-weighed mild steel specimens of uniform size were suspended in their respective test solutions for the time duration.

2.6 Measurement

The pH values of the test solutions were measured and recorded before the mild steel samples were immersed into the test solutions. The pH value was 1.25 before the mild steel was immersed and 0.46 after removing the immersed mild steel. The initial weights and final weights of the mild steel specimen were observed. The weight loss observed were calculated after measuring the final weight of each specimen. The environmental changes around the specimen as well as changes in specimen appearance, geometry were carefully monitored. The specimen were removed from their respective corrosive environment, washed with distilled water, dried and weighed. Corresponding weight losses were obtained and documented.

3. RESULTS AND DISCUSSION

The results of the weight loss were carefully observed and discussed below.

3.1 Weight Loss

This is the difference in weight over specific time intervals. The weight loss(g) of the specimen (mild steel) in the corrosive environment for the different set-up is tabulated for ease of computation.

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

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:

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

Where, k = Constant = 87.6;

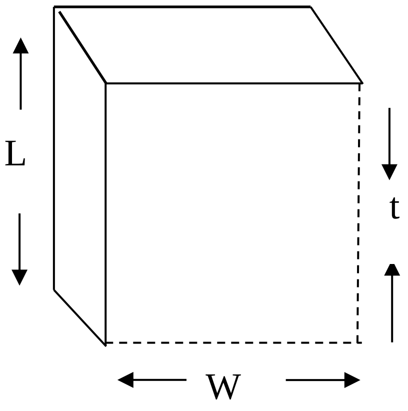
W = Weight loss = $W_{i(g)} - W_{f(g)}$ (Calculated below)

T = Time of Exposure = $200\text{hours}, (200/8760)\text{yr} = 0.023\text{yr}$.

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

K = Constant = 87.6

A = Surface Area of the mild steel sample exposed to corrosion = 2LW + 2Lt + 2Wt = 2(20 x 20) + 2(20 x 1.5) + 2(20 x 1.5) = 920mm^2



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

Table 1: The Corrosion rate of mild steel specimen immersed in HCL in the absence of Gmelina arborea inhibitor.

HCL at varying concentration (mol/dm^3)	**Initial weight W_i(g)**	**Final weight W_f (g)**	**Weight loss W(g) or Δw**	**Corrosion rate (mm/yr)**
0.47	22.190	20.760	1.430	0.754
0.10	22.190	18.870	3.320	1.751
1.43	22.190	16.750	5.440	2.869
1.91	22.190	14.910	7.280	3.839
2.39	22.190	13.340	8.850	4.667

Table 2: The Corrosion rate of mild steel specimen immersed in HCL in the presence of Gmelina arborea inhibitor.

HCL at varying concentration with Gmelina arborea inhibitor (mol/dm^3)	**Initial weight W_i(g)**	**Final weight W_f (g)**	**Weight loss W(g) or Δw**	**Corrosion rate (mm/yr)**
0.47	22.190	22.020	0.170	0.090
0.10	22.190	21.740	0.450	0.237
1.43	22.190	21.360	0.830	0.438
1.91	22.190	20.940	1.250	0.660
2.39	22.190	20.450	1.740	0.918

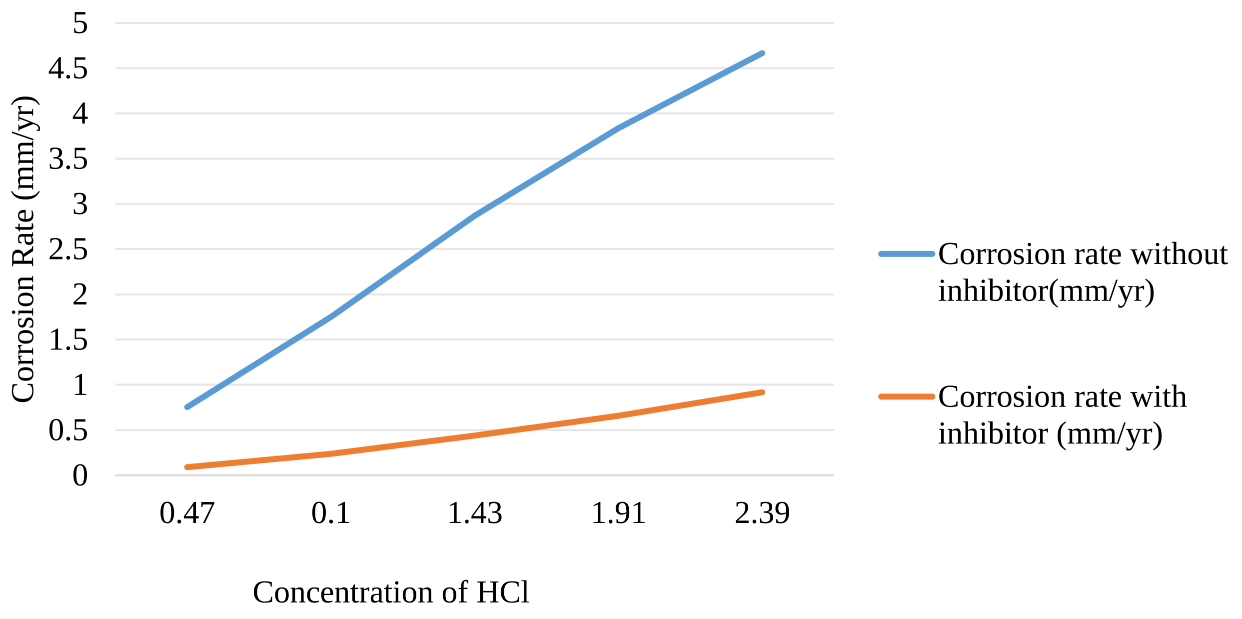


Figure 3: Graph of Corrosion Rate Against Corrosive Environment (HCl Concentration).

The results from the figure 3 above showed the corrosion behavior of mild steel when submerged in HCl of various concentration, in the absence and presence of Gmelina leave inhibitor. For the corrosion rate without inhibitor, the corrosion rate increases with rising HCl concentrations. At HCl concentration of 0.47mol/dm^3, the corrosion rate gave 0.754mm/yr, at 0.10mol/dm^3 it increased to 1.751mm/yr, at 1.43mol/dm^3 it further increased to 2.869mm/yr, at 1.91mol/dm^3 it gave 3.839mm/yr, and at final rate of 2.39mol/dm^3 it gave the highest corrosion rate of 4.667mol/dm^3. The increasing corrosion rate correlates with the increasing concentration of HCl. This is due to the higher availability of H$^+$ ions, which accelerates the electrochemical dissolution of mild steel. At the highest concentration (2.39 mol/dm^3), the rate of corrosion reached 4.667 mm/yr, showing an almost six-fold increase from the lowest concentration (0.47 mol/dm^3, 0.754 mm/yr). This rapid acceleration in corrosion rate is typical of metals exposed to more aggressive acidic conditions.

For the corrosion rate in the presence of the inhibitor (Gmelina Leaf), the inhibitor drastically reduced the corrosion rate at all concentrations of HCl. Observation showed that at the lowest concentration of 0.47 mol/dm^3, the rate drops from 0.754 mm/yr (without inhibitor) to 0.090 mm/yr (with inhibitor), showing a 88% reduction in corrosion rate. Even at the highest concentration of 2.39 mol/dm^3, the corrosion rate with the inhibitor is 0.918 mm/yr, which is an 80.3% reduction compared to the 4.667 mm/yr observed without the inhibitor.

Table 3: Percentage Reduction in corrosion rate of mild steel specimen with and without inhibitor.

HCl Concentration **(mol/dm³)**	Without Inhibitor (mm/yr)	With Inhibitor (mm/yr)	Reduction (%)
0.47	0.754	0.090	88.07
0.10	1.751	0.237	86.47
1.43	2.869	0.438	84.74
1.91	3.839	0.660	82.81
2.39	4.667	0.918	80.33

From the above table, it was observed that the Gmelina leaf inhibitor provides significant protection across all concentrations of HCl, with inhibition efficiency between 80% and 88%. The highest efficiency is observed at the lowest concentration of HCl (0.47 mol/dm^3), and while the efficiency decreases slightly with higher acid concentrations, it remains above 80% even in the most aggressive environments. The inhibitor shows high efficiency in preventing corrosion across all acid concentrations, with the maximum reduction in corrosion rate reaching almost 90%. The inhibitor performs better at lower concentrations, but still provides considerable protection as the acid concentration increases. The decreasing inhibition efficiency at higher concentrations might be attributed to increased competition between the H$^+$ ions and the inhibitor molecules for adsorption sites on the steel surface. However, even at the highest acid concentration (2.39 mol/dm^3), the inhibitor manages to reduce the corrosion rate significantly, indicating strong protective properties, as shown in the micrograph below (Figure 4 - 7). These results are promising for industries that deal with metal components exposed to acidic environments. The Gmelina leaf inhibitor's ability to drastically reduce corrosion rates suggests that it could be an environmentally friendly and cost-effective alternative to synthetic inhibitors, especially for applications involving mild steel in acidic conditions.

3.3 Microstructural Analysis

The micrographs of the mild steel with lowest (0.47mol/dm^3) and highest (2.39mol/dm^3) acid concentration in the absence and presence of inhibitor, was observed. The results are shown below,

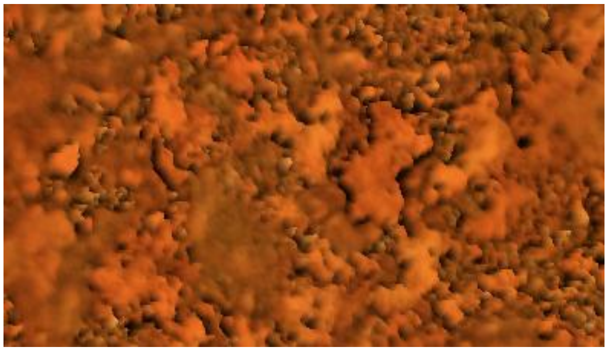


Figure 4: *Mild steel at 0.47mol/dm^3 without inhibitor*

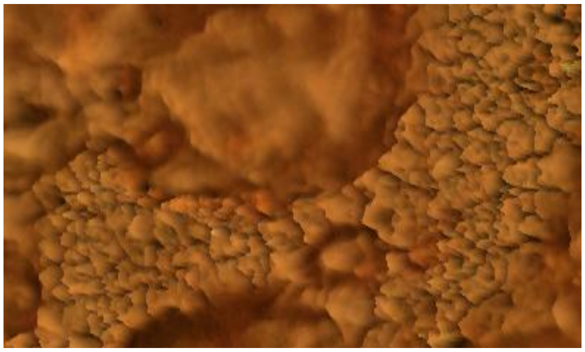


Figure 5: *Mild steel at 2.39mol/dm^3 without inhibitor*

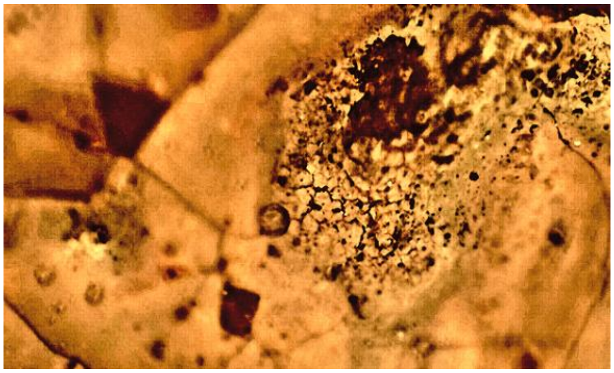


Figure 6: *Mild steel at 0.47mol/dm^3 with inhibitor*

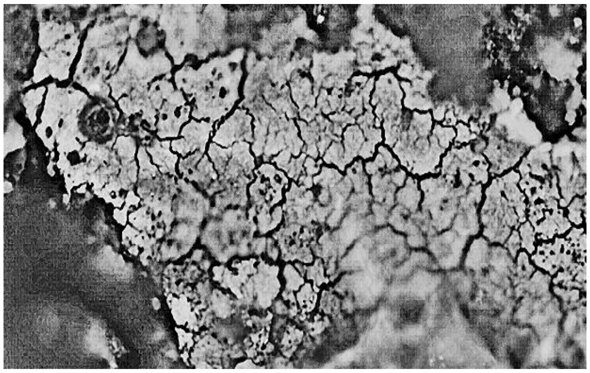


Figure 7: *Mild steel at 2.39mol/dm^3 with inhibitor*

4. CONCLUSION

This research demonstrates that the Gmelina leaf extract acts as an effective green corrosion inhibitor for mild steel when submerged in various concentrations of hydrochloric acid (HCl). The experimental results indicates that without the inhibitor, the corrosion rate of mild steel increases significantly as the concentration of HCl rises, ranging from 0.754 mm/yr at 0.47 mol/dm³ to 4.667 mm/yr at 2.39 mol/dm³. This illustrates the aggressive nature of the acidic environment and its capability to rapidly deteriorate mild steel. However, in the presence of the inhibitor, the corrosion rate is drastically reduced at all concentrations. The highest inhibition efficiency, approximately 88.07%, is observed at the lowest HCl concentration (0.47 mol/dm³), with the corrosion rate reduced to 0.090 mm/yr. Even at the highest concentration (2.39 mol/dm³), the inhibitor maintains a significant 80.33% reduction in the corrosion rate, bringing it down to 0.918 mm/yr. The Gmelina leaf extract demonstrated high inhibition efficiency, ranging from 80% to 88%, making it a promising environmentally friendly alternative to synthetic corrosion inhibitors for industrial applications. Its effectiveness is attributed to the formation of a protective layer on the mild steel surface, which limits metal interaction with the corrosive environment. Therefore, the use of Gmelina leaf extract as a green corrosion inhibitor offers substantial protection for mild steel in acidic environments, making it a viable solution for industries looking for cost-effective and sustainable corrosion prevention methods. Further investigation into its mechanism of action and scalability in industrial applications could broaden its usage.

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