

Performance Evaluation of *Azadirachta indica* as a Corrosion Inhibitor on Mild Steel

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Abstract

This study explores the performance evaluation of *Azadirachta indica* (Neem) leaf extract as a corrosion inhibitor for mild steel in 1 M H₂SO₄. The *Azadirachta indica* (Neem) leaves were sourced at the University of Nigeria, Nsukka. The leaves were prepared using extraction method. The leaf extract was subjected to metallurgical analysis such as phytochemical, pH where the values were determined, Fourier Transform Infrared Spectroscopy (FTIR) analysis was used to determine the functional groups that are associated the extract. The Spark Analytical instrument was used to determine the chemical composition of the mild steel. The mild steel samples were subjected to further analyses through the use of scanning electron microscope (SEM) attached Energy Dispersive Spectroscopy (EDX). This analytical technique was used to determine the morphology and elemental wt% in the sample. The X-ray diffraction technique was used to determine the crystal structures. The weight loss measurement experiment was performed for 240 hours because it gives a clear, measurable corrosion signal, reflects realistic industrial exposure, and aligns with standard practices in the field, making the results both reliable and comparable to existing research. The results revealed that the extract significantly decreases corrosion, with inhibition efficiencies of up to 64.58% at 10 ml and 98.46% at 30 ml of H₂SO₄ concentration. The extract shows high inhibition efficiency, reaching up to 98.46% at a H₂SO₄ concentration of 30 ml. The Fourier Transform Infrared Spectroscopy (FTIR) analysis reveals the presence of Hydroxyl (OH) groups, Carbonyl (C=O), Amines (N-H) groups, and Aromatic (C=C) in the protective film formed by the leaf extract. The crystalline structure revealed by X-ray Diffraction (XRD) analysis includes peaks that correspond to many substances, including Fe(MgSO₄), FeS₂, Fe(ZnSO₄), CaCO₃, Fe₂O₃, and other compounds. According to the Scanning Electron Microscopy (SEM) with Energy Dispersive Spectroscopy (EDX) analysis, the examined samples' shape and elemental weight (%) concentration are revealed. The presence of some compounds, such as Alkaloids (0.6%), flavonoids (5.8%), saponins (1.5%), tannins (3.6%), and phenols (7.8%) was confirmed by the phytochemical analysis. The leaf extract and 1M of H₂SO₄ were tested for acidity using a pH meter. According to the study, the leaf extract of *Azadirachta indica* shows promise as an eco-friendly corrosion inhibitor for mild steel in acidic environments, providing a possible industrial solution. The phytochemicals present provided the protective coating that forms on the mild steel surface, as the extract functions as a mixed-type inhibitor. The study shows how *Azadirachta indica* leaf extract can be used to prevent mild steel from corroding in 1M H₂SO₄ with respect to time and increasing concentration; the extract's inhibitory action improves greatly and better; the 30 ml concentration showed the maximum inhibition efficiency (%IE). According to these results, the leaf extract of *Azadirachta indica* shows promise as a natural corrosion inhibitor for mild steel in acidic conditions.

Keywords: Acidic environment, *Azadirachta indica*, Deterioration prevention, Leaf Extract, Mild steel.

1.0 Introduction

In numerous industries, including the production of chemicals, automobiles, and infrastructure, metal corrosion is a significant problem. Mild steel is widely used because it is inexpensive and simple to produce. It is susceptible to corrosion in acidic environments, such as those present in the production and storage of petrochemicals. One efficient method of reducing corrosion is to use corrosion inhibitors. However, many of the traditional corrosion inhibitors are hazardous and detrimental to the environment. Consequently, research on environmentally acceptable corrosion inhibitors are becoming more popular and effective. Several plant extracts have been studied and investigated recently for their ability to reduce corrosion. *Azadirachta indica* leaf extract, for instance, has been shown to prevent mild steel corrosion in H₂SO₄ solution. [1]. It was revealed that mild steel would not corrode in an H₂SO₄ solution when a leaf extract from *Acacia nilotica* was used as a corrosion inhibitor. [1], [2]. *Ocimum basilicum* and *Murraya koenigii* are among the other plant extracts investigated by [3-6]. The corrosion inhibition mechanism of plant extracts are attributed to phytochemicals such as phenolic acids, flavonoids, and alkaloids. These materials have the ability to form a barrier that stops corrosion by forming a thin film on the surface of the metal surface. [7-9]. Corrosion, which

is caused by the materials' interactions with their surroundings, is the spontaneous degradation of materials, particularly metals. Acids, moisture, oxygen, and other corrosive materials can speed up the process. "Corrosion" refers to the slow disintegration or deterioration of materials.

The irreversible degradation and destruction of steel material and its basic characteristics due to the surface's chemical or electrochemical reactivity to external elements, including oxygen, moisture, and acids, is another way for expressing it. Iron and steel are examples of more specialist metals that are typically described using this particular expression. Chemical reactions as well as additional interactions between a substance and its surroundings, such as those involving bacteria, dirt, hydrogen, and oxygen, can cause corrosion. One popular and obvious form of corrosion that can lead to several dangerous problems and situations is rust, which is produced when iron or steel breaks down in the presence of air and water. Metals and other materials may also corrode if subjected to high stress or pressure [10]. Iron, zinc, and other metals with higher reactivity corrode more easily than metals with lower reactivity, such as gold, platinum, and palladium. The reactivity series' proclivity to oxidise decreases with depth (oxidation potentials are very low). Plant Extracts are a variety of plant extracts, such as those derived from green tea, neem, and aloe vera. These types of green leaves have shown encouraging results in terms of their ability to suppress corrosion. The organic components of these natural extracts can form protective coatings on metal surfaces. As green corrosion inhibitors, biopolymers made from renewable resources, including starch and chitosan, are being studied. These materials can attach themselves to metal surfaces and form an impermeable barrier to stop corrosion. Some of these materials are formed into liquids, which include some ionic liquids, which have been categorised as green inhibitors due to their low toxicity and non-volatility. They can successfully resist rusting under certain situations.

Green inhibitors are designed to have the fewest possible adverse effects on the environment. They reduce the period that inhibitor residues are present in ecosystems because they biodegrade frequently. Because many green inhibitors are sourced from renewable resources like plants, they are more sustainable than inhibitors based on non-renewable or harmful elements. Green inhibitors often pose fewer risks to humans and ecosystems than standard inhibitors do, allaying concerns about health and safety. Green corrosion inhibitors are used in many different industries, such as transportation, oil and gas, construction, and the maritime sector. They are applied in a variety of settings to prevent corrosion in metal equipment, pipes, and buildings. The primary objectives of the current research are to discover new green inhibitors, enhance formulations, and understand the mechanisms underlying their actions. The goal is to provide effective and financially viable replacements for various corrosion conditions.

2.0 Materials and Methods

2.1 Materials

The Mild steel materials was obtained at the Forge and Fabrication Shop of the Ajaokuta Steel Company Limited while the sample was analyzed at the Foundry Shop using the Spark analytical instruments. The Azadirachta indica leaves were sourced at the University of Nigeria, Nsukka. The chemical H_2SO_4 used was obtained at Joe Chem, Chemical Shop, Nsukka, Enugu State, Nigeria.

2.2 Method

A steel sheet of thickness of 4cm x 5cm x 0.6cm was used for this investigation. A small hole of 3mm was drilled at the top of the coupons for proper handling and suspension of the coupons in the solution of H_2SO_4 and the leaf extract. The specimen were descaled, degreased, clean and dried and store in a desiccator. The extract for the experiments was prepared at the Metallurgical and Materials Engineering Laboratory, University of Nigeria, Nsukka as shown in[11] . Each coupon was polished using different grades of silicon carbide impregnated emery paper of 120, 400, 800 and 1000 grits. The coupons were weight using a digital weighing balance. The weighed coupons were immersed in each of the beakers containing 1M H_2SO_4 solution with and without plant extract of 10ml, 20ml and 30ml for a maximums period of 240 hours. The weight loss measurements were carried out after the immersion period of every 24hours with 1M of H_2SO_4 solution and the addition of varied extract. In addition, these processes were repeated until the total results were achieved. The corrosion rates of the mild steel in 1M of H_2SO_4 in the absence and presence of Azadirachta indica were determined at room temperature The equation for corrosion rate is expressed by[12]. Fresh healthy leaves of Azadirachta indica were obtained in a natural condition. The leaf samples washed and were dried for 3days under room temperature to remove water. Four (4) kg of the leaves were separated into different containers for easier handling. The investigated plant elements were dissolved and contained using the solvents. The extract was created because of the solution. The solvent was then removed, and the plant extract was isolated, If the extract was used in the food industry, it is not necessary to remove it. If not, a second stage of separation could be employed to produce a dry extract. [13]. The dried leaves were processed in a Vitamix Series 750 Blende The leaves were ground up, to 1000g of plant material which was combined with 2.0L of 100% methanol (Me

OH). Agitation techniques were used to remove the dry components for 48 hours at room temperature. The methanol was filtered, and the filtrate was then heated to 40°C in a rotary evaporator while being vacuumed to produce aqueous extracts.[14]

2.2.1 Spark Analysis

The samples were sourced from the Forge and fabrication shop of the Ajaokuta Steel Company Limited, Nigeria. The sample was subjected to a SPECTRO Analytical Instrument known as Spark Analyzer, where the chemical compositions of the materials were determined. Composition of the materials. The set up for this study consists of coupons of mild steel, each measuring 3cm by 3cm and having a density of 7.85 g/cm³.

2.3 Phytochemical Analysis

The leaf extract was subjected to phytochemical analysis, this analysis contributes to determining the quantitative and qualitative tests which are derived from plants and frequently possess a variety of bioactive properties. This analysis is essential to corrosion research when examining natural plant extracts as possible corrosion inhibitors. The exact compounds, which provide a plant extract its protective qualities, can be identified by phytochemical analysis, which also analyses the extract's capacity to prevent corrosion. Plants produce numerous compounds, such as alkaloids, flavonoids, tannins, saponins, and phenolics. Many of these materials can interact with metal surfaces to create protective coatings that can stop or lessen corrosion.[15]. When testing plant extract, such as *Azadirachta indica*, for this research goal, the procedure can identify which of the extract's contents are active in preventing mild steel from corroding in acidic environments. The presence of tannins in leaf extract indicates a combination with metal to produce metal ions to create complexes that cover the metal surface and inhibit further corrosive agent interaction. [16]. As antioxidants, flavonoids and phenolics may neutralise corrosive agents such as free radicals or acidic ions before they can attack the metal.[17].

2.4 Weight Loss Measurement

Ninety-six (96) mild steel coupons were used for this research investigation. The weight loss measurements were taken in solutions of 1mol of H₂SO₄, with and without the addition of 10-30 ml of plant extract as a corrosion inhibitor. The mild steel coupons were square-shaped 3cm by 3cm in size. Every sample was weighed using an electric scale, and the plastic cups into which the coupons are placed were given unique labels. Each plastic cup had 50 ml of the appropriate acid solution when the specimen was placed inside, and this volume was maintained throughout. To act as the control in the conditions, the sample coupons were cleaned and submerged in an acidic solution. The remaining clean coupons were submerged in the solution at varied inhibitor concentrations (10ml, 20ml, and 30ml). The samples were taken out of the test solution, cleaned properly to remove any corroded materials. The prepared samples were dipped in acetone, dried, and weighed again to ascertain the parameters of weight loss. The weight loss *W* (g), the corrosion rate *Cr* (mm/y), and the percentage inhibition efficiency (I.E) were all calculated from the observed data. Equation 1

$$W = W_i - W_f \quad (1)$$

This equation was used to compute the weight loss (*W*), where *W_i* and *W_f* respectively, represent the initial and final weights. The specimens were measured with the use of an electronic weighing balance. The specimen was suspended in the acidic solution using a thread. The experimental readings were taken following the experimental design and the technique. The experiments were performed for 240 hours, with the initial hours of 48. The interval of hours between each experiment was 48 hours. Which was designed as 48, 96, 144, 192, and 240. The weight loss analyses were computed using the collected data.

2.5 Corrosion Rate

The weight loss of coupons at room temperature, therefore, at a certain concentration and various immersion times, can be used to compute the mild steel corrosion rate. The formula used in calculating the Corrosion rate for each case during the experiment is known as equation (2).

$$\text{Corrosion rate} = \frac{K \times W}{A \times T \times D} \quad (\text{mm}/\text{yr}) \quad (2)$$

The constant *k* is dependent on the unit. The exposure period, *T*, is expressed in hours to the closest 0.01 hour, while the area, *A*, is expressed in cm² to the closest 0.01 cm². To the nearest milligram, *W* represents the mass loss in grams. In g/cm³, *D* is the density. The corrosion rate with the correct value of *K* can be calculated using a variety of units by expressing corrosion rates using the *T*, *A*, *W*, and *D* units mentioned above. where *A* is the surface area of the exposed metal (11 cm²), *t* is the exposure time (hours), *D* is the density of mild steel (7.8 g/cm³), *W* is the weight lost over time as a result of mild steel corrosion (g), and *K* is a constant determined by 87.6 x 10³.

2.6 Corrosion Inhibition Efficiency

The percentage of inhibitor efficiency (I.E.) was computed using equation (3);

$$\text{Inhibitor Efficiency (\% I.E.)} = \frac{CR_u - CR_i}{CR_u} \times 100 \quad (3)$$

Where: % I.E = Percentage inhibitor efficiency

CR_u = The rate of corrosion of the uncontrolled system

CR_i = the rate of corrosion of the inhibited system,

= where % I.E. = Percentage Inhibitor Efficiency

During the experiment, determining the inhibitor efficiency (%I. E.) for every scenario

2.7 Surface Coverage

The amount that the inhibitor molecules covered the mild steel surface at room temperature and at different immersion periods was ascertained using Equation (4).

$$H = \frac{W_0 - W_1}{W_0} \quad (4)$$

3.0 Results and discussion

3.1 Spark analysis

The spark test confirmed that the sample was mild steel, characterized by a carbon content of 0.2%. This low carbon content was in line with mild steel's characteristics, which include its malleability, ductility, and comparatively lower hardness when compared to steels with higher carbon content. The chemical composition of mild steel, including the percentage of each element present. The chemical composition of mild steel is a key factor in determining its characteristics and behaviour in various situations.[18]. Table 1 indicates that, among other elements, the composition of mild steel contains manganese (0.58%) and iron (< 96.081%). The strength, resistance to corrosion, and weldability of the steel can all be affected by these factors. Knowing the chemical composition is crucial to choosing the appropriate material for a certain application [19].

Table 1: Chemical Compositions of Mild Steel

Elements	%C	%	% C	%Mn	%S	% P	%Cr	%Ni	%Cr	%Mo	%Al	%Cu	%Co	%V	%Ti
(%)	0.2	0.58	0.2	0.58	0.0013	0.0074	0.051	0.034	0.1	0.0069	0.129	0.54	0.013	<0.0010	0.0021
	%W	%Pb	%W	%Mg	% B	%Sn	%Zn	%As	%Bi	%Ca	%Ce	%Zr	%La	Nb	%Fe
	0.0094	0.038	0.0094	0.014	0.0016	0.0045	>0.036	0.0036	<0.0020	>0.016	0.025	<0.0015	0.062	<0.0040	<96.081

3.2 Phytochemicals Analysis

The leaf extract was subjected to both quantitative and qualitative testing to identify the phytochemicals. The phytochemical makeup of Azadirachta indica (neem) is rich in many bioactive compounds, which enhance its medicinal properties. Alkaloids are widely recognised for their antibacterial and anti-inflammatory properties, as well as other medicinal benefits. Their presence nevertheless increases the plant's overall bioactivity despite the very small percentage. Table 2 lists the phytochemicals that were present in the extract. The final percentage was 0.6%. Plants need flavonoids, which are potent antioxidants, to protect them from oxidative damage. Because they also contain antibacterial and anti-inflammatory properties, they are good for human health. The result was 5.8%. Research has indicated that Azadirachta indica has a high flavonoid content. The presence of saponins improves Azadirachta indica's medicinal benefits because they have been demonstrated to possess antibacterial, anti-inflammatory, and antioxidant capabilities. The value of saponins was 1.5%. The tannins are used in traditional medicine because of their well-known astringent and antioxidant properties, as well as their antibacterial and anti-inflammatory properties. The value of the tannins was 3.6%.[20]. Plants are shielded from oxidative damage by potent antioxidants called phenolic compounds, which also contain antibacterial and anti-inflammatory qualities that benefit human health. The obtained result was 7.8% [21]. According to recent research, Azadirachta indica contains similar amounts of phytochemicals. Azadirachta indica, for example, was reported to have a high flavonoid content (13.80%) and alkaloids (10.67%) by [22-23].

A different study [20] found that the leaf extracts of Azadirachta indica contained alkaloids, flavonoids, terpenoids, glycosides, phenols, steroids, tannins, and saponins. Azadirachta indica is a useful plant for both traditional and modern medicine because of these phytochemicals, which also contribute plant's therapeutic properties.

Table 2: Essential phytochemicals in Azadirachta indica leaf extract

Phytochemical	Alkaloids (%)	Flavonoids (%)	Saponins (%)	Tannins (%)	Phenol (%)
Composition (mg/L)	0.6	5.8	1.5	3.6	7.8

3.3 pH Value

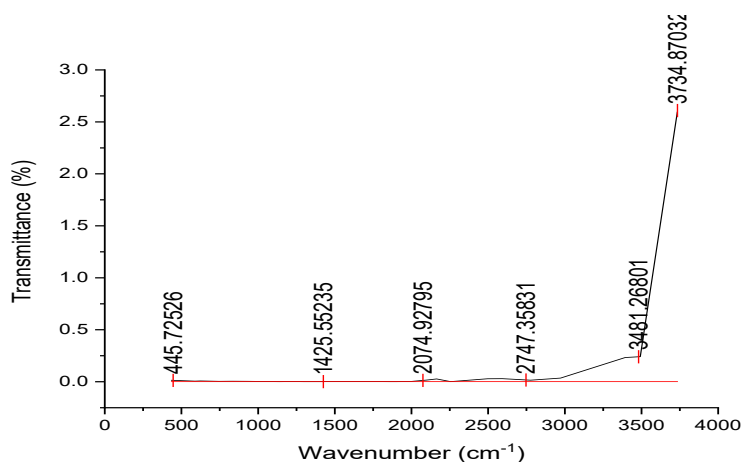
The pH values of 1M of H₂SO₄ and Azadirachta indica extract were 1.0 and 0.5, respectively, as indicated in Table 3. These pH readings indicate that the sulphuric acid solution and the extract are both acidic. From 0 to 14, the pH scale indicates how basic or acidic a solution is. Despite being neutral, a pH of 7 is associated with acidity and basicity. Because Azadirachta indica contains specific phytochemicals like flavonoids, tannins, or phenolic components, the extract has an acidic pH of 1.0. With a pH of 0.5 for 1M of H₂SO₄, a strong acidic character is implied due to the high sulphuric acid concentration. Azadirachta indica extract's potential medical benefits, including its antibacterial and antioxidant qualities, may be due to its acidic composition. These drugs' stability, effectiveness, and interactions with other substances or biological systems may all be impacted by their pH levels. [24].

Table 3: The pH values

pH	Azadirachta indica extract	1mol of H ₂ SO ₄
Value	1.0	0.5

3.4 Fourier Transform Infrared Spectroscopy (FTIR)

Figure 1 shows the FTIR of Azadirachta indica extract. FTIR analysis of the protective film formed by Azadirachta indica leaf extract in 1M H₂SO₄ showed hydroxyl, carbonyl, amine, sulfonate, sulfate, aromatic, and aliphatic groups. By generating stable and protective complexes that prevent corrosion, these functional groups indicate that the resulting extract compounds adsorbed into the mild steel surface through hydrophobic interactions, π - π stacking, electrostatic interactions, and hydrogen bonding.

**Figure 1 FTIR of Azadirachta indica extract**

The FT-IR identified several key components that created a protective thin film layer that stopped the release of hydrogen ions (H⁺) in the presence of acid, including C-C stretching, aromatic compounds, N-H₂ symmetric stretching vibration, N-H symmetric stretching, and others. The functional groups identified by FTIR analysis of the protective film formed by leaf extract in H₂SO₄. The hydroxyl (OH) groups, found in alcohols, phenols, and carboxylic acids, are known to possess corrosion inhibition properties by forming hydrogen bonds with the metal surface or donating electrons to the metal ions. By coordinating with metal ions or establishing stable complexes with the metal surface, the carbonyl (C=O) groups present in aldehydes, ketones, carboxylic acids, esters, and amides are known to have corrosion-inhibiting qualities. [25]. Through coordination with metal ions or the formation of stable complexes with the metal surface, the amines (N-H) groups present in amines, amides, and anilines are known to have corrosion prevention abilities.[26]. By giving electrons to the metal ions or adhering to the metal surface via π - π stacking, the aromatic (C=C) groups present in aromatic compounds like phenols and anilines are known to have corrosion-inhibiting qualities [27].

3.5 Weight Loss Measurement

The weight loss assessment is a widely used method for determining the rate of metal corrosion. The corrosion rate in this study was measured in millimetres per year, or mm/yr, for different leaf extract

concentrations (10 ml, 20ml and 30 ml). The corrosion rate steadily decreases at all leaf extract concentrations, indicating that *Azadirachta indica* prevents mild steel from corroding. The higher corrosion rate in the control sample relative to the samples that had leaf extract added shows how effective the extract is as a corrosion inhibitor. The corrosion rate sharply decreases with increasing leaf extract concentration; 30 ml exhibits the lowest corrosion rate[28]. The control sample's gradual corrosion shows a natural decrease in corrosion rate brought on by the metal's reaction with the acid. As the leaf extract concentration rises, the corrosion rate dramatically drops at 10 ml, 20 ml, and 30 ml, suggesting that the extract prevents mild steel from corroding.[29].

Table 4 Weight Loss Measurement

Time(hrs)	Corrosion rate (mm/yr.)	Corrosion rate (mm/yr.)	Corrosion rate (mm/yr.)	Corrosion rate (mm/yr.)
	Control	10ml	20ml	30ml
48	0.00923	0.0071	0.00568	0.00155
96	0.00701	0.00542	0.00381	0.000975
144	0.00508	0.00323	0.00192	0.000517
192	0.00325	0.00199	0.000881	0.000307
240	0.00153	0.00087	0.000462	0.000154

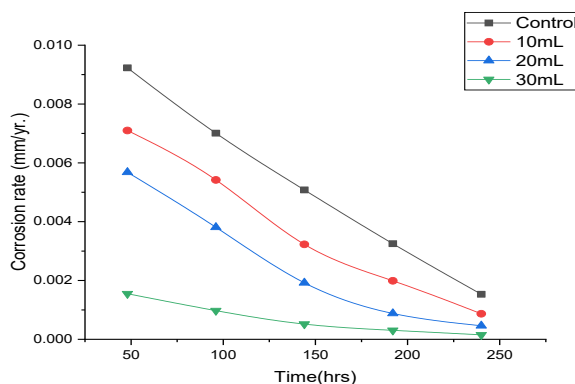


Figure 6: Corrosion rate (mm/yr) vs Time (hr)

3.7 Inhibition Efficiency (%IE)

The corrosion rates of the control sample and the sample containing the leaf extract were used to compute the inhibitory efficiency (%IE). For all leaf extract concentrations, the percentage IE rises with time, suggesting that the extract's inhibitory action gets better with time. The inhibitory activity is concentration-dependent since the %IE increases as the leaf extract concentration does. The study found that extracts from *Azadirachta indica* significantly reduce mild steel corrosion in acidic environments. At dosages of 10 ml to 30 ml, the inhibitory effectiveness ranges from 50.43% to 94.26%. According to the [30] study, the effectiveness of inhibition increases with time and inhibitor concentration. The leaf extract of *Azadirachta indica* shows promise as a mild steel corrosion inhibitor in acidic conditions (Table 5). Inhibitory efficiency increases with both concentration and time, with the maximum value observed at 30 ml concentration. These conclusions are supported by recent research showing that *Azadirachta indica* extracts are efficient at preventing rusting.[31-33].

Table 5 Mild steel inhibition efficiency (%IE) during 240 hours using 1.0 mol of H₂SO₄ and 0.7 g of the leaf extract.

Time (hrs)	Inhibition Efficiency(%IE) 10ml	Inhibition Efficiency(%IE) 20ml	Inhibition Efficiency(%IE) 30ml
48	50.43	70.63	89.22
96	60.77	77.83	91.37
144	65.72	78.76	92.36
192	70.82	80.37	93.96
240	75.68	87.8	94.26

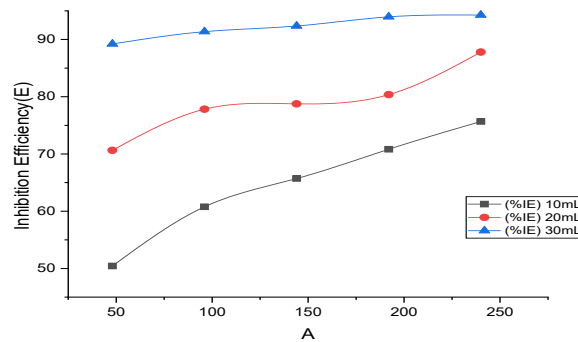


Figure 6: Inhibition efficiency (IE%) for 240 hours with inhibitor concentration (ml)

3.5 Scanning Electron Microscopy (SEM)/Energy Dispersive Spectroscopy (EDS)

SEM/EDX Results for 0.9g of *Azadirachta indica* Leaf Extract on Mild Steel in 10ml and 30ml of H_2SO_4 : A Comprehensive Comparison. Figure 6 displays the EDX of *Azadirachta indica* extract at 1mol H_2SO_4 10ml, while Plate 1 displays the SEM of the extract at 0.9 H_2SO_4 10ml.[34]. SEM and EDS examined the surface appearance and composition of mild steel samples treated with *Azadirachta indica* extract. The extract reduced corrosion by forming a protective coating on the metal surface, according to the results.[34] SEM and EDS examined the surface morphology and composition of steel rebars treated with *Azadirachta indica* extract. The results revealed that the extract resisted corrosion and produced a protective layer on the metal surface.

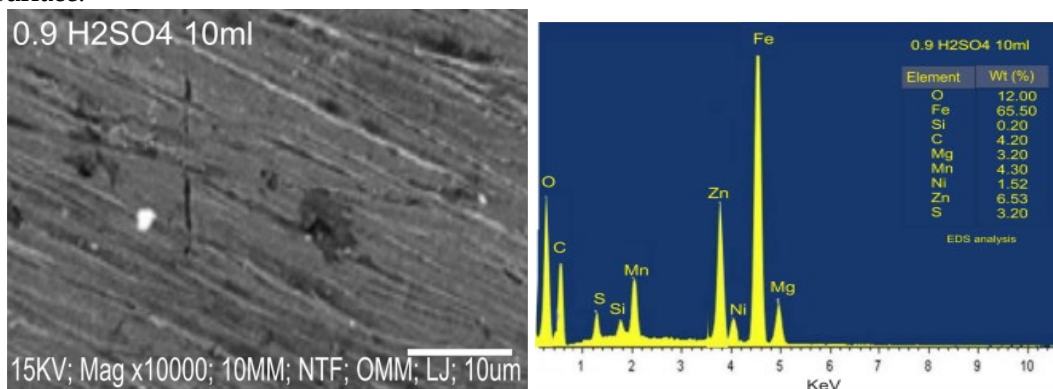


Plate 1 SEM of *Azadirachta indica* extract at 0.9g in 10ml of $1MH_2SO_4$

Figure 7 EDX of *Azadirachta indica* extract 0.9g in 10ml of $1M H_2SO_4$

SEM was used to analyse the surface morphology of mild steel samples treated with *Azadirachta indica* extract in the study by[35]. According to the results, the surface was consistently smooth and successfully prevented corrosion. A thin, homogeneous coating was applied to mild steel. Less pitting and cracking indicate less localised deterioration. The protective coating on the surface lowered the mild steel. Scanning electron microscopy was used to examine the surface morphology of steel rebar's treated with *Azadirachta indica* extract. [36]. This study examined the effectiveness of *Azadirachta indica* extract in preventing mild steel corrosion. [37]. The findings showed that the metal surface developed a thin layer that acted as a barrier against corrosion. [38] used SEM to evaluate the surface morphology of mild steel samples that had been treated with plant extracts. The results showed the creation of a thin coating on the metal surface, indicating effective inhibition of corrosion.[38]. SEM was used to analyse the surface morphology of mild steel samples treated with plant extracts. The results showed the formation of a protective layer on the metal surface, indicating effective inhibition of corrosion. [38]. The research included an investigation into how well *Azadirachta indica* extract prevented mild steel from corroding. The elemental weight (%) composition was determined by EDX analysis, with particular attention paid to 65.50%Fe, 12 %O, 4.20%C, 3.20%S, 3.20%Mg, and 4.30%. Plate 2 and Figure 8 display the *Azadirachta indica* extract's SEM and EDX at 0.9g in 30ml of $1M H_2SO_4$ respectively.[39]. In this study, EDX was used to analyse the elemental composition of mild steel samples treated with *Azadirachta indica* extract. The findings included a number of elements, such as Fe, O, C, and others. [39]. In this work, EDX was used to analyse the elemental composition of steel rebars treated with *Azadirachta indica* extract. The findings included several elements, such as Fe, O, C, and others [39].

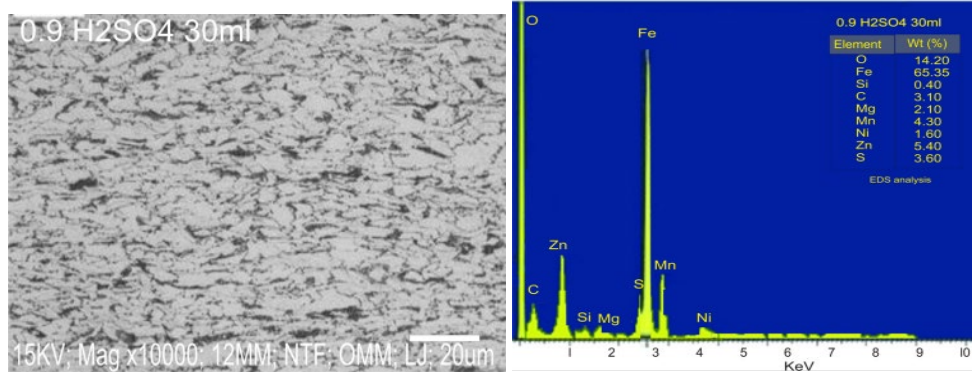


Plate 2 SEM of Azadirachta indica extract at 0.9g in 30ml of 1M₂SO₄ 10ml

Figure 8 EDX of Azadirachta indica extract 0.9g in 30ml H₂SO₄

A smooth, homogeneous surface morphology suggests good corrosion inhibition, according to SEM analysis. The mild steel even has a layer of protection. Reduced pits and fissures indicate less localised corrosion and a protective layer that lowers the reactivity of mild steel. The elemental weight (%) with 65.35%Fe, 12.20%O, 0.20%C, 3.2%S, 4.3%Mg, and 4.30%Mg was found by EDX analysis. The carbon content of the 10 ml solution is larger (4.20%) than that of the 30 ml solution (0.20%). [39]. Compared to 10ml (3.20%), there was a sign of increased Mn in 30ml (4.3%). The presence of multiple ingredients in the extracts demonstrates various methods and levels of corrosion inhibition efficiency. The SEM/EDX analysis shows that the leaf extract effectively reduces corrosion and pit formation on mild steel in both 10 ml and 30 ml H₂SO₄ by forming a protective layer. [40].

3.6 X-ray Diffraction (XRD)

Differences in the crystalline structure and corrosion inhibition characteristics of leaf extract as a green corrosion inhibitor for mild steel in 10ml, 20ml and 30Ll H₂SO₄ are revealed by XRD analysis. The presence of related compounds, including Fe(MgSO₄), FeS₂, Fe(ZnSO₄), CaCO₃, Fe₂O₃, CO₂CrO₄, Mn (Fe)SiO₄, and Al(Mn, Fe), was indicated by the strong peaks created by the crystalline structure in 1M H₂SO₄. [41-44].

By creating a protective crystalline layer, the corrosion inhibition lowered the rate of corrosion. The sulphur compounds showed that a sulphide layer had formed, improving protection. An investigation into the effectiveness of Azadirachta indica extracts as mild steel corrosion inhibitors in acidic environments reveals that the extracts work well in H₂SO₄ solutions, with the efficacy of inhibition rising with temperature and extract content. According to the study, a protective coating can be created by phytochemical components chemically adhering to the metal surface. [45-47]. Sharp peaks developed in 30 ml in 1M H₂SO₄, suggesting the existence of a crystalline structure. FeS₂, SiO₂ (ZnSO₄), Al (Mn, Fe), Ca (Mn), Fe₂O₃, Zn (Fe) SiO₄, and MgSO₄ are the equivalent peaks. An amorphous structure with no distinguishable peaks was visible in a broad halo. [48-50]. An amorphous phase resulted from the crystalline structure being broken by the increased acidity. Sulfur's presence indicated the existence of a disordered form, which aided in the protective process. The leaf extract often produces a crystalline protective layer when 1mol H₂SO₄ is present in 10ml of the extract, whereas in 1mol H₂SO₄, it forms an amorphous layer. Both successfully stop corrosion, but they react differently to varying acidity levels. The XRD of Azadirachta indica extract at 0.9 M H₂SO₄, 10ml and 0.9 M H₂SO₄, 30ml are displayed in Figures 8 and 9, respectively. By creating protective coatings on metal surfaces, Azadirachta indica extract has been shown in experiments to lower corrosion rates in acidic environments. The extract's ability to block is due to the substances it contains, such as tannins and trisulfides, adhering to the metal surface. The extract of Azadirachta indica inhibits corrosion in H₂SO₄ solutions, and its efficacy increases with extract concentration. [51-52]. The components of the extract create a protective coating by adhering to the metal surface. The structure of the protective layer may be upset by increased acidity, which could impact the layer's ability to suppress corrosion [53-54].

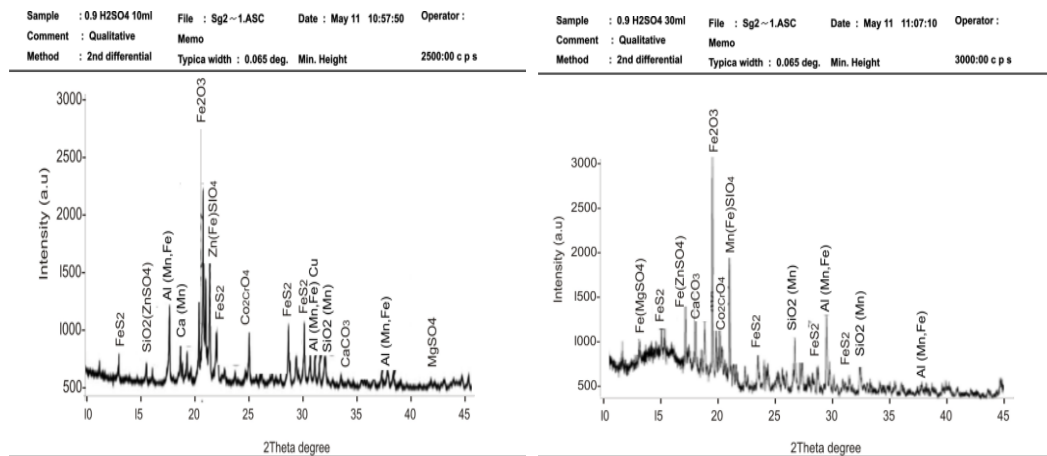


Figure 8 XRD of Azadirachta indica extract at 0.9 H₂SO₄ 10ml **Figure 9 XRD of Azadirachta indica extract at 0.9 H₂SO₄ 30ml**

4.0 Conclusion

This study investigates the possibility of using Azadirachta indica (neem) leaf extract to prevent mild steel from corroding in acidic conditions. Specifically, the extracts from 10 ml, 20 ml, and 30 ml were immersed in 1M H₂SO₄. Among the constituents that constitute mild steel are carbon (0.2%), manganese (0.58%), and iron (less than 96.081%). These components may have an impact on the steel's weldability, strength, and resistance to corrosion.

1. The result revealed an inhibitory efficiency of up to 64.58% at 10 ml and 98.46% at 30 ml of H₂SO₄ concentration; Azadirachta indica leaf extract decreases the corrosion rate.
2. The phytochemical analysis indicates that the extract has an inhibiting effect because it contains alkaloids, flavonoids, saponins, tannins, and phenols.
3. The FTIR Analysis shows that the leaf extract is a protective film that comprises hydroxyl (OH), carbonyl (C=O), amine (N-H), and aromatic (C=C) groups
- 4 The XRD Analysis revealed the presence of some compounds such as Fe (MgSO₄), FeS₂, Fe (ZnSO₄), CaCO₃, Fe₂O₃, and other substances are symbolised by peaks in the crystalline structure of the protective coating.
- 5 The SEM/EDX Analysis show that there was a protective coating that was formed on the mild steel surface, as shown by the morphology and elemental weight (%) concentration of the examined samples.
6. The measurement of the weight Loss result shows that the corrosion rate decreases as the leaf extract concentration increased, with the 30 ml concentration exhibiting the lowest corrosion rate.
7. The inhibition efficiency (%IE) revealed that the inhibitive action was concentration-dependent and improved with time as the leaf extract concentration increased.
8. The inhibitive effect indicates that at concentrations of 10 ml to 30 ml, the extract shows a range of 64.58% to 98.46% inhibition efficiencies versus mild steel corrosion in acidic medium.

According to the study, Azadirachta indica leaf extract shows promise as an eco-friendly corrosion inhibitor for mild steel in acidic environments, providing a possible industrial application option. Because of the phytochemicals present and the protective coating that forms on the mild steel surface, the extract functions as a mixed-type inhibitor. The extract is a good substitute for conventional corrosion inhibitors because its inhibitory action improves with time and concentration. The results indicate that the leaf extract of Azadirachta indica may be a viable industrial solution, providing a safe and efficient means of preventing mild steel from corroding in acidic settings.

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6. Conflict of interest

The authors disclose no conflicts of interest.

7. Authors' Contribution Statement

Ocheri C. Conceptualisation, Methodology, Writing Original Draft, Validation, Funding acquisition review/editing; V.S. Aigbodion Writing original draft and methodology, Supervision; Ameh E.O, Ihebuechukwu C. Ezeaku and Okafor C. A analyzed the data obtained and plotting of all the graphs , Agbo

K.O performed the weight loss analysis and interpretation of the results while Omonigho R.E² was involved in the electrochemical analysis, spark analysis interpretation.

8. Data availability statement

The authors confirm that the data supporting the findings of this study are available within the article.

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