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The Inhibitory Effect of Ethanolic Extract of *Lophira alata* (Ironwood) on the Corrosion of Mild Steel in 5 M Hydrochloric Acid (HCl)

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ABSTRACT
Corrosion inhibition studies were conducted using stem extracts of *Lophira alata* (ironwood) to assess their effect on the corrosion of mild steel in acidic media. The stems were washed, air-dried in the shade, and ground into powder. Ethanol extraction was used to obtain stock solutions from the processed material following standard protocols. The results indicated a reduction in corrosion rate with increasing inhibitor concentration. Inhibition efficiencies of 60% and 55% were observed at 10 mL and 7.5 mL concentrations, respectively, demonstrating that higher concentrations of the stem extract enhance inhibition efficiency. Adsorption isotherm analysis revealed that the Temkin isotherm most accurately described the adsorption process (R2 = 0.988), while the Langmuir model showed a lower correlation (R2 = 0.842). Overall, *Lophira alata* stem extract proved to be an effective inhibitor of mild steel corrosion in hydrochloric acid environments. Achieving 60% inhibition efficiency underscores the potential for significant reductions in maintenance and replacement costs in industries utilizing mild steel, while providing an environmentally friendly alternative to synthetic inhibitors.
Keywords: *Lophira alata* stem (ironwood), mild steel, hydrochloric (HCL), phytochemical screening of extract, extraction process, weight loss,

INTRODUCTION

Corrosion of materials is a significant global issue due to its detrimental impact on the structural integrity of materials. Although research on plant-based inhibitors for corrosion protection is ongoing, a substantial gap remains in understanding their effectiveness in highly concentrated acidic environments, such as 5 M HCl. Addressing this gap is the primary objective of the present investigation. Metallic materials are the most widely used group, particularly in mechanical engineering, transportation, electronics, and construction industries [1,2]. However, the extensive use of metals and alloys is limited by the persistent problem of corrosion [3]. Corrosion has been extensively studied since the industrial revolution in the late eighteenth century [4]. It is defined as the deterioration of metal surfaces due to reactions with the surrounding environment [5]. Corrosion can cause severe damage to metal and alloy structures, resulting in economic losses from repairs, replacements, product losses, safety hazards, and environmental pollution. Consequently, corrosion is an undesirable phenomenon that requires effective prevention [6].

Engineers consistently seek more effective methods to mitigate metal corrosion [7]. Various strategies are available to prevent corrosion and slow its progression, thereby extending the lifespan of metallic and alloy materials. These approaches include the use of corrosion-resistant alloys, cathodic and anodic protection, application of protective coatings (8), and the addition of corrosion inhibitors to the environment (9). Among these, inhibitors are widely adopted due to their ease of application. Many heterocyclic compounds containing oxygen, sulphur, and nitrogen function as effective corrosion inhibitors [10]. Effective inhibitors displace water from the metal surface, interact with anodic and cathodic sites to retard corrosion reactions, and prevent the transport of water and corrosive species [11].However, most conventional inhibitors are expensive, toxic, and non-biodegradable, raising environmental concerns [12]. The hazardous effects of synthetic organic inhibitors [13] and the demand for cost-effective, non-toxic, and eco-friendly alternatives have shifted research focus toward natural products [14]. Plants, due to their complex molecular structures and diverse physical, chemical, and biological properties, are recognized as promising sources of corrosion inhibitors [15]. This study was designed to evaluate the effect of Lophira alata (ironwood) leaf extracts on the corrosion inhibition of mild steel in 5 M and 1 M hydrochloric acid solutions, aiming to expand the beneficial applications of plant extracts. Gravimetric and gasometric methods were employed for the investigation. The economic impact of metallic corrosion is considerable; approximately 5% of an industrialized nation's income is allocated to corrosion prevention and the maintenance or replacement of products lost or contaminated due to corrosion reactions. Globally, the World Corrosion Organization estimates that corrosion costs the world economy approximately 3-4% of the world's GDP annually. These statistics highlight the urgent need for efficient and environmentally sustainable solutions, such as green inhibitors. Common consequences of corrosion include the rusting of automotive body panels, radiators, and exhaust components. Industries rely heavily on metals and alloys, and a significant challenge is protecting these materials from corrosion when exposed to electrolytes, such as acids. Steel is a critical alloy due to its broad industrial applications and low production cost. Corrosion of steel structures results in degradation and eventual failure of components and systems during both manufacturing and service life, prompting extensive research into effective mitigation strategies.

Aims and objectives

1. To determine whether varying concentrations of *Lophira alata* (ironwood) stem extract can achieve a measurable inhibition efficiency of at least 50% on the corrosion of mild steel in acidic media.
2. To determine and confirm the inhibition mechanism of *Lophira alata* extract on mild steel corrosion by evaluating surface coverage and adsorption isotherms.
3. To measure the corrosion rate of mild steel in both the absence and presence of *Lophira alata* extract and assess the statistical significance of observed differences.

LITERATURE REVIEW

The use of corrosion inhibitors is an economical and practical way to combat corrosion of steel parts in acidic environments [16]. Corrosion inhibitors are chemicals, either synthetic or natural, which, when added in small amounts to an environment, decrease the rate of attack by the environment on the metals [17]. Nevertheless, the reputation and use of these synthetic compounds as corrosion inhibitors is diminishing due to strict environmental regulations and health concerns over their toxic effects on man and animals [18,19]. The use of extracts from plant parts as corrosion inhibitors, perhaps, is the answer to all the environmental concerns and fears surrounding synthetic corrosion inhibitors [20,21]. Plant extracts are environmentally friendly phytochemicals with structures similar to those of synthetic corrosion inhibitors. They possess atoms such as oxygen, sulphur, phosphorus, nitrogen, and/or conjugated carbon chains that may contain aromatic rings [22].In a study on the phytochemical screening of *Cucurbita pepo*, the plant's leaves were found to contain phytochemical components rich in heteroatoms, including alkanoïds, tannins, saponins, flavonoids, phenols, steroids, coumarins, reducing sugars, and anthocyanins. A review of the literature indicates that the leaves of this plant have not been studied for their corrosion-inhibitory properties. This paper reports our findings on the use of ethanol extract of the leaves of Cucurbita pepo (CP) (pumpkin) against the corrosion of mild steel in 1.0 M HCL using weight loss and linear polarization measurements.

Cause of Corrosion

In nature, most metals are found in a chemically combined state known as an ore. All the metals except gold, platinum, and silver exist in nature in the form of their oxides, carbonates, sulphides, sulphates, etc. These combined forms of the metals represent their thermodynamically stable state (i.e., the low-energy state). The

metals are extracted from these ores at a high energy cost.
Metals in the uncombined state have higher energy and are unstable. It is their natural tendency to return to the low-energy state, that is, the combined state, by recombining with the elements in the environment. This is the main reason for corrosion (Al-Mhyawi 2020).

Basic process involved in corrosion

The basic process of metallic corrosion in aqueous solution consists of the anodic dissolution of metals and the cathodic reduction of oxidants present in the solution:

$$MM \rightarrow M2\ +(aq)+2e{-}M{-}\ - - - - - - - - - - - - - - - - - anodicoxidation\ \ 2Oxaq{+}2e{-}M \rightarrow 2Red.(e{-}redox)(aq) - - - - - - - - - - - - - - reduction$$

In the formulae, MM is the metal in the state of metallic bonding, M2+aq is the hydrated metal ion in aqueous solution, e-M is the electron in the metal, Oxaq is an oxidant, and 2Red. is a reductant, and e redox is the redox electron in the reductant.

The overall corrosion reaction is then written as follows (David and Williams, 2016): MM + 2Ox(aq) → M2+(aq)+2Red (e- redox)(aq)

These reactions are charge-transfer processes that occur at the interface between the metal and aqueous solution; hence, they depend on the interfacial potential, which corresponds to the electrode potential of metals in electrochemical terms. In physical terms, the electrode potential represents the energy level of electrons, called the Fermi level, in an electrode immersed in an electrolyte.
In practice, for normal metallic corrosion, the cathodic process is the reduction of hydrogen ions and/or oxygen

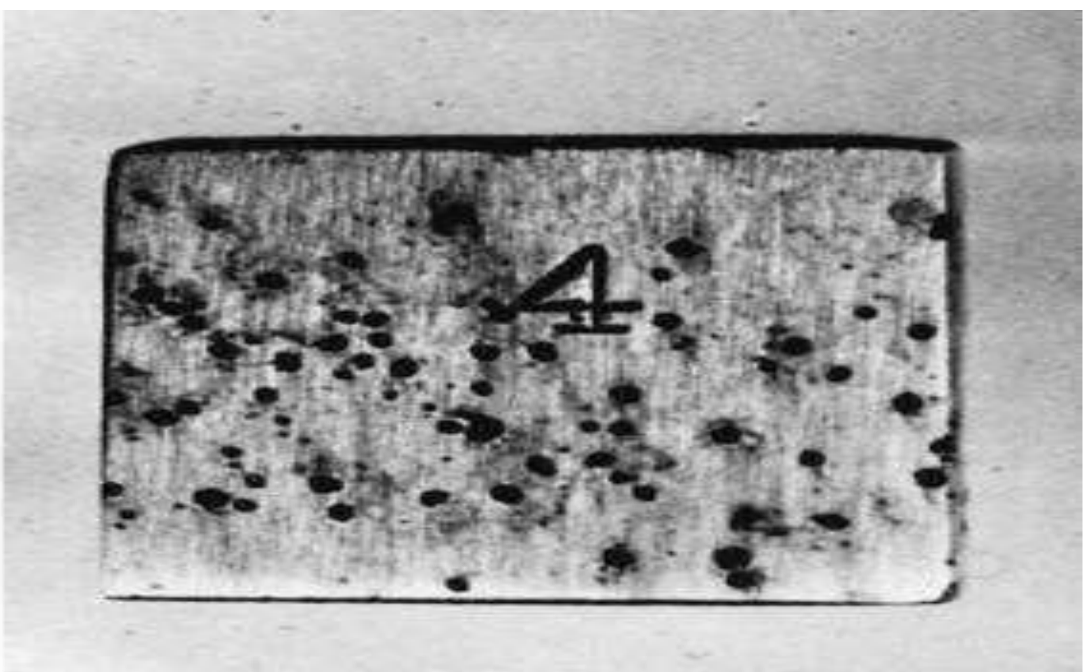


Plate 1: The pitting of a 304 stainless steel plate by an acid-chloride solution

2.1.1 Erosion corrosion

An increase in the rate of corrosion as a result of relative motion of the environment is termed erosion corrosion. This type of corrosion provokes uniform thinning of the metal surface, which is associated with the exposure to a high velocity fluid, which causes the corrosion product to be stripped from the metal surface, resulting in the exposure of the bare metal, which can be corroded again, causing an accelerated attack. This type of corrosion is further exacerbated when fluids contain solid particles that are harder than the metal surface, which hit the metal constantly[25,26].

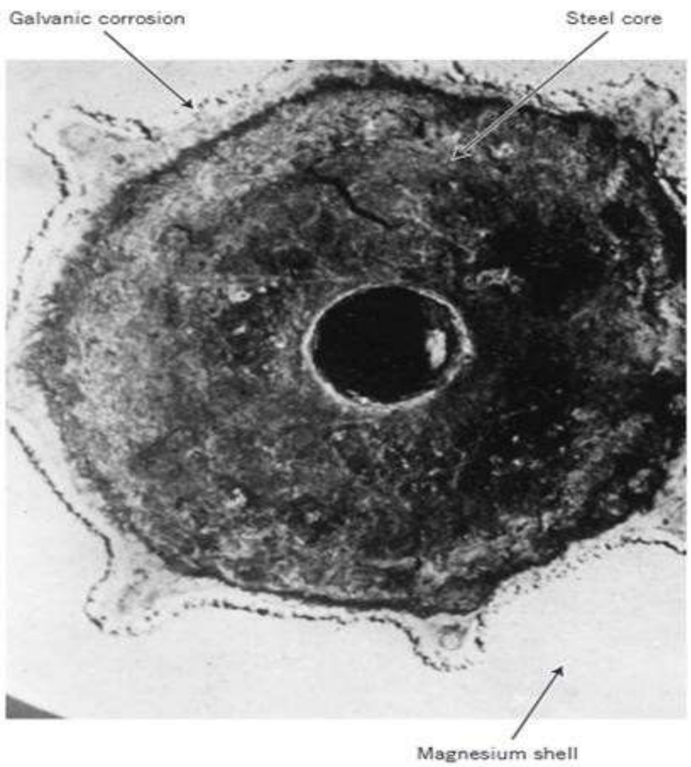
2.1.2 Stress corrosion cracking

This type of corrosion promotes the formation of a fracture in the metal structure due to mechanical stress and a chemically aggressive medium [27,28].

2.1.3 Galvanic or dimetallic corrosion

Occurs when there is a potential difference between dissimilar metals immersed in a corrosive solution; the potential difference produces a flow of electrons between the metals, where the less resistant metal is the anode (metal active), and the most resistant is the cathode (noble metal). This attack can be extremely destructive, dramatically accelerating the corrosion rate of the most reactive metal, but the severity degree of galvanic corrosion depends not only on the potential difference between the two metals, but also on the involved surface area ratios, [29,30].

Plate 2: Galvanic corrosion around the inlet of a single-cyclebilge pump that is found on fishing vessels.



2.1.4 Hydrogen embrittlement

This is associated with the hydrogen atoms that are produced on the metal surface in an aqueous medium; a reduction reaction occurs when atomic hydrogen penetrates the metal; the presence of defects allow the interaction between the hydrogen atoms and the metal, forming molecular hydrogen, which being trapped by the metal, provides enough pressure to form blisters, resulting in micro-cracks. This type of failure occurs mainly in basic media, where there are compounds such as sulphides and/or cyanides; this corrosion process is also present in plants with catalytic refining processes. In this kind of corrosion process, some hydrogen atoms diffuse through steel and become retained, where they recombine with each other, forming a very strong internal pressure that exceeds the strength of steel, forming blisters [31].

2.1.5 Crevice corrosion

This is frequently observed in passivated metals and alloys when they are exposed to environments that contain halide ions (especially chloride). Crevice corrosion could lead to initiation of cracks that propagate failure through leaking, mechanical failure and freezing of joints [32].

2.2 Inhibitors

Inhibitors are substances that, when added in relatively low concentrations to the environment, decrease its corrosiveness. Of course, the specific inhibitor depends both on alloy and on the corrosive environment. There are several mechanisms that may account for the effectiveness of inhibitors. Some react with and virtually eliminate a chemically active species in the solution (such as dissolved oxygen). Other inhibitor molecules attach themselves to the corroding surface and interfere with either the oxidation or the reduction reaction, or form a very thin protective coating. Inhibitors are normally used in closed systems such as automobile radiators and steam boilers [34].

Physical barriers to corrosion are applied on surfaces in the form of films and coatings. A large diversity of metallic and non-metallic coating materials are available. It is essential that the coating maintain a high degree of surface adhesion, which undoubtedly requires some pre-application surface treatment. In most cases, the coating must be virtually nonreactive in the corrosive environment and resistant to mechanical damage that exposes the bare metal to the corrosive environment. All three material types – metals, ceramics, and polymers – are used as coatings for metals .

Once corrosion has already started, a corrosion inhibitor may be used to slow the rate of damage, depending on the corrosives involved and the situation. Some corrosion inhibitors will also remove surface layers of corrosion to help restore a material to its original finish before depositing a layer of protection. It is a good idea to regularly inspect systems treated with corrosion inhibitors to confirm that the system is still protected and to check for signs of corrosion and system failure [35].

2.3 Mechanism of Action of Corrosion Inhibitors

Generally, the mechanism of the inhibitor is one or more of three that are cited below:

- The inhibitor is chemically or physically adsorbed on the surface of the metal and forms a protective thin film with inhibitor effect or by combination between inhibitor ions and metallic surface;
- The inhibitor leads a formation of a film by oxide protection of the base metal;
- The inhibitor reacts with a potential corrosive component present in aqueous media and the product is a complex.

2.4 Classification of Inhibitors

2.4.1 Anodic inhibitors

Anodic inhibitors (also called passivation inhibitors) act by a reducing anodic reaction, that is, blocks the anode reaction and causes a large shift of the corrosion potential. This shift forces the metallic surface into the passivation region. In general, the inhibitors react with the corrosion product, initially formed, resulting in a cohesive and insoluble film on the metal surface. They are also sometimes referred to as passivators. Chromates, nitrates, tungstate, molybdates are some examples of anodic Inhibitors .

2.1.1 Cathodic inhibitors

Cathodic inhibitors act by either slowing the cathodic reaction itself or selectively precipitating on cathodic areas to limit the diffusion of reducing species to the surface. These inhibitors have metal ions able to produce a cathodic reaction due to alkalinity, thus producing insoluble compounds that precipitate selectively on cathodic sites. Deposit over the metal a compact and adherent film, restricting the diffusion of reducible species in these areas. Thus, increasing the impedance of the surface and the diffusion restriction of the reducible species, that is, the oxygen diffusion and electrons conductive in these areas. These inhibitors cause high cathodic inhibition .

2.1.2 Mixed inhibitors

Mixed inhibitors work by reducing both the cathodic and anodic reactions. They are typically film forming compounds that cause the formation of precipitates on the surface blocking both anodic and cathodic sites indirectly.

Hard water that is high in calcium and magnesium is less corrosive than soft water because of the tendency of the salts in the hard water to precipitate on the surface of the metal forming a protective film.

The most common inhibitors of this category are the silicates and the phosphates. Sodium silicate, for example, is used in many domestic water softeners to prevent the occurrence of rust water. In aerated hot water systems, sodium silicate protects steel, copper and brass. However, protection is not always reliable and depends heavily on pH. Phosphates also require oxygen for effective inhibition. Silicates and phosphates do not afford the degree of protection provided by chromates and nitrites; however, they are very useful in situations where non-toxic additives are required .

2.1.3 Green corrosion inhibitors

The term "green inhibitor" or "eco-friendly inhibitor" refers to the substances that are biocompatibility in nature, environmentally acceptable, readily available and renewable source. Due to bio-degradability, eco-friendliness, low cost and easy availability, the extracts of some common plants-based chemicals and their by-products have been tried as inhibitors for metals under different environments (15). Green corrosion inhibitors are biodegradable and do not contain heavy metals or other toxic compounds.

Green corrosion inhibitors can be grouped into two categories, namely organic green inhibitor and inorganic green inhibitors. Molecular structure of inhibitor is the main factor determining its characteristics. Presence of hetero atom (S, N, O) with free electron pairs, aromatic rings with delocalized π-electrons, high molecular weight alkyl chains, substituent group in general improves inhibition efficiency. It is noticed that organic compounds show higher inhibition efficiency as compared to inorganic.

2.2 Iron Wood (Lophira alata)

Lophira alata, commonly known as azobe, ekki or the red ironwood tree, is a specie of plant in the family Ochnaeae. It is found in Cameroun, the Republic of Congo, the Democratic Republic of the Congo, Ivory Coast, Equatorial Guinea, Gabon, Ghana, Liberia, Nigeria, Sierra Leone, Sudan and Uganda. Its natural habitat is subtropical or tropical moist lowland forests. It is threatened by habitat loss.

The timber is extremely hard and used for railroad ties, groynes and bridge planking. It is strong and resistant making it useful for demanding constructions outdoors. The timber also has better electrical properties than other wood making it possible to use it in poles for electric fences without separate isolators. The colour is reddish brown and the wood is abrasive, dulling tools rapidly. (Wikipedia).

Phytochemical screening reports have shown that the stem contain alkaloids, saponins, glycosides, phytosterols, tannis, flavonoids and terpenooids while reducing sugar was absent. (29). The plant Lophira alata was selected for corrosion because the natural extracts have been widely used to protect metal materials from corrosion. The efficiency of these extracts as corrosion inhibition is commonly evaluated through electrochemical tests. Corrosion inhibitors of Lophira alata (iron wood) are substance that are added in small amounts on metal surfaces or are added to the corrosive medium, reducing the tendency to be affected by corrosion.

The plant Lophira alata is selected because the plant is not expensive, non-toxic and eco-friendly based on emergency research (30).

3.0 METHODOLOGY

Materials and Equipment

Materials and the equipment used for the setup are:

- Weighing balance
- Copper wire
- Hand gloves
- Beakers
- Round-bottom flask
- Hydrochloric Acid
- Ironwood stem (*Lophira alata*)
- Mild steel

Extraction Process

The stems of Ironwood (*Lophira alata*) were collected from an agricultural research farm. The stem extract was prepared as described by (31) with slight modification. The stem was dried and ground into a powder with a particle size of approximately 100 micrometers. It was soaked in 1 litre of ethanol with a purity of 99.8% for about 4 days, then in double-distilled water, and then dried at room temperature. The extract was heated to a temperature of 50-55 °C to accelerate ethanol evaporation without damaging or burning the active ingredients. Subsequently, the extract was filtered through cheesecloth, reduced to 10% of its original volume using a water bath at 40 °C, and finally dried as a powder.

Phytochemical screening of extracts

Tannin determination finely ground sample (0.2g) was weighed into a 50 ml sample bottle.1 0 mL of 70% aqueous acetone was added and properly covered. The bottle was put in an ice bath shaker and shaken for 2 hours at 30°C. Ach solution was then centrifuged, and the supernatant was stored on ice. 0.2 ml of each solution was pipetted into the test tube, and 0.8 ml of distilled water was added.

Standard tannic acid solutions were prepared from a 0.5 mg/mL stock, diluted to 1 mL with distilled water. 0.5 ml of olin-Ciocalteu reagent was added to both the sample and the standard, followed by 2.5 ml of 20% Na_2CO_3. The solutions were then vortexed and incubated for 40 minutes at room temperature. Their absorbance was read at 725 nm against a reagent blank prepared from the same solution, and a standard tannic acid curve was prepared.

Determination of total flavonoid The total flavonoid content of the extract was determined using a colourimetric assay developed by (33). To 0.2 ml of the extract, 0.3 ml of 5% $NaNO_3$ was added at zero time. After 5 minutes, 0.6 ml of 10% $AlCl_3$ was added, and after 6 minutes, 2 ml of 1 M NaOH was added to the mixture, followed by 2.1 ml of distilled water. Absorbance was read at 510 nm against the reagent blank, and flavonoid content was expressed as mg rutin equivalent.

Determination of saponin the spectrophotometric method of Brunner will be used for saponin determination. 2 g of the finely ground sample will be weighed into a 250m l beaker, and 100 ml of Isobutyl alcohol or (But-2-ol) will be added. A shaker will be used to mix the mixture for 5 hours to ensure uniform mixing.

The mixture will now be filtered with No 1 Whatman filter paper into a 100 ml beaker containing 20 ml of 40% saturated solution of magnesium carbonate ($MgCO_3$). The mixture obtained again will be filtered through No. 1 Whatman filter paper to obtain a clean colorless solution. 1 ml of the colorless solution will be taken into a 50 ml volumetric flask using a pipette, 2 ml of 5% iron (iii) chloride ($FeCl_3$) solution will be added and made up to the mark with distilled water. It would allow standing for 30 minutes for the color to develop. The absorbance is read against the blank at 380nm.

Determination of alkaloid Sample (5 g) was weighed into a 250 ml beaker, and 200 ml of 10% acetic acid in ethanol was added, allowed to stand for 4m in. This was filtered, and the extract was concentrated in a water bath to one-quarter of the original volume. Concentrated ammonium hydroxide was added dropwise to the extract until the precipitation was completed. Thew whole solution was allowed to settle and the precipitate was collected and washed with dilute ammonium hydroxide and then filtered. There is then the alkaloid, which was dried and weighed.

%Alkaloid = W3 – W2 X 100

Determination of cardiac glycosides

The procedure described by Sofowora was used. 10 ml of the extract was pipetted into a 250 ml conical flask. 0 ml chloroform was added and shaken on vortex mixer for 1h our. The mixture was filtered into a 100 ml conical flask. 10 mL of pyridine and 2 mL of 29% sodium nitroprusside were added, and the mixture was shaken thoroughly for 10 minutes. 3m l of 20% NaOH was added to develop a brownish-yellow colour. Glycosides standard (Digitoxin). A concentration range of 0–50m g/mL was prepared from a stock solution, and the absorbance was read at 510 nm (Kingstone, 2020).

Determination of terpenoid

The procedure described by Sofowora was used. A finely ground sample (5 g) was weighed into a 50 ml conical flask. 20 ml of chloroform: methanol (2:1) was added, the mixture was shaken thoroughly, and allowed to stand for 15m in at room temp. The suspension was centrifuged at 3000r pm; the supernatant was discarded, and the precipitate was re-washed with 20m l chloroform:methanol (2:1), then re-centrifuged. Again, the precipitate was dissolved in i40 mlof 10% SDS solution. 1 mL of 0.01 M ferric chloride was added, and the mixture was allowed to stand for 30 minutes before measuring the absorbance at 510 nm.

Determination of steroid

A quantitative determination of steroid was determined by weighing a 5 g of the finely powdered sample into a 100 ml conical flask and 50 ml of pyridine was added to it, and shake for 30 min at room temperature. 3 mL of 250 mg/mL metallic copper powder or copper(1) oxide was added, and the mixture was incubated in the dark for 1 hour, after which the absorbance was measured at 350n m against a reagent blank.

In each determination, specific constituents such as tannins, flavonoids, and saponins play a significant role in the corrosion inhibition mechanism. Tannins are known to adsorb onto metal surfaces, forming a protective layer that hinders corrosion. Flavonoids, with their aromatic structures, effectively occupy active metal sites to block corrosion agents. Saponins facilitate the formation of a consistent film on the metal surface, which provides an additional barrier against corrosive elements. This understanding of how each compound contributes underscores their importance in enhancing the adsorptive properties of the *Lophira alata* extract and its efficacy as a corrosion inhibitor.

Preparation of coupons for the test

The material used for this study is a mild steel sheet. The choice of mild steel is due to its versatility as a construction material. It is widely used in the construction industry due to its availability and strength. It finds widespread application in the utilities, food, chemical, and petrochemical industries, even though it is easily affected by the aggressive environment. It is used in the shell of a pressure vessel or the rotating shaft of a machine because of its strength. It is more prone to corrosion attack.

Metal Preparation for the experiment

To conduct the weight-loss experiment, the metal was cut into 50mm wide, 40mm long, and 0.5mm thick. It was polished into a mirror state (rough to medium to smooth) using energy paper of different sizes. The mild steel sample was cleaned with acetone and dried. The mild steel was kept in a desiccator.

The surface area of the coupon is: A =
$2[wL + Lh + hw]$ (cm^2)

Where W = width of the sample
L = length of the sample
h = thickness of the sample

L = 50mm = 5cm W=

40mm = 4cm

h = 0.5mm = 0.05cm

$A = 2[5 \times 4 + 5 \times 0.05 + 4 \times 0.05]$

$A = 2[20.45]$

$A = 40.90cm^2$

Media/Environment

The environment utilized in this study is HCL has been described earlier under the metal treatment section. The connection of the HCL used in this study was 0.5M.

Carrying out the corrosion test

In order to carry out the corrosion test, the mild steel sample was removed from the corrosion unit. It was washed with distilled water and cleaned with tissue paper after which it was dried. The weight of the mild steel was measured to determine the weight loss at that particular hour it was immersed in the corrosion unit .

Weight Loss Experiment

Weight loss measurement were performed using 500ml capacity beakers containing 150ml test solution under total immersion in stagnant aerated condition at room temperature (25^0c). The pre-cleaned and weighed mild steel coupons were suspended in beakers with the help of rods and hooks. The coupons were withdrawn at 24 hours interval progressively for 120 hours, cleaned as previously reported and reweighed. The weight loss in grams was taken as the difference in the weight of the mild steel coupons before and after immersion in different test solutions. Tests were performed for the blank solution (0.5m HCL), *Lophira alata* root extracts concentration of 2.5 – 10g/L at room temperature. The experiments were done in duplicates to ensure reproducibility. From the weight loss value, corrosion rates were computed using the expression.

$$C.R. = \frac{K\Delta W}{DAt}$$

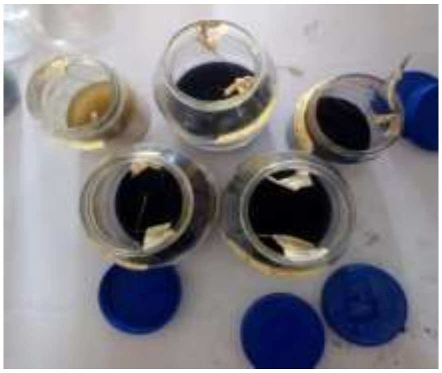
Where: C.R. is the corrosion rate, ΔW is the weight loss (g) D = metal density A = Area of the coupon (cm^2) t = the time of exposure (h) K = constant

The surface coverage was calculated using the expression:

$$\theta = \left[\frac{CR_0 - CR_1}{CR_0}\right]$$

The inhibition efficiency was calculated using the expression:

$$I.E = \frac{CR_0 - CR_1}{CR_0} \times 100\%$$



Container with inhibition ready for corrosion test

Mild steel coupons

Digital weighing balance

Results for Stem

Table 1: Calculated Result of weight loss, corrosion rate, surface coverage and inhibition efficiency

Time (hours)	Concentration of inhibitors (ml)	Initial weight (g)	Final weight (g)	Weight loss (g)	Corrosion rate	Surface coverage	Inhibition efficiency (%)
24	Blank	14.13	13.99	0.14	0.001589	---	---
	2.5	14.45	14.33	0.12	0.001362	0.143	14
	5.0	14.39	14.28	0.11	0.001249	0.214	21
	7.5	14.13	14.03	0.10	0.001135	0.295	29
	10	14.29	14.22	0.07	0.000795	0.499	50
48	Blank	13.92	13.76	0.16	0.000908	---	---
	2.5	14.22	14.08	0.14	0.000795	0.124	12
	5.0	14.25	14.13	0.12	0.000681	0.250	25
	7.5	13.97	13.88	0.09	0.000511	0.437	44
	10	14.21	14.13	0.08	0.000454	0.510	51
72	Blank	13.63	13.46	0.17	0.000643	---	---
	2.5	14.18	14.05	0.13	0.000492	0.235	24
	5.0	14.22	14.11	0.11	0.000416	0.353	35
	7.5	13.72	13.63	0.09	0.000341	0.470	47
	10	14.17	14.12	0.05	0.000189	0.706	55
96	Blank	13.62	13.44	0.18	0.000511	---	---
	2.5	13.86	13.71	0.15	0.000426	0.306	31
	5.0	13.56	13.44	0.12	0.000341	0.333	33
	7.5	13.55	13.48	0.07	0.000199	0.611	52
	10	13.86	13.83	0.07	0.000085	0.830	60
120	Blank	13.60	13.37	0.23	0.000522	---	---
	2.5	13.80	13.66	0.14	0.000318	0.390	39
	5.0	13.56	13.43	0.13	0.000295	0.430	43
	7.5	13.49	13.39	0.10	0.000227	0.700	55
	10	13.84	13.80	0.04	0.000080	0.847	60

Table 2: Adsorption Isotherm

Time (hours)	Concentration of inhibitors (ml)	Surface coverage	C/θ	LogC
24	Blank	---		
	2.5	0.0924	27.06	0.4
	5.0	0.1428	35.01	0.7
	7.5	0.2353	31.87	0.9
	10	0.4286	23.33	1
48	Blank	---		
	2.5	0.1053	23.74	0.4
	5.0	0.1491	33.53	0.7
	7.5	0.2544	29.48	0.9
	10	0.5000	20	1
72	Blank	---		
	2.5	0.1053	23.74	0.4
	5.0	0.1579	31.67	0.7
	7.5	0.4079	18.39	0.9
	10	0.4868	20.54	1
96	Blank	---		
	2.5	0.1395	17.92	0.4
	5.0	0.2093	23.89	0.7
	7.5	0.3488	21.50	0.9
	10	0.4651	21.50	1
120	Blank	---		
	2.5	0.217	11.52	0.4
	5.0	0.304	16.45	0.7
	7.5	0.391	19.18	0.9
	10	0.522	19.16	1

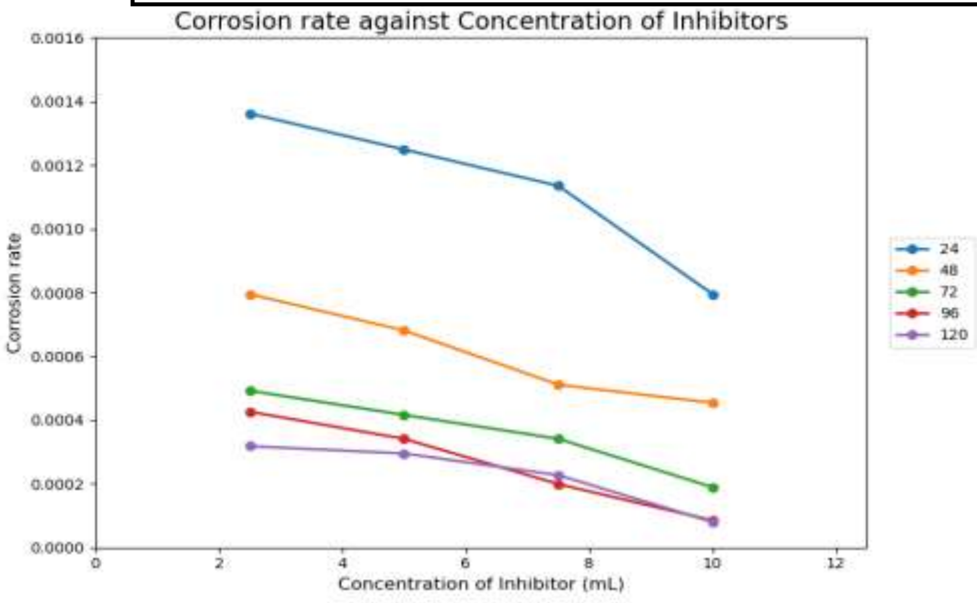


Figure 1: Plot of Corrosion rate versus Inhibitor concentration at various immersion times

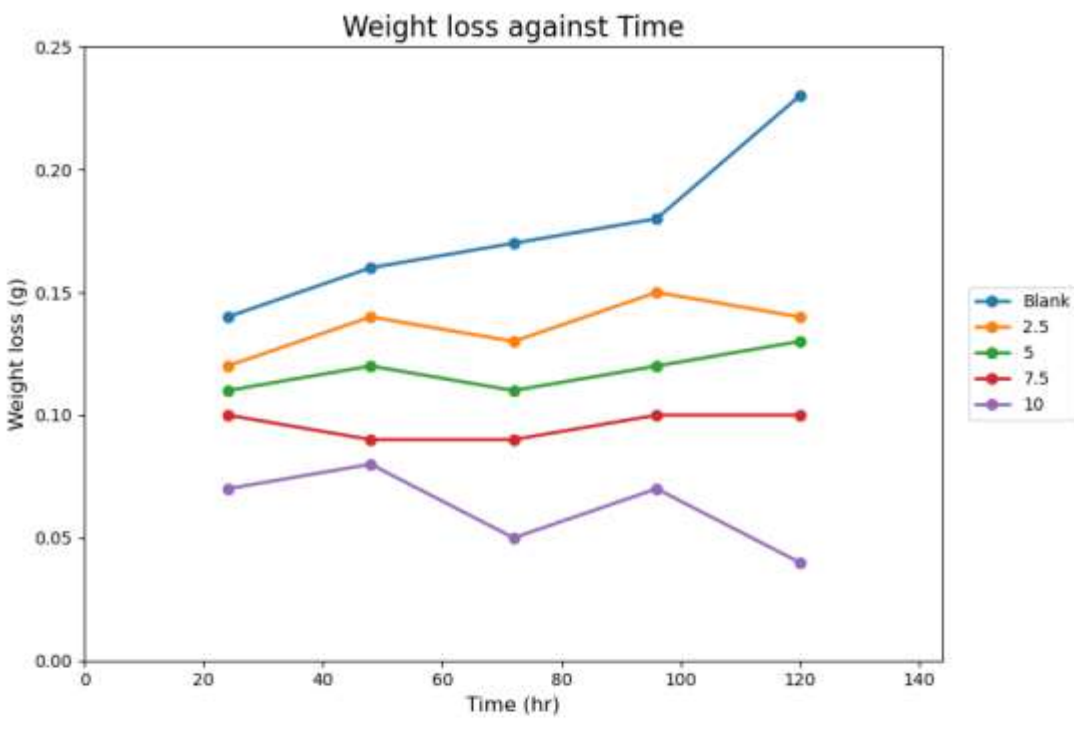


Figure 2: Plot of Weight loss versus time

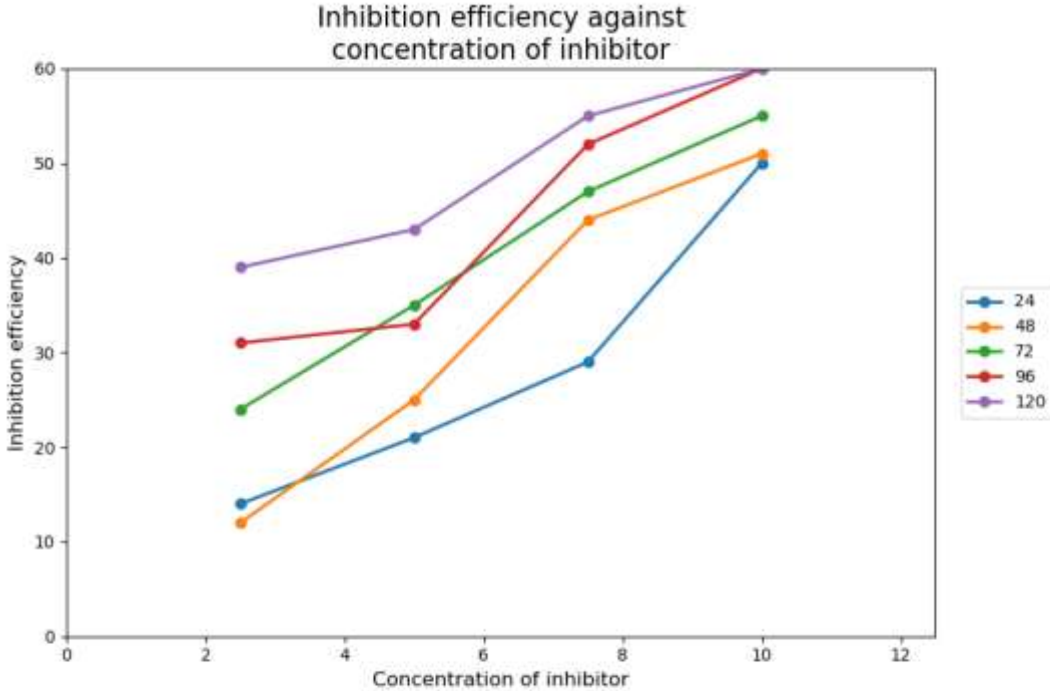


Figure 3: Plot of Inhibition efficiency versus concentration of inhibitor

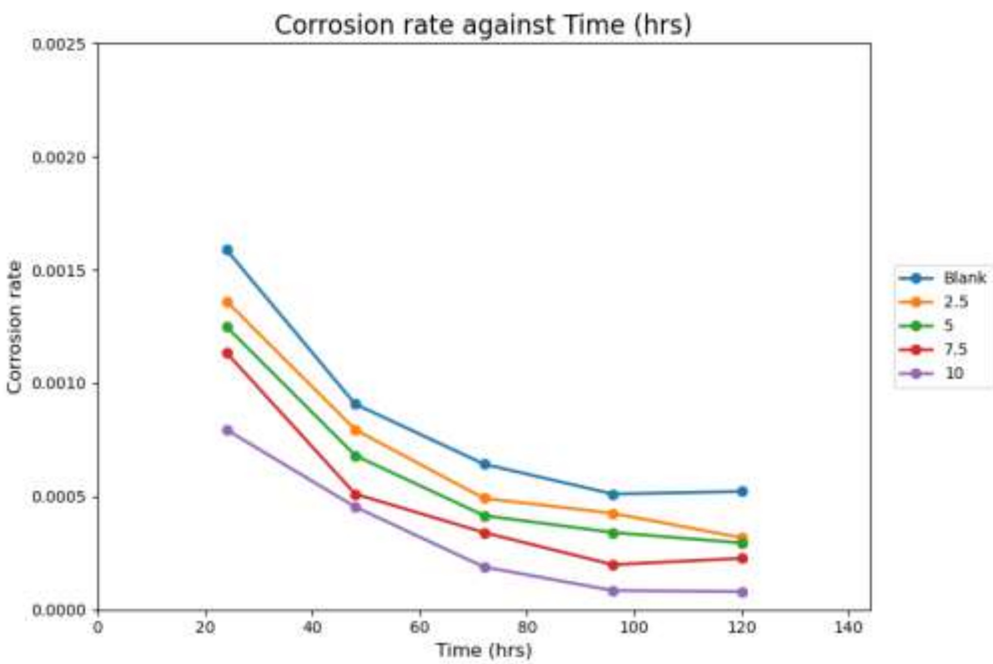


Figure 4: Plot of corrosion rate versus time

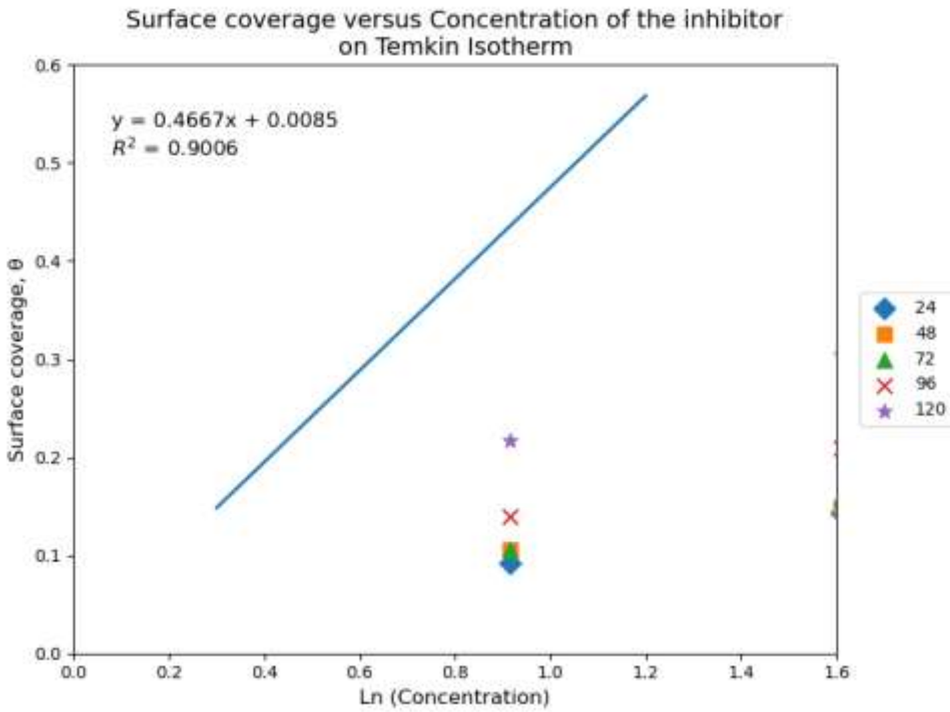


Figure 5: Surface coverage versus Concentration of the inhibitor on Temkin Isotherm

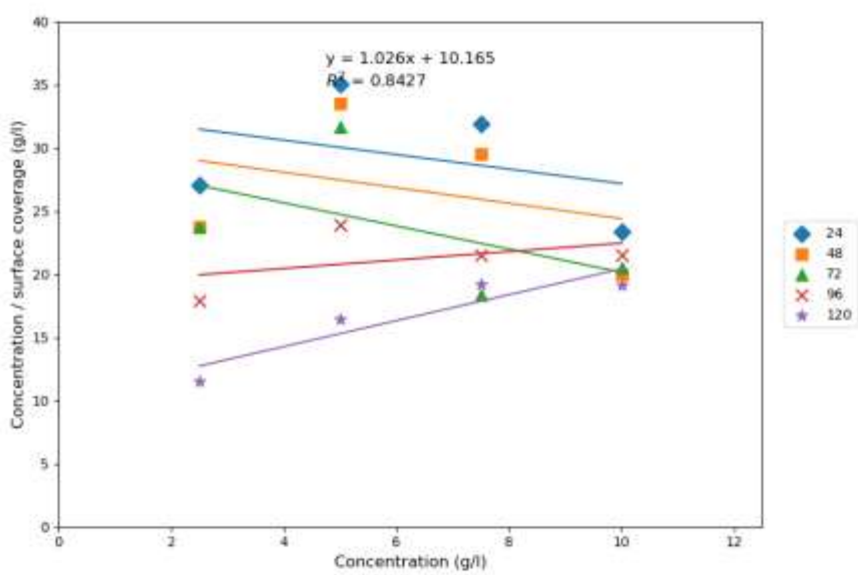


Figure 6: Plot of surface coverage versus concentration of inhibitors at various immersion times on Langmuir Isotherm

4.2 DISCUSSION

Weight Loss Studies: The average corrosion rates calculated from equation 1 were plotted against different concentrations of the inhibitor in acidic media at various time intervals, as shown in Figure 1. Figure 1 demonstrates a significant reduction, with a four-fold decrease in the corrosion rate of mild steel observed at higher concentrations of *Lophira alata* inhibitor. This quantification clearly illustrates the extent of the inhibitor's effect, making the trend more evident.

Figure 1 shows that the corrosion rate of mild steel was largely dependent on the inhibitor concentration in the sample solutions. As indicated in Figure 1, the corrosion rate of mild steel is greatly reduced as the concentration of *Lophira alata* inhibitor increases and varies appreciably with immersion period.

Figure 2 shows the weight loss versus time curves for mild steel in the absence and presence of the inhibitor at different concentrations. The curves indicate that the weight loss of mild steel decreases as inhibitor concentration increases. Figure 3 displays the evaluated inhibition efficiency as a function of inhibitor concentration at various immersion periods, showing that inhibition efficiency increases proportionally with higher concentrations of the extract. Incorporating statistical measures such as confidence intervals or p-values would provide a clearer indication of the statistical significance of the inhibition efficiency results and enhance the reliability of the conclusions. The corrosion rate over time (hr) for various immersion periods. The plots show that the higher the time interval, the lower the corrosion rate of the mild steel.

Figure 5 shows plot of Temkim Isotherm for mild steel inHCl of different concentration of *Lophira alata* extract. Temkin adsorption with the highest regression coefficient (R2=0.988) close to 1, unity.

Figure 6 shows the Langmuir adsorption isotherm for mild steel in HCl with different concentrations of *Lophira alata* extract. Langmuir adsorption Isotherm was tested. The experimental data were best described by the Langmuir Isotherm, with the lowest regression coefficient (R2) not close to 1. As shown in the graph, the slope of the Langmuir plot (R2 = 0.842) was not close to 1.The value of the regression coefficient (R2) for both the Temkin and Langmuir adsorption isotherms showed that the Temkin Isotherm is the best model for the adsorption, with R2 = 0.988, close to 1 (unity), while the Langmuir isotherm has R2 = 0.842, not close to 1 (unity).

The results of this investigation indicate that the inhibition efficiency of *Lophira alata* (ironwood) stem extract increases with higher extract concentrations, with a maximum inhibition efficiency of 52.24% achieved at a 0.05 g concentration in acidic medium. Industry standards consider a corrosion inhibition efficiency above 50% effective for practical applications, supporting the viability of *Lophira alata* extract for mild steel protection. Overall, the findings demonstrate that *Lophira alata* stem extract is an effective inhibitor of mild steel corrosion in hydrochloric acid media.

CONCLUSION

From the results and findings of the study, the following conclusions were drawn:

1. The rate of weight loss was higher in the medium without the inhibitor concentration. The corrosion of mild steel was found to reduce in the presence of inhibitor extracts. The reduction in the corrosion rate was due to the presence of phytochemical constituents in the plant extract, which contain heteroatom orbitals that block the active sites on the metals.
2. The inhibitor's efficiency increases with increasing extract concentration. Surface coverage increases with increase in the concentration of the inhibitor.
3. For practical applications, this inhibitor could be pilot-tested in the oil and gas industry, particularly for pipelines exposed to acidic environments. The use of *Lophira alata* extract in such contexts may significantly reduce maintenance costs while providing an environmentally friendly alternative. Future research should investigate similar industrial scenarios to fully realize the potential of naturally derived inhibitors.

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