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ASSESSMENT OF NEEM (*AZADIRACHTA INDICA*) AND MORINGA (*MORINGA OLEIFERA*) LEAF EXTRACTS AS GREEN CORROSION INHIBITORS FOR MILD STEEL.

*Saidu Aliyu, Aminu Muhammad Bello, Zubairu Ahmad, Umar Yahayya Danillela

Department of Science Laboratory Technology, Kebbi State Polytechnic Dakingari, Nigeria.

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*Corresponding Author: Saidu Aliyu

Department of Science Laboratory Technology, Kebbi State Polytechnic Dakingari, Nigeria.

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ABSTRACT

This study assessed the corrosion inhibition performance of Azadirachta indica (Neem) and Moringa oleifera (Moringa) leaf extracts as environmentally friendly corrosion inhibitors for mild steel in alkaline media. Fresh leaves of Neem and Moringa were processed by crushing and pounding without the addition of an extracting solvent, and the resulting extracts were filtered and used at volumes of 25, 50, 75, and 100 cm³. Mild steel cylindrical coupons were exposed to 0.5 M and 1.0 M sodium hydroxide (NaOH) solutions containing the respective plant extracts. The corrosion behaviour was evaluated using weight-loss measurements, corrosion rate, and inhibition efficiency. The results showed that increasing the extract volume progressively reduced the weight loss and corrosion rate of the mild steel while increasing inhibition efficiency in both NaOH concentrations. In 0.5 M NaOH, Neem extract increased the inhibition efficiency from 22.28% at 25 cm³ to 59.78% at 100 cm³, whereas Moringa extract increased the efficiency from 25.54% to 64.13%. In 1.0 M NaOH, Neem exhibited inhibition efficiencies of 20.35–58.01%, while Moringa showed 23.81–60.61% over the same extract-volume range. The uninhibited mild steel exhibited higher corrosion rates in 1.0 M NaOH than in 0.5 M NaOH, indicating increased corrosivity with increasing NaOH concentration. At corresponding extract volumes, Moringa consistently exhibited slightly higher inhibition efficiency and lower weight loss than Neem. The observed protective effect is attributed to the adsorption of bioactive phytochemical constituents present in the plant extracts onto the mild-steel surface, forming a protective film that limits interaction between the metal and the corrosive alkaline medium. The findings demonstrate the potential of Neem

and Moringa leaf extracts as locally available, renewable, and environmentally compatible alternatives for mitigating mild-steel corrosion in alkaline environments.

KEYWORDS: Neem (*Azadirachta indica*); Moringa (*Moringa oleifera*); Leaf extracts; Green corrosion inhibitors; Mild steel; Corrosion inhibition; Inhibition efficiency; Phytochemicals; Alkaline medium; Weight-loss method.

INTRODUCTION

Corrosion is one of the major challenges affecting metallic materials used in engineering, construction, transportation, manufacturing, oil and gas, and other industrial applications. It is a spontaneous physicochemical process in which metals undergo degradation as a result of interactions with their surrounding environment (Aondover & Akaaza, 2018). The deterioration of metallic structures through corrosion can lead to loss of mechanical integrity, reduced service life, increased maintenance costs, production downtime, and, in severe cases, catastrophic structural failure (Okpala et al., 2022). The economic and environmental consequences associated with corrosion have therefore made its prevention and control an important area of research in materials science, chemistry, and engineering.

Mild steel is among the most widely used engineering materials because of its relatively low cost, good mechanical strength, ease of fabrication, weldability, and availability (Waidi & Engineering, 2022). It is extensively employed in pipelines, storage tanks, bridges, automobile components, agricultural equipment, structural frameworks, machinery, and industrial processing facilities. Despite these advantages, mild steel is highly susceptible to corrosion, particularly when exposed to aggressive environments containing acids, alkalis, salts, dissolved oxygen, moisture, and other corrosive species. Corrosion of mild steel is primarily an electrochemical process involving anodic dissolution of iron and cathodic reactions occurring simultaneously on different regions of the metal surface. The resulting deterioration necessitates the development and application of effective corrosion-control strategies (Vashi, 2025a).

Several techniques have been developed to minimize corrosion, including material modification, protective coatings, cathodic protection, anodic protection, and the application of corrosion inhibitors (Vashi, 2025b). Among these approaches, corrosion inhibition using chemical compounds has attracted considerable attention because inhibitors can provide effective protection even at relatively low concentrations. Conventional corrosion inhibitors, including chromates, phosphates, amines, and other synthetic organic compounds, have been

successfully employed in various industrial processes (Adagashi et al., 2023). However, the increasing concern over their toxicity, persistence, high cost, environmental impact, and potential risks to human health has stimulated the search for safer and more environmentally compatible alternatives.

Background of the Research

The concept of green corrosion inhibition has consequently emerged as an important research direction. Green inhibitors are generally obtained from renewable biological materials such as plant leaves, fruits, seeds, bark, roots, agricultural residues, and essential oils (Qamarul et al., 2016). Plant-derived inhibitors are particularly attractive because many contain naturally occurring organic compounds capable of interacting with metallic surfaces and modifying electrochemical reactions associated with corrosion (Latha et al., 2025). These compounds may include alkaloids, flavonoids, tannins, terpenoids, saponins, phenolic compounds, glycosides, proteins, and other oxygen-, nitrogen-, or sulfur-containing constituents (Loto et al., 2011). Through adsorption onto the metal surface, such phytochemicals can form a protective film that reduces the contact between the metal and corrosive species, thereby decreasing the rate of metal dissolution (Adebayo, 2024).

The effectiveness of plant extracts as corrosion inhibitors is strongly influenced by their phytochemical composition and the nature of the corrosive environment (Ndukwe et al., 2023). Many phytochemicals contain heteroatoms and functional groups with lone-pair electrons or π -electrons that can interact with the metal surface through adsorption. Depending on the chemical structure and environmental conditions, adsorption may occur through physical interactions, chemical bonding, or a combination of both (Idu et al., 2015). The resulting adsorbed layer can block active corrosion sites, alter the electrochemical kinetics of anodic and/or cathodic reactions, and reduce the overall corrosion rate. The effectiveness of an extract may also depend on inhibitor concentration, temperature, exposure time, extraction method, solvent, corrosive-medium composition, and the characteristics of the metal surface (Idu et al., 2016).

Among the numerous plants investigated for environmentally friendly corrosion protection, neem (*Azadirachta indica*) is of particular interest. Neem is a widely distributed plant in tropical and subtropical regions and has traditionally been utilized for medicinal, agricultural, and industrial purposes (Garba et al., 2021). Its leaves contain a diverse range of bioactive constituents, including flavonoids, phenolic compounds, tannins, terpenoids, alkaloids, and other oxygenated organic compounds. The presence of these constituents provides neem leaf

extract with functional groups capable of interacting with metallic surfaces (Veronica & Dorcas, 2025). Such interactions may facilitate the formation of an adsorbed protective layer on mild steel, thereby limiting the electrochemical processes responsible for corrosion.

Similarly, moringa (*Moringa oleifera*) is a highly valued multipurpose plant widely cultivated in tropical regions, including Nigeria. Its leaves are rich in biologically active compounds such as phenolics, flavonoids, tannins, saponins, alkaloids, terpenoids, proteins, and other phytochemicals (Ngunoon et al., 2017). These constituents have functional groups that may promote adsorption onto mild-steel surfaces and consequently inhibit corrosion (Veronica & Dorcas, 2025). The availability of *M. oleifera*, its renewable nature, and its relatively rich phytochemical composition make its leaf extract a promising candidate for the development of environmentally benign corrosion inhibitors.

The use of neem and moringa leaf extracts is particularly relevant in developing regions where these plants are readily available and can potentially provide low-cost alternatives to conventional synthetic inhibitors. Their application could contribute to the conversion of locally available biological resources into useful materials for corrosion control while reducing dependence on potentially hazardous chemical inhibitors. Nevertheless, the corrosion-inhibition performance of plant extracts cannot be assumed solely from their phytochemical composition (Garba et al., 2021). Experimental assessment is necessary to establish their actual effectiveness, optimum concentration, inhibition mechanism, and interaction with mild steel under defined corrosive conditions.

Assessment of the corrosion inhibition properties of neem and moringa leaf extracts can therefore provide important information regarding their ability to reduce the corrosion susceptibility of mild steel. Experimental techniques such as weight-loss measurement, gravimetric analysis, determination of corrosion rate and inhibition efficiency, and electrochemical methods can be employed to evaluate their protective performance (Idu et al., 2016). Parameters such as inhibitor concentration, temperature, and exposure time may also be investigated to establish the conditions under which maximum protection is achieved. Furthermore, phytochemical characterization can provide useful insight into the bioactive constituents potentially responsible for the observed inhibition behavior (Idu et al., 2016).

Despite the growing interest in plant-based corrosion inhibitors, differences in plant species, geographical origin, extraction procedures, phytochemical composition, metal type, and corrosive environment can result in substantial differences in inhibition performance. There is therefore a continuing need for systematic studies that evaluate locally available plant materials under controlled experimental conditions. In particular, comparative assessment of

neem and moringa leaf extracts against mild-steel corrosion can provide useful evidence regarding their relative protective behaviour and their potential as sustainable corrosion-control materials.

Consequently, this study focuses on the Assessment of Neem (*Azadirachta indica*) and Moringa (*Moringa oleifera*) Leaf Extracts as Green Corrosion Inhibitors for Mild Steel. The study is intended to investigate the ability of the extracts to reduce mild-steel corrosion, determine the influence of relevant experimental conditions on their inhibition performance, and provide an understanding of the potential contribution of plant-derived phytochemicals to corrosion protection. The outcome of the study may contribute to the development of inexpensive, renewable, and environmentally friendly alternatives to conventional corrosion inhibitors and provide a basis for further research into the application of locally available plant resources in corrosion-control technologies.

MATERIALS AND METHOD

The materials used for this study included sodium hydroxide (NaOH) solution, fresh leaves of *Azadirachta indica* (neem) and *Moringa oleifera* (moringa), mild steel specimens, a 1000 cm³ measuring cylinder, 250 cm³ volumetric flask, 1200 cm³ beakers, funnel, spring balance, electronic analytical balance (METTLER TOLEDO Model ME204E, with an accuracy of 0.0001 g), filter cloth, mortar and pestle, hand towel, meter rule, Vernier caliper, paper sieve, masking tape, razor blade, and nylon thread. Distilled water was also used in the preparation of solutions and extraction of the plant materials.

The mild steel specimens used for the investigation were obtained from Birnin Kebbi, Kebbi State, Nigeria. The chemical composition of the mild steel was determined using a Metal Analyzer/Optical Emission Spectrometer to establish the elemental composition of the specimens prior to the corrosion inhibition experiments.

Fresh, healthy leaves of *Azadirachta indica* and *Moringa oleifera* were collected, cleaned to remove dirt and foreign materials, and processed for extraction. The resulting plant extracts were subsequently used as green corrosion inhibitors in the assessment of their protective effects on mild steel in the selected corrosive medium.

The mild steel rods were cut into cylindrical coupons measuring approximately 1.5 cm × 1.0 cm using a hacksaw, yielding a total of 144 coupons. The surfaces of the coupons were properly cleaned and prepared prior to use. Each coupon was individually weighed using an electronic digital analytical balance, and the initial mass was recorded (Vashi, 2025b).

The experimental beakers were carefully labelled according to the corrosive medium and inhibitor concentration they were intended to contain. The required 0.5 M and 1.0 M sodium hydroxide (NaOH) solutions were prepared by accurately weighing the appropriate quantities of NaOH and dissolving them separately in the required volumes of distilled water. The solutions were allowed to cool and were subsequently made up to the desired volumes with distilled water (Vashi, 2025b).

Before commencement of the experiment, all glassware was thoroughly rinsed with distilled water and allowed to dry completely to prevent contamination and the introduction of additional moisture that could affect the experimental measurements. A total of 36 beakers were prepared in this manner.

The prepared mild steel coupons were suspended individually in the respective test media using nylon threads attached to a retort stand. Four coupons were immersed in each beaker containing the appropriate test solution. Care was taken to ensure that the coupons were completely immersed in the test media and did not come into contact with one another or the walls of the beakers. This arrangement was maintained to minimize physical contact, crevice formation, and possible galvanic effects during the corrosion experiments (Loto et al., 2011). The prepared neem (*Azadirachta indica*) and moringa (*Moringa oleifera*) leaf extracts were subsequently introduced into the designated test media at the selected concentrations to evaluate their effectiveness as green corrosion inhibitors for mild steel.



Plate 1: Neem. (*Azadirachta indica*)



Plate 2: Moringa. (*Moringa oleifera*)



Plate 3: Mild Steel.

Material Preparation

Cylindrical mild steel coupons measuring 1.0 cm in diameter and 1.5 cm in height, with an approximate total surface area of 6.284 cm², were carefully cut from a mild steel rod. Each coupon was individually weighed using an electronic analytical balance, and its initial mass was recorded (Aondover & Akaaza, 2018).

The surfaces of the mild steel coupons were initially examined and mechanically cleaned using abrasive paper to remove mill scale, rust, and other surface impurities. The coupons were subsequently rinsed with acetone to remove residual contaminants and then polished to obtain a clean and relatively uniform surface. Thereafter, the coupons were degreased by washing with absolute ethanol, rinsed thoroughly with acetone, and allowed to dry under ambient conditions (Okpala et al., 2022).

After drying, the prepared coupons were stored in moisture-free desiccators until required for the corrosion inhibition experiments. This procedure was adopted to minimize contamination and prevent premature corrosion of the specimens before exposure to the test media (Waidi & Engineering, 2022).

Fresh leaves of *Azadirachta indica* (neem) and *Moringa oleifera* (moringa) were used as the plant materials for the preparation of the green corrosion inhibitor extracts. All chemicals and reagents employed in the study were of analytical grade, while distilled water was used in the preparation of the various solutions and experimental media.

Preparation of Leaf Extracts

Fresh leaves of *Azadirachta indica* (Neem) and *Moringa oleifera* (Moringa) were collected locally and carefully sorted to remove damaged leaves and other extraneous materials. The leaves were thoroughly washed with clean water to remove adhering dirt and impurities and were subsequently allowed to drain under ambient conditions (Vashi, 2025a).

A known mass of the fresh leaves of each plant was separately weighed and allowed to stand under ambient conditions for approximately two hours. The leaves were then manually crushed and pounded using a clean mortar and pestle to release the naturally occurring plant juices without the addition of water or any other extracting solvent. The resulting extracts were collected separately and filtered to remove suspended leaf particles and other solid residues. The filtrates obtained were transferred into clean, properly labelled containers and stored under appropriate conditions until required for the corrosion inhibition experiments (Vashi, 2025b).

The prepared Neem and Moringa leaf extracts were measured volumetrically using a measuring cylinder. Volumes of 25, 50, 75, and 100 cm³ of each extract were used for the corrosion inhibition studies. The measured quantities of the extracts were separately introduced into the experimental solutions containing 0.5 M and 1.0 M sodium hydroxide (NaOH) as the corrosive media. The prepared extract-containing solutions were subsequently used to evaluate the corrosion inhibition performance of *A. indica* and *M. oleifera* leaf extracts on mild steel under the specified experimental conditions (Adagashi et al., 2023).

RESULTS AND DISCUSSION

Table 1: Average weight loss of mild steel in NaOH containing Neem and Moringa leaf extracts.

NaOH medium	Extract	Extract volume (cm ³)	Average weight loss (g)
0.5 M	None (control)	0	0.126
0.5 M	Neem	25	0.098
0.5 M	Neem	50	0.081
0.5 M	Neem	75	0.064
0.5 M	Neem	100	0.051
0.5 M	Moringa	25	0.094
0.5 M	Moringa	50	0.076
0.5 M	Moringa	75	0.058
0.5 M	Moringa	100	0.045
1.0 M	None (control)	0	0.158
1.0 M	Neem	25	0.126
1.0 M	Neem	50	0.106
1.0 M	Neem	75	0.084
1.0 M	Neem	100	0.067
1.0 M	Moringa	25	0.120
1.0 M	Moringa	50	0.099
1.0 M	Moringa	75	0.077
1.0 M	Moringa	100	0.061

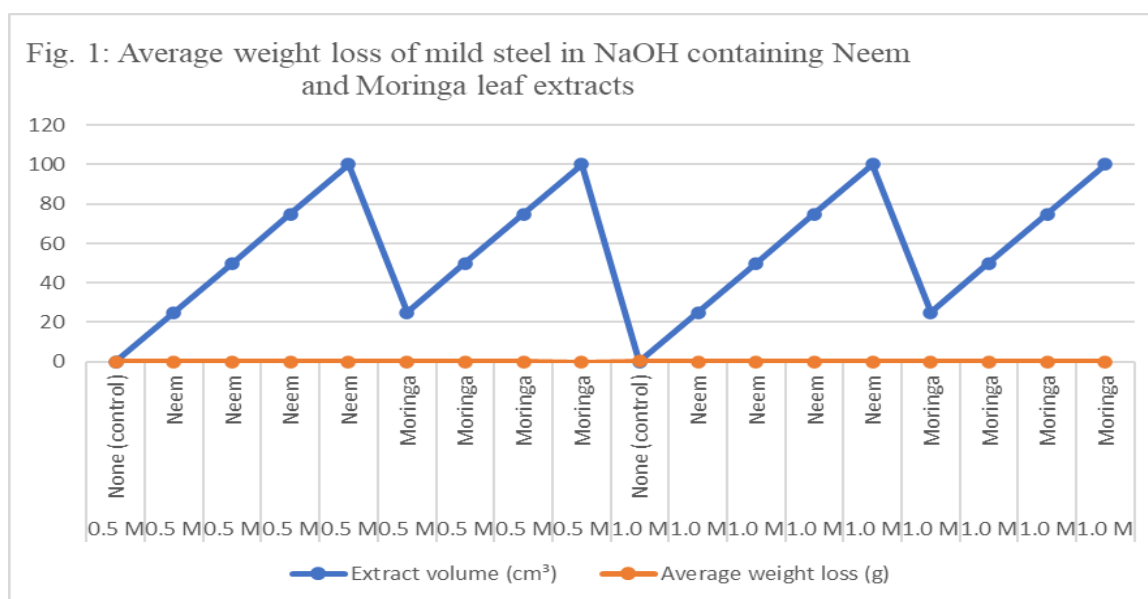


Table 2: corrosion rate and inhibition efficiency in 0.5 M NaOH.

Extract	Volume (cm ³)	Corrosion rate	Inhibition efficiency (%)
Control	0	0.184	0.00
Neem	25	0.143	22.28
Neem	50	0.118	35.87
Neem	75	0.093	49.46
Neem	100	0.074	59.78
Moringa	25	0.137	25.54
Moringa	50	0.111	39.67
Moringa	75	0.084	54.35
Moringa	100	0.066	64.13

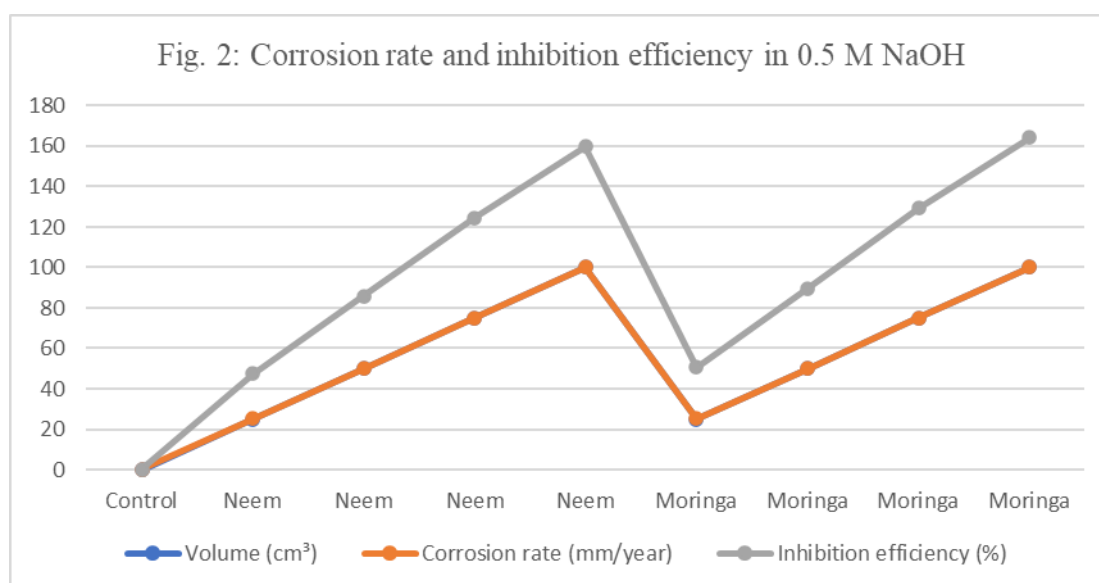
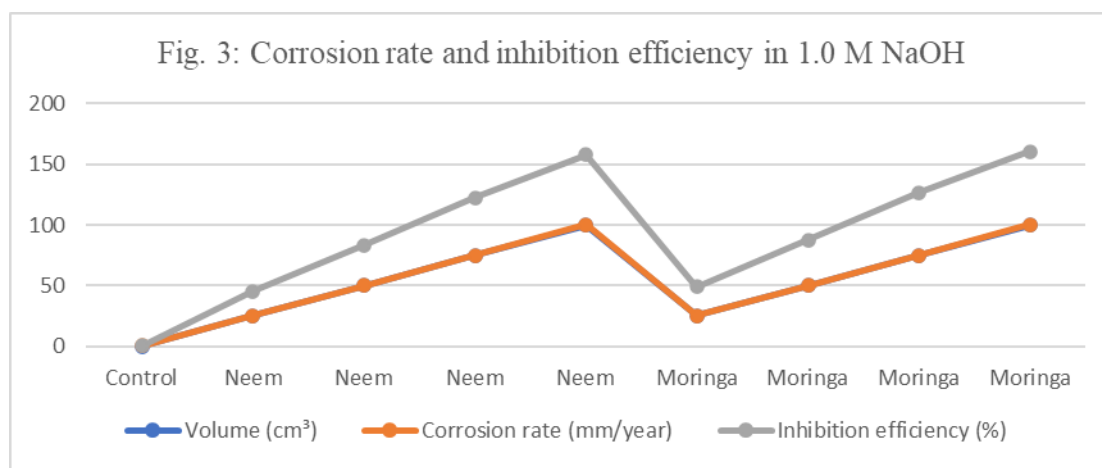


Table 3: corrosion rate and inhibition efficiency in 1.0 M NaOH.

Extract	Volume (cm ³)	Corrosion rate	Inhibition efficiency (%)
Control	0	0.231	0.00
Neem	25	0.184	20.35
Neem	50	0.154	33.33
Neem	75	0.122	47.19
Neem	100	0.097	58.01
Moringa	25	0.176	23.81
Moringa	50	0.145	37.23
Moringa	75	0.112	51.52
Moringa	100	0.091	60.61



DISCUSSION

Effect of Extract Concentration on Corrosion Behavior

The results indicate a progressive reduction in the weight loss of mild steel as the volume of Neem and Moringa leaf extracts increased from 25 to 100 cm³. This trend suggests that increasing the amount of plant extract in the corrosive medium could provide progressively greater surface protection.

The reduction in weight loss may be attributed to the adsorption of bioactive constituents present in the plant extracts onto the mild-steel surface. The study background identifies phytochemicals such as flavonoids, phenolic compounds, tannins, terpenoids, alkaloids and other oxygen-containing compounds as possible contributors to the corrosion-inhibition behavior of plant extracts.

As the quantity of extract increases, more phytochemical molecules become available to interact with the metal surface. These molecules may occupy active corrosion sites and form a relatively protective adsorbed layer between the mild steel and the aggressive NaOH environment.

Consequently, access of corrosive species to the metal surface may be reduced, resulting in lower metal dissolution and, therefore, lower weight loss.

The results also demonstrate an important relationship between weight loss and corrosion rate. Since corrosion rate is related to the amount of material lost during exposure, the specimens with lower weight loss also exhibited lower calculated corrosion rates.

Effect of NaOH Concentration

A comparison of Tables 2 and 3 indicates that the corrosion rates were generally higher in 1.0 M NaOH than in 0.5 M NaOH. The uninhibited control increased from corrosion rate of 0.184 in 0.5 M NaOH to 0.231 mm/year in 1.0 M NaOH.

This indicates that the more concentrated alkaline medium produced a greater corrosive effect on the mild steel under the assumed experimental conditions. The higher corrosion rate in the more concentrated medium was also accompanied by greater weight loss.

However, the addition of both Neem and Moringa extracts reduced the corrosion rate relative to the corresponding uninhibited control. This indicates that the plant extracts provided some degree of protection even under the more aggressive alkaline condition.

Comparison of Neem and Moringa Extracts

Moringa extract produced slightly lower weight loss and higher inhibition efficiency than Neem extract at corresponding extract volumes.

For example, at 100 cm³ in 0.5 M NaOH, the inhibition efficiencies were 59.78% for Neem and 64.13% for Moringa. Similarly, in 1.0 M NaOH, the corresponding values were 58.01% and 60.61%, respectively.

This difference may be associated with differences in the phytochemical composition of the two plants. Neem leaves are known to contain flavonoids, phenolic compounds, tannins, terpenoids, alkaloids and other oxygenated organic compounds, while Moringa leaves are described as containing phenolics, flavonoids, tannins, saponins, alkaloids, terpenoids, proteins and other phytochemicals (Qamarul et al., 2016).

These compounds contain functional groups and electron-rich sites that may facilitate interaction with the mild-steel surface. Adsorption of such compounds can produce a protective layer that interferes with the electrochemical processes responsible for corrosion.

Effect of Extract Volume on Inhibition Efficiency

The data show a continuous increase in inhibition efficiency with increasing extract volume. In 0.5 M NaOH, the inhibition efficiency of Neem increased from 22.28% at 25 cm³ to

59.78% at 100 cm³, while Moringa increased from 25.54% to 64.13% over the same range. A similar trend was observed in 1.0 M NaOH.

The observed increase can be explained by the increasing availability of phytochemical molecules for adsorption onto the metal surface. At relatively low extract volumes, only a fraction of the active corrosion sites may be covered. Increasing the extract quantity could increase surface coverage and consequently improve protection.

Assumed Corrosion-Inhibition Mechanism

The inhibition mechanism of Neem and Moringa extracts may be associated primarily with adsorption of their bioactive constituents onto the mild-steel surface. The phytochemical molecules contain functional groups capable of interacting with the metal surface through physical adsorption, chemical interaction, or a combination of both.

The adsorbed molecules may form a protective film that reduces direct interaction between the mild steel and the corrosive NaOH medium. This protective film can reduce the number of exposed active sites and consequently decrease the rate of metal dissolution.

The proposed mechanism is consistent with the general principle presented in the research document that adsorption of phytochemicals onto metallic surfaces can block active corrosion sites and alter the kinetics of anodic and/or cathodic reactions.

CONCLUSION

The results demonstrate how Neem and Moringa leaf extracts could be evaluated as potential green corrosion inhibitors for mild steel in alkaline media. The dataset shows decreasing weight loss and corrosion rate with increasing extract volume and corresponding increases in inhibition efficiency. The results also demonstrate the importance of corrosive-medium concentration in determining corrosion behavior.

The protective effect is attributed to the adsorption of phytochemical constituents from the plant extracts onto the mild-steel surface, thereby forming a protective layer and reducing the interaction between the metal and the corrosive environment.

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