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DOI: https://doi.org/10.64388/IREV9I9-1714784

Investigation of The Inhibitive Properties of Mangifera Indica (Mango) And Annona Muricata (Soursop) Blend Leaves Extract On Carbon Steel in 0.5M H_2SO_4

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Abstract**: *The inhibition efficiency of mango (Mangnifera indica) and Soursop (Anonna muricata) blend leaves extract as inhibitor of carbon steel in 0.5M H_2SO_4 acidic solution is presented. The corrosion inhibition study was carried out using, gravimetric method. Gas Chromatography (GC) and Fourier Transform Infrared Spectroscopy (FTIR) were used to analyze the Mangifera indica and Annona muricata blend leaves extract. Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology of steel coupons before and after exposure to the corrosive environment. Analyses of the results revealed that adsorption of the Mangifera indica and Annona muricata blend leaves extract on the surface of the carbon steel was spontaneous and occurred according to the mechanism of physical adsorption. The inhibition efficiency was dependent on concentration of the extract and time. Mangifera indica and Annona muricata blend leaves extract exhibited the highest inhibition efficiency (about 93.68%) observed at 48 hours of 1.0 g/ml of extract concentration. At increased concentration of extract, the corrosion rate of carbon steel samples gradually decreased as the days progressed. The least corrosion rate of 2.99 mm/yr was obtained at 1.0g/ml extract concentration. The result showed that Mangifera indica and Annona muricata blend leaves extract is a good inhibitor for the corrosion of carbon steel in H_2SO_4 media. It has a high significant effect on the reduction of the corrosion of carbon steel at room temperature as a result of the formation of films on the substrate thereby displacing water molecules from the metal surface when compared with the control experiment.***

Keywords: Blend, Carbon Steel, Corrosion, inhibition, Extract

I. INTRODUCTION

Corrosion poses a great challenge in industries reliant on metallic materials, posing significant economic and safety concerns. It is the gradual deterioration of metals through chemical reactions with the environment, often resulting in the formation of oxides, hydroxides, or salts on the metal surface (Amadi & Wami, 2023). This process compromises the structural integrity of materials, leading to equipment failures, increased maintenance costs, and potential safety hazards (Ukpaka et al., 2011).

Carbon steel is a versatile material widely used across various industries due to its exceptional properties such as high tensile strength, durability, and affordability. It serves as a fundamental component in construction, manufacturing, transportation, energy production, and numerous other sectors. Its importance stems from its ability to withstand heavy loads, extreme temperatures, and harsh environmental conditions (Amadi et al., 2026).

Owing to the increasing ecological awareness, as well as the strict environmental regulations, and consequently the need to develop environmentally friendly processes, attention is currently focused on the development of "green" alternatives to mitigating corrosion. Green approaches to corrosion mitigation entail the use of substances, techniques, and methodologies that reduce or eliminate the use of products, by-products, solvents, reagents, and so forth that are hazardous to human health or the environment in combating corrosion (Khaled and Al-Mobarak, 2012; Uwah et al., 2013). Among the alternative corrosion inhibitors, organic substances containing polar functions with nitrogen, oxygen and/or sulphur atoms in a conjugated system have been reported to exhibit good inhibiting properties (Bashir et al., 2018).

Plants have been recognized as sources of naturally occurring compounds. Most of the compounds extracted from plants are used in traditional applications such as pharmaceuticals and biofuels. Furthermore, naturally occurring compounds are of interest because they are cost-effective, have abundant availability and more importantly their environmental acceptability. Due to these advantages, extracts of some common plants and plant products have been tried as corrosion inhibitors for metals and alloys under different environments. The qualities mentioned above have made plants become an important source of a wide range of eco-friendly (green) corrosion inhibitors (Hynes et al., 2021).

The corrosion of carbon steel in acidic environments, particularly in sulfuric acid (H_2SO_4) solutions, poses a significant challenge across various industries including manufacturing, chemical processing, and infrastructure. Despite the implementation of corrosion mitigation strategies, the need for effective and environmentally sustainable corrosion inhibitors remains crucial (Dahmani et al., 2010).

In recent years, there has been growing interest in exploring natural products as potential corrosion inhibitors due to their eco-friendly nature and low toxicity. *Mangifera indica* (Mango leaves) and *Annona muricata* (Soursop leaves) are among the botanical sources that have shown promising inhibitive properties against corrosion in various studies (Jmiai et al., 2021).

However, while individual extracts of *Mangifera indica* and *Annona muricata* leaves have demonstrated corrosion inhibition efficacy, there is a dearth of research focusing on their combined inhibitive effects when used in blend extracts. This undoubtedly is the sole concern of this paper to investigate the corrosion inhibition efficacy of a blend extract derived from *Mangifera indica* and *Annona muricata* leaves on carbon steel in a 0.5M H_2SO_4 environment. It is the purpose of this paper to prove that the blend extract of two different plant leaves will be more effective in curbing corrosion than the individual plant extract, hence, this work presents an opportunity to explore synergistic effects of blend extract which has the potential to enhance corrosion inhibition more than an individual plant extract.

This study is important because it aims to provide valuable insights into using natural extracts from *Mangifera indica* and *Annona muricata* leaves as corrosion inhibitors for carbon steel in acidic environments. This research could offer a cost-effective and eco-friendly alternative to conventional corrosion inhibitors. Additionally, understanding the inhibition mechanisms and optimization parameters could lead to the development of more efficient corrosion protection methods, benefiting industries where carbon steel is extensively used, such as construction, automotive, and manufacturing. Ultimately, the findings of this study could help to extend the lifespan of carbon steel components, reducing maintenance costs, and minimizing environmental impact.

II. MATERIALS AND METHODS

2.1. Materials

The following materials were used; carbon steel coupons, venier calipers, cutting machines, desiccators, analytical weighing machine, spatula, thread, ethanol, sulphuric acid, acetone, distilled water, Glasswares, *Mangifera indica* and *Annona muricata* leaves, Fourier transform infrared spectrophotometer(FTIR), Gas chromatography-mass spectrometer, SEM–model: RhenomProx, Phenom World Eindhoven, Netherlands, Stop watch, knife, plastic bucket, grinding machine, filter paper, masking tape, emery papers, calculators, computer, graphs, note books.

2.2 Methods

2.2.1 Sample collection

The *Mangifera indica* and *Annona muricata* leaves were obtained from Apani Town in Ikwerre Local Government Area of Rivers State. The leaves so collected were put in a nylon bag and put into an air conditioned vehicle to preserve the leaves from being damaged by high temperature of the environment. The leaves were transported to Chemical & Petrochemical laboratory to be blended.

2.2.2 Preparation of Coupons

Carbon steel was obtained from the Mechanical Workshop at Rivers State University. The carbon steel was cut into coupons of dimensions 50mm x 25mmm x 1mm. The coupons were cleaned followed by polishing to a uniform surface finish with emery paper to expose a shining polished surface. To remove any oil and organic impurities, the coupons were degreased with acetone and finally washed with distilled water, dried in air and then stored in desiccators. The accurate weight of each coupon was taken using an analytical weighing balance and the initial weight was recorded. A total of 30 coupons were prepared and used for the study.

2.2.3 Preparation of 0.5M H_2SO_4 Acid Solutions

The solution of 0.5M H_2SO_4 was prepared using distilled water. It was prepared with the aid of an analytical weighing balance, volumetric flask, and beakers. For the preparation of 0.5M H_2SO_4, 27.12 ml H_2SO_4 (98.08% pure, specific gravity of 1.84) was added to 1liter of distilled water in a measuring cylinder. The solution was made up to 1 litre with the addition of distilled water. The acidity was verified by a pH measurement.

2.2.4 Extraction of the Plant Extracts

The *Mangifera indica* and *Annona muricata* Leaves were washed with distilled water to remove surface impurities. After washing, the leaves are air-dried in a well-ventilated area away from direct sunlight to preserve their phytochemical constituents. After air drying, the dried leaves were separately ground to increase the surface area and stored in closed containers. The dried and grounded leaves were measured and mixed in predetermined ratios of 50:50 to form a blended mixture. 20 grams of each of the blended plant leaves were measured and soaked in 1litre of ethanol (99.7% v/v) for 24 hours. At the end of the 24 hours, each plant mixture was filtered. The filtrate obtained is a mixture of the plant extract and the ethanol. The plant extract obtained in ethanol solvent was concentrated by evaporating the ethanol from the mixture. The plant extract was weighed and stored for the corrosion inhibition study.

2.2.5 Characterization of the Plant Extracts

2.2.5.1 GC MS Analysis of the Plant Extracts

Chemical analysis of each of the plant extracts was carried out using a gas chromatography-mass spectrometer (GCMS-QP2010, SHIMADZU). The gas chromatography-mass spectrometer combined the features of gas chromatography (GC) and mass spectrometry (MS) to identify different substances within a test sample of the blended plant extract. In the GC, the plant extract was separated into individual substances when heated. The heated substances were carried through a column with an inert gas. As the separated substances emerged from the column opening, they flew into the MS. The MS identified the compounds of the plant extract by the mass of the analyte molecule.

2.2.5.2 FTIR analysis of the plant extracts

FTIR spectrophotometer is a powerful instrument used in identifying the type of bonding especially functional groups existing in organic compounds (El Ibrahim, et al., 2020). Extracts contain organic compounds and these organic compounds are adsorbed on the metal surface providing protection against corrosion. Therefore, the FTIR analysis can be suitable in predicting whether organic inhibitors are adsorbed or not adsorbed; FTIR spectra were used to support the fact that corrosion inhibition of carbon steel in an acid medium is due to the adsorption of inhibitor molecules on the carbon steel surfaces as well as providing new bonding information on the metal surface after immersion in inhibited H_2SO_4 solutions.

The isolated inhibitor and the protective film formed over carbon steel surfaces by the inhibitor molecule were analyzed separately using FTIR spectroscopy using the KBr pellet method. The specimen was immersed in the corrosive medium consisting of 0.2-1.0g/l of the inhibitor for 8 hours, which resulted in the formation of a fine protective film over the carbon steel surface. Further, the film were carefully scratched from the carbon steel surface and analyzed by FTIR spectroscopy. The analyses were carried out by using the Perkin Elmer System FTIR instrument.

2.2.5.3 Scanning Electron Microscopy (SEM) Analysis of Metals

Scanning electron microscopy (SEM) was used for monitoring the surface morphological changes. In this study, the retrieved carbon steel coupons which were used for the experiment in the absence and presence of the inhibitor were subjected to SEM analysis after being cleaned with distilled water and dried in acetone.

2.2.6 *Experimental Procedures*

The weight loss method was carried out at room temperature using different concentrations of the blended plant extracts. Five (5) weighed metal coupon was separately immersed in 250 ml open beakers containing 100ml of 0.5 H_2SO_4 for control experiment. Five (5) weighed metal coupons were separately immersed in different 250 ml open beakers each containing 100ml of 0.5M H_2SO_4 with different concentrations (0.2, 0.4, 0.6, 0.8, 1.0 g/L) of the blended plant extracts. The variation of weight loss was monitored periodically in different media, in the absence (control) and presence of different concentrations of the plant extracts. The coupons were taken out after 24hrs, 48hrs, 72hrs, 96hrs and 120hrs respectively and immersed in acetone, scrubbed with a bristle brush under running water, dried and reweighed. The weight loss was calculated in grammes as the difference between the initial weight and the weight after the removal of the corrosion product. The experimental readings were recorded. The weight loss (Δw), corrosion rate (CR) and inhibition efficiency (IE) were obtained using equations (1), (2) and (3) respectively.

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DOI: https://doi.org/10.64388/IREV9I9-1714784

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

$$CR = \frac{\Delta m \times 8.76 \times 10^4}{\rho A t}\left(\frac{mm}{year}\right) \quad (2)$$

$$IE\ \% = \omega = \frac{(\omega_0 - \omega_1)}{\omega_0} \times 100 \quad (3)$$

where W_i and W_f are the initial and final weight of metal samples respectively; ω_1 and ω_0 are the weight loss values in the presence and absence of inhibitor, respectively. A is the total area of the specimen and t is the immersion time.

III. RESULTS AND DISCUSSION

3.1.1 *Gas Chromatography-Mass Spectrometry Analysis*

The phytochemical constituents identified in the ethanolic leaf extracts of *Mangifera indica* and *Annona muricata* leaves blend were analyzed using GC-MS, with a total run time of 40 minutes. The gas chromatogram shows the relative concentrations of various compounds getting eluted as a function of retention time. The heights of the peaks indicate the relative concentrations of the components present in the plant. GC-MS analysis revealed the presence of compounds with good inhibitive properties such as Sterols, stanols and Terpenoids, Butanal, oxime, 1,2,4-Thiadiazole-3,5-diamine, IsoCaryophyllene, D-Limonene, 2-Propanone,1-hydroxy and, Linolenic acid. The inhibitive properties of *mangifera indica* and *muricata indica* blend extracts are in consonance with literature (Khan et al., 2019; Ebenso et al., 2008). The carbonyl group, carbon double bonds, and the presence of the aromatic group also suggest that the leaves blend extract can serve as a good corrosion inhibitor of carbon steel (Dehghani et al., 2019).

3.1.2 *Fourier Transform Infrared Spectrophotometer (FTIR) Analysis*

The FTIR spectra of the pure plant extracts and the corrosion products associated with these extracts are presented. The detailed analysis, including peak positions, intensities, and functional group assignments for the FTIR data of the plant extracts and the corrosion products, is in consonance with literature (Khaled et al., 2009; Mobin et al., 2019; Oyewole et al., 2021). The observed shifts and disappearances of certain functional groups in the scratched metal oxide films, as revealed in the analysis are indicative of the active functional groups that play a crucial role in inhibiting corrosion in metals (Chigondo & Chigondo 2016; Neriyana & Alva 2020;). The adsorption operation in this analysis indicated that the extracts were adsorbed on the surface of the metal.

3.1.3 *Metal surface study using Scanning electron microscopy (SEM)*

Scanning Electron Microscopy (SEM) was employed to investigate the surface morphology of steel coupons before and after exposure to the corrosive environment with and without the leaf extract. This analysis provides critical insights into the extent of corrosion and the protective role of the extract. The SEM images revealed distinct differences in the surface morphology of the steel coupons. The micrographs of the corroded metals in the corrosive media (control) and in the presence of the plant extracts are presented in Figure 1 and Figure 2. The steel coupons exposed to the corrosive medium without any inhibitor exhibited significant pitting and roughness. This finding suggests that the corrosive environment was aggressive, leading to considerable material loss. In contrast, the coupons treated with the leaf extract displayed a smoother surface with fewer corrosion features. The SEM images indicated the formation of a protective layer, which may be attributed to the adsorption of phytochemical constituents from the leaf extract (Brown et al., 2021; Eduok et al., 2012; Gerengi et al., 2016). This layer appears to mitigate the interaction between the steel surface and corrosive agents, thus enhancing corrosion resistance.

Figure 1: The micrograph of corroded carbon steel in H_2SO_4

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DOI: https://doi.org/10.64388/IREV9I9-1714784

Figure 2: The micrograph of corroded carbon steel in the presence of *Mangifera indica* and *Annona muricata* leaves blend extract.

The morphology of the carbon steel surface depicted in Figure 1 indicates significant degradation in the absence of inhibitors, characterized by extensive uniform corrosion. In contrast, Figure 2 illustrates that the application of green inhibitors effectively mitigated the corrosion rate. This reduction can be attributed to the formation of an adsorbed inhibitor film on the carbon steel surface. The protective properties of this film are corroborated by the inhibition efficiency measurements as seen in Chung et al., 2020; Aralu et al., 2021; Bahlakeh et al., 2019.

3.1.4 Weight Loss Studies

Tables 1 shows the result of weight loss. Table 2 shows the corrosion rate (CR) and Table 3 shows the inhibition efficiency of the carbon steel in H_2SO_4 acid media using *Mangifera indica* and *Annona muricata* blend leaves extract. These were evaluated using equations (1), (2) and (3) respectively.

Table 1: Weight loss(g) analysis of experimental data (Extract and Control) at different time

Time (Hrs)	Control	0.2	0.4	0.6	0.8	1.0
24	0.18	0.15	0.14	0.13	0.13	0.11
48	0.22	0.19	0.18	0.16	0.15	0.12
72	0.24	0.23	0.23	0.21	0.18	0.16
96	0.27	0.27	0.25	0.24	0.22	0.19
120	0.31	0.29	0.27	0.25	0.25	0.21

Table 2: Corrosion rate (mm/yr) of Carbon Steel (Extract and Control) at different time

Time (Hrs)	Control	0.2	0.4	0.6	0.8	1.0
24	2.56	2.13	1.99	1.85	1.85	1.56
48	3.12	2.70	2.56	2.27	2.13	1.71
72	3.41	3.27	3.27	2.99	2.56	2.27
96	3.83	3.84	3.55	3.41	3.13	2.70
120	4.40	4.12	3.84	3.55	3.55	2.99

Table 3: Inhibition efficiency (%) of Carbon Steel with different Concentrations of *Mangifera indica* and *Annona muricata at different time*

Conc (g/ml)	24	48	72	96	120
0.2	87.5	90	89.05	88.75	88.85
0.4	88.33	90.53	89.05	89.58	89.62
0.6	89.17	91.58	90.00	90.00	90.38
0.8	89.17	92.11	91.43	90.83	90.38
1.0	90.83	93.68	92.38	92.08	91.92

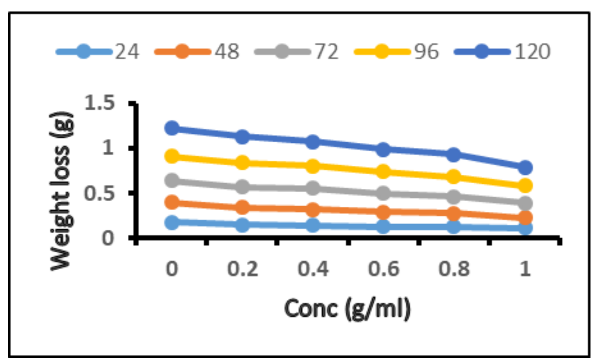

Figure 3: Weight loss of carbon steel immersed in $0.5MH_2SO_4$ with different Concentrations of *Mangifera indica* and *Annona muricata* leaves blend extract at different Time

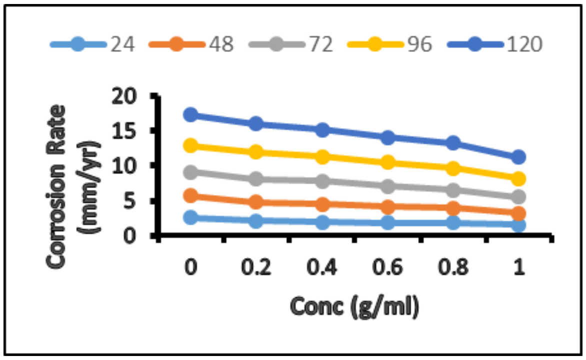

Figure 4: Corrosion Rate of carbon steel immersed in 0.5MH_2SO_4 with different Concentrations of *Mangifera indica* and *Annona muricata* leaves blend extract at different Time

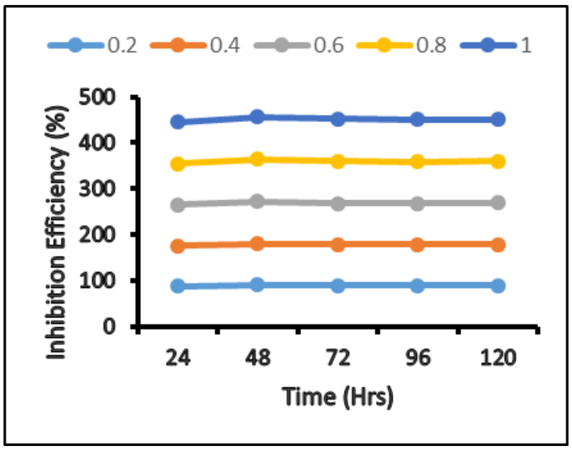

Figure 5: Corrosion Inhibition Efficiency with different concentration of *Mangifera indica* and *Annona muricata*blend leaves extract at different Time on Carbon Steel

The reduction in weight loss and corrosion rate in the presence of the plant extract as seen in Figure 3 and Figure 4 can be attributed to the adsorption of the phytochemicals onto the carbon steel surface, which forms a protective barrier that inhibits the interaction between the metal and corrosive agents. This barrier function is crucial in slowing down the electrochemical reactions responsible for corrosion (Patni et al., 2013; Rani & Basu 2012).

Additionally, the results suggest a concentration-dependent relationship, where higher concentrations of the *Mangifera indica* and *Annona muricata* blend leaves extract correlate with greater inhibition efficiency as seen in Figure 5. This observation aligns with previous studies that have reported enhanced protective effects at elevated concentrations of natural inhibitors (Sedik et al., 2020; Ugi et al., 2018).

From Table 4, it is seen that the control samples exhibited higher corrosion rates due to the aggressive nature of the acid. However, as exposure time increased, samples treated with leaf extract showed significant reductions in corrosion rates, with the effectiveness varying according to the concentration. Higher concentrations of the inhibitor corresponded to lower corrosion rates, indicating a more robust protective film formation on the metal surface. This is in consonance with literature (Nitin & Sudesh, 2015).

In contrast, samples treated with leaf extract showed reduced weight loss as immersion time increased. The leaf extract's active compounds adsorbed onto the metal surface, forming a protective barrier that mitigated corrosion. This barrier became increasingly effective over time, resulting in a progressive decrease in weight loss compared to the control samples. The results demonstrate that the presence of the leaf extract significantly slows corrosion rates, highlighting its potential as an effective long-term corrosion inhibitor in acidic conditions (Wang et al., 2021; Zhang et al., 2021).

CONCLUSION

The *Mangifera indica* and *Annona muricata* blend leaves extract examined was found to be an effective inhibitor for the corrosion of carbon steel. The inhibition efficiency of the leaf extract increased with an increase in extract concentrations. The extracts exert their inhibitive properties by being adsorbed spontaneously on the surface of the carbon steel. SEM examinations showed that the control samples were mostly affected compared with the coupons treated with the plant extracts. Similarly, it was observed that the presence of extracts reduced surface erosion and pitting. FTIR and GC-MS profiling identified the presence of fatty acids, phenols, flavonoids, and antioxidant compounds with an affinity for metal surface binding, hence, *Mangifera indica* and *Anona muricata* blend leaves extract can effectively be used to curb corrosion problems.

ACKNOWLEDGMENT

We wish to acknowledge the assistance of the laboratory Technologists in Chemical and Petrochemical Engineering, Faculty of Engineering, Rivers State University, Port Harcourt.

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