JCARM
Journal of Contemporary Academic Research and Methodologies

An Online Peer Reviewed / Refereed Journal
Volume 1 | Issue 3 | April 2026
Website: www.journal.jcarm.in

Research

Assessing Corrosion Inhibition Behavior of Sodom Apple (Calotropis Procera) Latex Extract for the Prevention of Corrosion on Mild Steel.

H. A. Bukar[1]*, M. B. Maina[1], A. B. Muhammad[1]

[1]Department of Mechanical Engineering, University of Maiduguri, Borno State, Nigeria.

Correspondence should be addressed to: hassanbkmail@gmail.com

Abstract: Assessment of the corrosion inhibition behaviour of Sodom apple (Calotropis Procera) latex extract for the prevention of corrosion on mild steel using gravitation method was conducted in this research. The latex was extracted and Phytochemical analysis of the extract was conducted. The presence of saponins, alkaloids, terpenes, flavonoids, glycosides, reducing sugars and tannins were tested for by the simple qualitative and quantitative methods. Corrosion test was carryout using 16 mild steel sheet coupons in 0.5 M H2SO4 acidic medium with and without addition of the plant extract (inhibitors). The corrosion inhibition behaviour of the latex test using gravitational method and the result revealed that latex is effective in inhibiting corrosion. The analysis showed that the inhibition efficiency of the inhibitor increased with the increase of plant extract concentration but mildly reduces with increase in exposure time. It is recommended that further work should be carried on the corrosion inhibition efficiency of Sodom apple (calotropis procera) latex in alloys and other corrosive mediums. The effect of increasing the inhibitor concentration beyond 2.5ml should be looked into. Also, the storage stability, durability and industrial applicability of the Sodom apple (calotropis procera) latex need to be explored.

Keywords: Sodom-apple, Corrosion, inhibition, Phytochemical, Weight-loss.

INTRODUCTION

According to El-Etre (2003) and Ibrahimi et al. (2021), corrosion is the slow deterioration of metals or alloys caused by chemical reactions at their surface with their surroundings. This results in material deterioration, structural compromise, and eventually the need for expensive remediation efforts, such as replacement or extensive repair.

Corrosion is a catastrophic phenomenon bedevilling many sectors of the Nigerian economy.

One of the major industrial sectors in Nigeria experiencing this problem is the Oil and Gas industry. Nigeria's oil and gas industry is highly susceptible to corrosion because of the country's humid environment, the high salt content of the coastal air, and the kinds of extracted crude oil that contain corrosive compounds like sulfur. Nigeria's corrosion expenses are expected by the Nigerian National Petroleum Corporation (NNPC) to surpass US$765 million annually for pipeline replacements and repairs (NNPC, 2020). When indirect effects like production delays, environmental remediation, and litigation after pipeline breaks are taken into consideration, associated costs are much higher. Nigeria loses about US$10 billion annually as a result of oil spills and the ensuing closure of production facilities, according to the NEITI (2019).

And Mild steel is commonly used in a wide range of industries due to its cheap cost and availability (Benabdellah *et al*. 2006, Satapathy*et al.* 2009). Observations showed that the major causes of failure such as ageing, corrosion, mechanical failures-welding defect, stress etc. (Achebe *et al*., 2012). Corrosion phenomena, control and prevention are unavoidable major scientific issue that must be addressed daily as far as there are increasing needs of metallic materials in all facets of technological development (Abba-Aji *et al:*, 2020; Loto *et al.,* 2011). Corrosion has a wide range of impacts, many of which are more detrimental to the safe, dependable, and effective operation of machinery or structures than the mere loss of a metal mass. Even though the amount of metal damaged is very minor, failure of various kinds and the need for costly replacement may occur (Umoren, 2009). The attack pattern is heavily influenced by a number of variables related to the metal, the state of the service, and the type of prison setting. It is easy to categorize corrosion based on how it appears (Fontana et al., 2012). Prevention and control involve material selection, protective coatings, cathodic protection, and environmental modifications (inhibitors) are the methods used to eliminate or reduce corrosions (DeBruijn and Whitton, 2021).

Corrosion inhibitors are widely used in industry to reduce the corrosion rate of metals and alloy in contact with aggressive environments (Monticelli, 2018)). Most of the corrosion inhibitors are synthetic chemicals, expensive and very hazardous to environments. Therefore it is a desire to source for environmentally safe inhibitors (Majidi, 2004). Among the several methods of corrosion and prevention, the use of corrosion inhibitors is very popular. Corrosion inhibitors are substances which when added in small concentrations to corrosive media decrease or prevent the reaction of the metal with the media (Riggs, 1973, Ashassi-Sorkhabi, 2008, Rani and Bharathi, 2012). Corrosion inhibitors are the most practical and economical way to fight corrosion. Particularly on low-carbon steel surfaces, corrosion inhibitors stop corrosion by adhering to the metal surface and blocking one or more electrochemical reactions at the solution/metal interface.Anodic (passivating), cathodic (precipitating), and mixed-type inhibitors—which are further divided into inorganic, organic, and green categories—are the primary types (Răú et al., 2025).

Mild steel corrosion can be effectively prevented by inhibitors, although some organic inhibitors in use are synthetic chemicals (heavy metals), expensive and very hazardous to environment. Therefore, it is desirable to source for environmentally safe inhibitors (Paul *et al.,* 2012, Loto *et al.,* 2011, Ambrish *et al.,* 2010). This has prompted a search for inexpensive, renewable, and non-toxic green corrosion inhibitors. Due to their plant-based origins, these green inhibitors are both broadly accessible and eco-friendly (Presuel-Moreno et al., 2008; Abdel-Gaber *et al.,* 2008; Răú et al., 2025).

Green corrosion inhibitors use phytochemicals like tannins, flavonoids, and alkaloids to create protective films on metal surfaces (Bhoomika et al., 2024). Extracts from plants like Aloe vera, tannic acid, jatropha, pomegranate peel, and onion extract are effective sources that frequently achieve over 90% efficiency in preventing steel corrosion (Loto *et al.,* 2011; Fazal et al., 2023; Wang et al., 2023; Holla et al., 2024; González- & Di Turo et al., 2024; Parangusan et al., 2025). This work assessed the corrosion inhibition behavior of Sodom Apple (Calotropis procera) *latex* in prevention of corrosion of mild steel in H_2SO_4. The Sodom apple plants (Calotropis procera) are in abundance in the northern Nigeria growing as a weed. Plate 1 presents a typical Sodom apple (Calotropis Procera) plant.

Figure 1: Sodom apple (Calotropis Procera) plant

Loto *et al.* (2011) investigated the corrosion and plant extract inhibitive protection of mild steel specimens immersed in 0.5 hydrochloric acid was investigate at ambient temperature by gravimetric and metallographic methods, extracts of kola plant and tobacco in different concentrates were used as green inhibitors. Similarly Anafi and Obi (2004) investigate the corrosion inhibition of mild steel in simulated media by methanolic extract of bitter leave. They found out that the inhibition ability of bitter leaf against corrosion was best in sea water where it inhibited an inhibitive efficiency of 61.19%. Chaudhari and Vashi (2016**)** Studied henna leaves extract as green corrosion inhibition for mild steel in acetic acid. The study indicates the corrosion inhibition efficiency increases in concentration of extract the result obtained shows that henna leaves act as an efficient inhibitor. Rochaa *et al.,* (2014) Observed that the aqueous extracts of mango and orange peels were shown to be good corrosion inhibitors for carbon steel in a 1M HCl solution. Okon et al. (2017) reported that the inhibition of the corrosion of mild steel in 1M H_2SO_4 solution by *jatropha tanjorensis* leaf extract has been studied using weight loss techniques. The result obtained showed that the *jatropha tanjorensis* leaf effectively inhibited the corrosion of mild steel in H2SO4 solution. The highest efficiency was found to occurred at 0.5 g/L jatropha tanjorensis leaf concentration at 333k by weight loss measurements. Ibrahim and abouzour (2011) looked at the inhibition effect of Fig leaves extract on corrosion of mild steel in 2M acid solution. Inhibition efficiency of as high as 87% were achieved for Fig leaves extract of above 200 ppm. Furthermore ,Ibisi *et al*. (2017) studied The inhibitory behavior of Piper guineense leaves extract and Vernoni aamygdalina leaves extract on corrosion of mild steel in 2.5M HCl solution, are comparatively studied using gravimetrical and gasometrical methods respectively. The results obtained showed that both Piper guineense leaves extract and Vernonia amygdalina leaves extract efficiently inhibit corrosion of mild steel in concentrated corrosive medium.

MATERIALS AND METHODS

Material/Equipment

The materials used for this study include:

Mild steel sheet (5cmx5cmx1cm) specimen, Sodom apple latex extract, Ethanol, acetone, distilled water and H_2SO_4 acid solution

Equipment

The equipment used in this study includes:

i. Digital Weighing balance (0.0001gm accuracy) used for weighting coupons and plant extract.
ii. Beaker (250ml) used for holding the acid solution and the inhibitors in to which the mild steel coupon sample were immersed.
iii. Desiccator was used for drying and keeping the prepared samples of the coupon air tied.
iv. Microprocessor digitalized machine was used for measuring PH value of plants extract.
v. Thread was used for the suspension of the mild steel coupon in the corrosive media.
vi. Measuring Cylinder (100ml) was used for measuring the volume of H_2SO_4 solution.
vii. Volumetric flask was use to dilute H_2SO_4 solution with water.
viii. Thermostat was used for measuring the temperature where the experiments was carried out.
ix. Funnel was used for guiding the extracts during the pouring process.

Methods

Extraction of inhibitors

The milky emulsion from the Sodom apple was tapped behind NNPC depot Maiduguri, Borno state Nigeria. The latex was tapped by cutting the fresh leaves and stems of the plants. The white latex was squeezed in to collection containers and stored under ambient conditions.

Determination of the Phytochemical constituents in the Calotropis Procera latex

The Phytochemical screening of the Sodom apple (Calotropis Procera) latex was carried out in Department of Pharmacy, University of Maiduguri in order to identify the main groups of active chemical constituents present in the latex by their colour reaction. The presence of saponins, alkaloids, terpenes, flavonoids, glycosides, reducing sugars and tannins were tested for by the simple qualitative and quantitative methods by adopting the method reported by Odeja et al., (2015) and Okewale and Olaitan; (2017). The tests conducted are:

i. Test for reducing sugars (Fehling's test)

The aqueous ethanol extract (0.5 g in 5 ml of water) was added to boiling Fehling's solution in a test tube. The solution was observed for a colour reaction.

ii. Test for Anthraquinones

0.5 g of the extract was boiled with 10 ml of sulphuric acid (H_2SO_4) and filtered while hot. The filtrate was shaken with 5 ml of chloroform. The chloroform layer was pipetted into another test tube and 1 ml of dilute ammonia was added. The resulting solution was observed for colour changes.

iii. Test for Terpenoids (Salkowski test)

2 ml of chloroform was added to 0.5 g of the latex. Concentrated H_2S0_4 (3 ml) was carefully added to form a layer. A reddish brown coloration of the interface indicates the presence of Terpenoids.

iv. Test for Flavonoids

Three different test methods were used to test the flavonoids content of the latex. First, dilute ammonia (5 ml) was added to a portion of an aqueous filtrate of the extract. Concentrated sulphuric acid (1 ml) was added. A yellow colouration that disappears on standing indicates the presence of flavonoids. Second, a few drops of 1% aluminium solution were added to a portion of the filtrate. A yellow colouration indicates the presence of flavonoids. Third, a portion of the extract was heated with 10 ml of ethyl acetate over a steam bath for 3 min. The mixture was filtered and 4 ml of the filtrate was shaken with 1 ml of dilute ammonia solution. A yellow colouration indicates the presence of flavonoids.

Test for Saponins

To 0.5 g of extract was added 5 ml of distilled water in a test tube. The solution was shaken vigourously and observed for a stable persistent froth. The frothing was mixed with 3 drops of olive oil and shaken vigourously after which it was observed for the formation of an emulsion.

Test for Tannins

About 0.5 g of the extract was boiled 10 ml of water in a test tube and then filtered. A few drops of 0.1% ferric chloride was added and observed for brownish green or a blue-black colouration.

Test for Cardiac glycosides (Keller-Killiani test)

To 0.5 g of extract diluted to 5 ml in water was added 2 ml of glacial acetic acid containing one drop of ferric chloride solution. This was underlayed with 1 ml of concentrated sulphuric acid. A brown ring at the interface indicated the presence of a deoxysugar characteristic of cardenolides. A violet ring may appear below the brownring, while in the acetic acid layer a greenish ring may form just above the brown ring and gradually spread throughout this layer.

Preparation of Mild Steel Coupon (Sample)

The mild steel sheet coupon used for this research was obtained from the Faculty of Engineering Teaching Workshop (Mechanical Workshop) University of Maiduguri, Borno state, Nigeria. The coupons were polished with silicon carbide emery cloth and cut 16 pieces of coupons, each having a dimension of 6cm x 6cm x 0.1cm. The coupons were washed with acetone, dried in air and kept in a desiccator. The weight loss test method (Gravimetric Technique) was used to study the efficacy of the corrosion inhibitor. The coupons were suspended using nylon thread and glass rod in a 100ml beaker with 100ml of the 0.1M HCl without and with different concentrations of the inhibitor.

Preparation of 0.5 M H_2SO_4 Solution

The concentration H_2SO_4 solution has a density of 1.84g/cm^3 and percentage purity of 98%. It has a molar mass of 98g/mol.

$$Molarity = \frac{\%\, purity\ of\ solution\ x\ density\ x\ 10}{molar\ mass\ of\ the\ solution} \qquad 1$$

$$Molarity = \frac{1000x1.84x0.98}{98} = 18.40M$$

From the relation:

$$C_1V_1 = C_2V_2 \qquad 2$$

Where: C_1 is the concentration of the stock, C_2 is the required molarity of the solution (0.5M), V_1 is the volume of stock solution needed to prepare the 0.5 M acid and V_2 is the volume of acid required (1000cm^3**)**. Similarly, the volume of the standard H_2SO_4 solution required for 1000ml of 0.5 M H_2SO_4 can be obtained as follows:

$$18.4 \times V_1 = 2 \times 1000$$

Hence $V1 = \frac{2x1000}{18.40} = 108.69ml$

Corrosion Inhibition Test

Gravimetric Technique

The 16 cut coupons were and each were then suspended in 15 cL of 0.5M H_2SO_4 various concentration of the latex (blank, 0.5ml, 1ml, 1.5ml, 2ml, 2.5ml) for the period of 14 days. The specimens were taken out, washed with distilled water, rinsed with ethanol, dried manually, and weighed again to obtain its new mass after every 24 hours. The experiment was carried out in duplicate and the average value stated. The weight-loss was calculated after each measurement. From these data, the various values of the inhibition efficiency (I.E %), Corrosion rate (Cr) and Surface coverage (θ) was calculated using the following mathematical relationships:

3.3.1 Weight loss

Loss in weight (W_L) as result of corrosion was calculated using Equation 3

$$W_L=W_i-W_f \qquad 3$$

Where W_i and W_f are initial and final weights of the mild steel coupon.

3.3.2 Corrosion rate

The corrosion rate of mild steel can be calculated from weight loss of coupon at a fixed concentration and varied immersion with time. Corrosion rate was calculated using Equation 4

$$Cr\ (mmy^{-1}) = \frac{KxWL}{AtD} \qquad 4$$

where k is a constant given by 87.6, W_L is corrosion weight loss of mild steel (g) in the t, A is the surface area of the metal exposed ($24cm^2$), t is the exposure time (hours) and D is the density of the mild steel (7.8 g/cm^3).

3.3.3 Corrosion inhibition efficiency

The percentage of the inhibitor efficiency (I.E) was calculated using Equation 5

$$I.E = \frac{Wo-Wi}{Wo} X\ 100 \qquad 5$$

RESULTS AND DISCUSSION

Phytochemical Screening

The Phytochemical analysis shows the chemical compounds that are present the Calotropis procera latex. Table 1 shows the type and quantities of different compounds contained in the Calotropis procera latex. The results shows strong presence ($_{++}$) of Cardiac glycoside, saponins, Anthraquinine and while Carbohydrates, Flavonoid and Tannins are in moderate quantizes ($_{+}$). The presence of tannins, Saponins, flavonoid, Anthraquinine and cardiac glycoside shows a promising prospect of inhibiting corrosion. These natural compounds found in the latex serves as a barrier at the surface of mild steel through the mechanism of adsorption, thereby inhibiting or retarding the corrosion process of mild steel sheet. Phytochemical constituent of the latex contains rich naturally synthesized biodegradable organic compounds which combat corrosion on mild steel in aggressive acidic media. These natural compounds found in the latex serves as a barrier at the surface of mild steel through the mechanism of adsorption, thereby inhibiting or retarding the corrosion process of mild steel sheet. Phytochemical constituent of the latex contains rich naturally synthesized biodegradable organic compounds which combat corrosion on mild steel in aggressive acidic media.

Table 1: Qualitative analysis of phytochemical screening of plants extract

Phytochemicals	Calotropis procera latex
Carbohydrates	+
Cardiac glycoside	++
Reducing sugar	–
Anthraquinine	++
Saponins	++
Flavonoid	+
Tannins	+

Key: + mildly presence, ++ strongly presence, - absence

According to the Phytochemical test results in Table 1, the presence of tannins, saponins, and anthraquinones with functional groups comprising carbon, nitrogen, and oxygen in the chemical structure of the Calotropis procera latex also improves the process of corrosion inhibitor adsorption on the mild steel. Additionally, this supports the findings of (Nwigbo et al., 2012; Prithiba et al., 2014; Owate et al., 2014, Okewale and Olaitan, 2017). These substances have been shown to enhance mild steel's ability to withstand corrosion in harsh acidic environments (Umoren et al., 2006). According to Barmatov et al. (2012), molecules combining nitrogen and acetylenic alcohols are said to form a coating on the metal surface and can delay both the cathodic reaction of hydrogen evolution and the anodic reaction of metal dissolution.

Results obtained from weight loss measurement

The weight loss of mild steel coupon was studied at and interval of 24hr for two consecutive weeks (14 days) in the absence and presence of concentration of Calotropis procera latex in 15 cl of H_2S0_4 acid solution at (0.5ml, 1ml, 1.5, 2ml and 2.5ml) latex concentration. Figures 1 and 2 depict the nature of weight losses by the coupons under different concentration of the inhibitor and the inhibition efficiency of the Calotropis procera latex. The Figure 1 showed that the weight loss of the mild steel coupon decreases with the increase in concentration of the Calotropis procera latex. The coupons exposed to the H_2S0_4 acid solution with 0 and 0.5ml concentration of the Calotropis procera latex (inhibitor) exhibited high weight losses of about 0.25g/day. However, as the concentration of the inhibitor increases from 1.0ml to 2.5ml, the rate of weight losses experienced by the coupons also decreases, where the coupons exhibited weight losses in the range of 0.03g – 0.1g as the exposure time increases. The inhibition efficiency of the inhibitor is very high at concentration of 1.0ml, 1.5ml, 2ml, to 2.5ml respectively. The adsorption phenomena of one or more of the Calotropis milky emulsion organic compounds, containing more than one inhibitor corrosive function group such as formyl and hydroxyl group. This behavior exhibited by the Calotropis procera latex inhibitor is in agreement with that was reported by (Iwah et al., 2013; Zhou et al., 2012; Casaletto et al 2018).

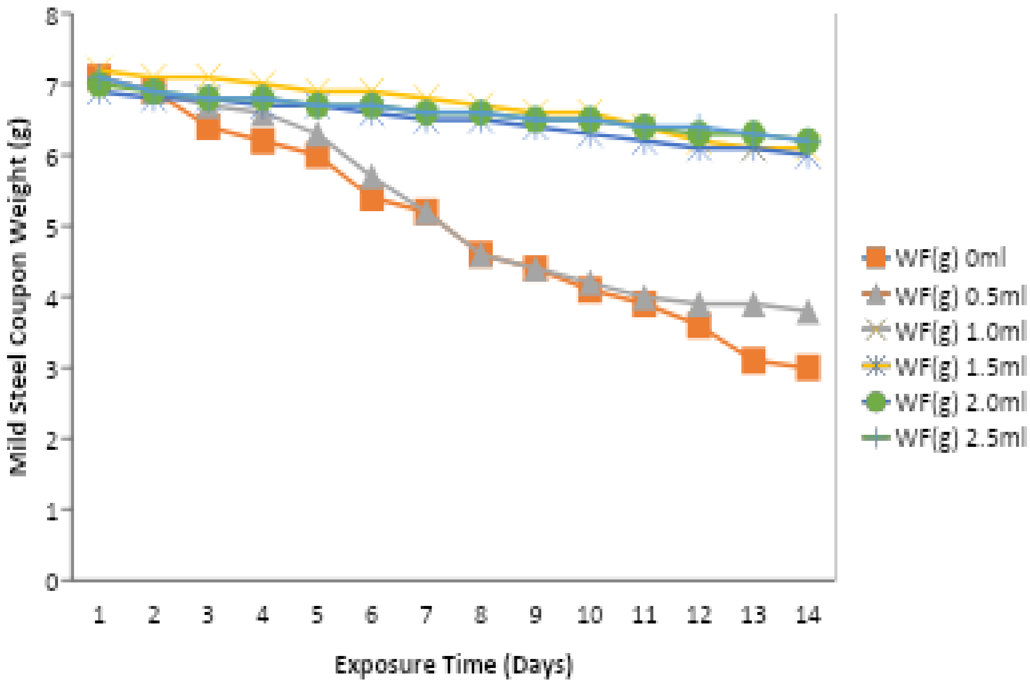

Figure 1: Weight Losses by the Coupons under Different Concentration of the Inhibitor

Figure 2 shows the **i**nhibition efficiencies exhibited by the Calotropis procera latex inhibitor in the H_2SO_4. The figure showed that the coupon with 0.5ml of the inhibitor exhibited an average inhibitor efficiency of 46.7% but as the exposure time increases, the coupon exhibited a drastic decrease in corrosion inhibition efficiency to about 18%. The figure further showed that the inhibitor efficiency of coupons with Calotropis procera latex concentrations (1.0ml, 1.5ml, 2.0ml and 2.5ml) exhibited increase in inhibitor efficiency with increase in inhibition concentration with the one having 2.5ml of Calotropis procera latex concentrations outperforming all the coupons with an inhibitor efficiency of 97.7% but all also exhibited mild drop in inhibitor efficiency with increase in exposure time to about 80%. The behaviour exhibited by the inhibitor is in line with the findings of Rajeev et al., (2012) and Okewale and Olaitan, (2017), the authors reported that it has been discovered that the effectiveness of inhibitors generally declines with exposure duration. The fact may be explained by the possibility of partial desorption of the inhibitor molecules that were previously adsorbed on the metal surface after a prolonged exposure time.

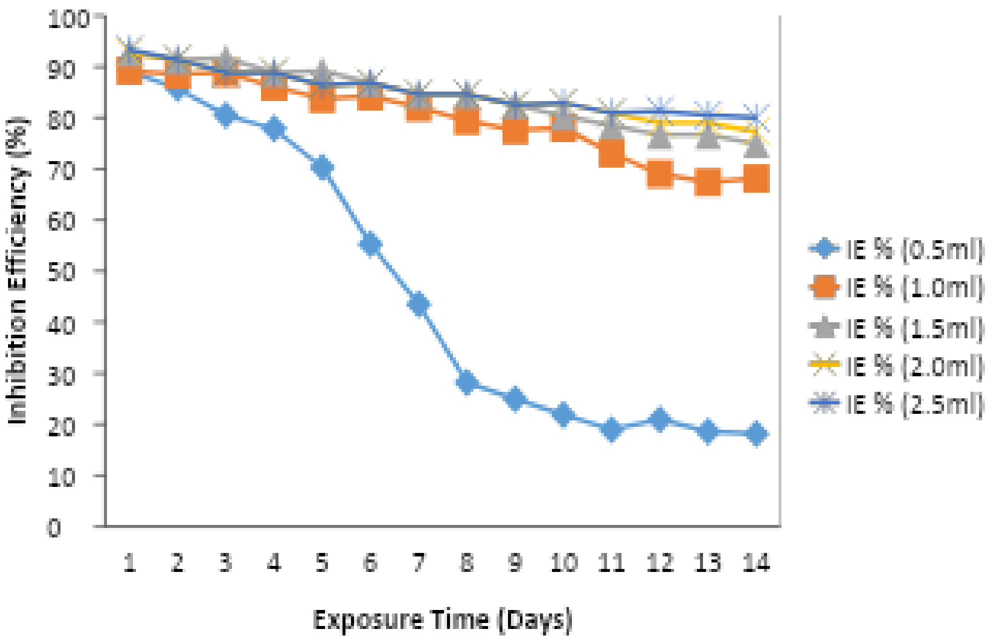

Figure 2: inhibition efficiency of the inhibitor at different concentrations

Figure 4 showed that as the inhibitor concentration rises with exposure time, the coupons' corrosion rate reduces. This shown that there is strong evidence that the inhibitor concentration lowers the rate of corrosion penetration. The adsorption of Calotropis procera latex molecules on the surface of mild steel is responsible for the notable reduction in the corrosion rate of mild steel treated with inhibitor extract. According to research by Buoklah et al. (2005) and Okewale and Olaitan (2017), inhibitor molecule functions as a physical barrier that limits the diffusion of ions to and from the mild steel surface, preventing the mild steel atoms (ions) from taking part in additional anodic or cathodic reactions (redox reactions).

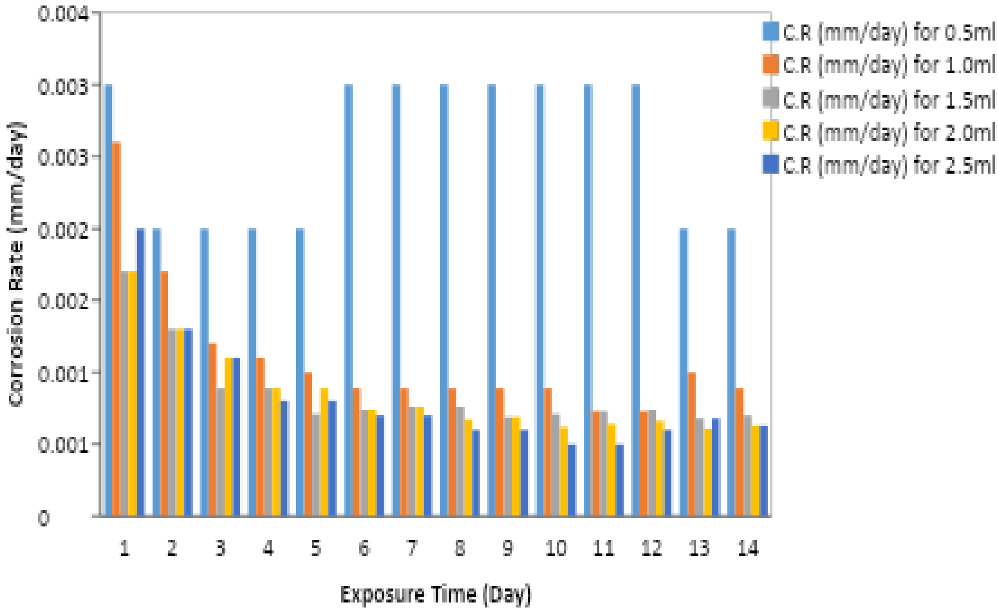

Figure 4: Corrosion rate against time of exposure

CONCULSION

Assessment of the corrosion inhibition behavior of Sodom apple (*Calotropis procera)* latex extract for the prevention of corrosion on mild steel using the gravitation method was conducted in this paper. Corrosion test was carried out using 16 mild steel sheet coupons in 0.5 M H_2SO_4 acidic medium with and without the addition of the plant extract (inhibitors). Calotropis procera milky emulsion (latex) was extracted from the plant. Phytochemical analysis was conducted, and the result showed that the latex contains corrosion inhibition compounds like tannins, saponins, and alkaloids. The corrosion inhibition behaviour of the latex was conducted and the result revealed that the latex is effective in inhibiting corrosion. The analysis showed that the inhibition efficiency of the inhibitor increased with the increase of plant extract concentration.

Recommendation for further study

Further work should be carried on the corrosion inhibition efficiency of Sodom apple (*Calotropis procera)* latex in alloys and other corrosive mediums. The effect of increasing the inhibitor concentration beyond 2.5ml should be looked into. Also, the storage stability, durability and industrial applicability of the Sodom apple (*calotropis procera)* latex need to be explored.

References

1. Achebe, C.H,Nenke, U.C, and Anisiji O.E.(2012). Analysis of Oil Pipeline Failure in the Oil and Gas.RetrievedMarch13,2013 from http://www.iaeng.org/publication/ IMECS2012/IMECS2012 pp1274-1279

2. Amitha, R. B. E., and Bharathi, B. J. B. (2012). Green inhibitors for corrosion protection of metals and alloys: An Overview, Hindawi Publishing Corporation, International Journal of Corrosion. 2012: 1-15.

3. Ashassi-Sorkhabi, H., Seifzade, D., Hosseini, M.G. (2008). Corros. Sci. 50 3363.

4. Bhoomika R. H., Mahesh, R., Manjunath, H.R., Anjanapura, V. R. (2024). Plant extracts as green corrosion inhibitors for different kinds of steel: A review, Heliyon, Vol 10(14) https://doi.org/10.1016/j.heliyon.2024.e33748.

5. Bill, N. and Gareth, H., (2003, February). NPL. Beginner Guide to Corrosion, pp. 1-10.

6. Bouklah, M., Hammouti, B., Benhadda, T. and Benkadour, M. (2005). Thiophene Derivatives as Effective Inhibitors for the Corrosion of Steel in 0.5 M H2SO4, Journal of Applied Electrochemistry, 35, 1095-1101.

7. Casaletto MP et al (2018). Inhibition of Cor-Ten steel corrosion by “green” extracts of Brassica campestris. Corros Sci 136:91–105

8. Crolet, J.L. Bonis, J.L. (1991), Prediction of the Risks of CO2 Corrosion in Oil and Gas Wells, SPE Production Engineering, Vol. 6, pp. 449-453.

9. DeBruijn, G. and Whitton, S. M. (2021). Chapter Five - Fluids, Editor(s): Gefei Liu, Applied Well Cementing Engineering, Gulf Professional Publishing, Pages 163-251, https://doi.org/10.1016/B978-0-12-821956-0.00012-2.

10. EL-Etre A.Y, (2003). Inhibition of aluminum corrosion using Opuntia extract. Corr. Sci. 4(5):2485-2495.

11. El-Etre,Y.A, (2007). "Inhibition of acid corrosion of carbon steel using aqueous extract of olive leaves. Journal of Colloid and Interface Science, 314(2) 578-583.

12. Fazal, B.R., Becker, T., Kinsella, B. et al. (2022). A review of plant extracts as green corrosion inhibitors for CO2 corrosion of carbon steel. npj Mater Degrad 6, 5 doi.org/10.1038/s41529-021-00201-5

13. Fontana, M.G (1987). Corrosion Engineering (Third Edition ed.). McGraw-Hill

14. International.

15. Garcia-Arriage, V., Alvarez-Ramirez, J., Amaya M., Sosa, E. (2010). H2S and O2influence on the corrosion of carbon steel immersed in a solution containing 3M diethanolamine. Corros, Sci. 52(2010) 2268-2279

16. González-Parra, J. R., & Di Turo, F. (2024). The Use of Plant Extracts as Sustainable Corrosion Inhibitors for Cultural Heritage Alloys: A Mini-Review. Sustainability, 16(5), 1868. https://doi.org/10.3390/su16051868

17. Holla, RB, Mahesh R, Manjunath HR, Anjanapura VR. (2024). Plant extracts as green corrosion inhibitors for different kinds of steel: A review. Heliyon, 10(14):e33748. doi: 10.1016/j.heliyon.2024.e33748..

18. Ibrahimi, B.E.; Nardeli, J.V.; Guo, L. An overview of corrosion. In Sustainable Corrosion Inhibitors I: Fundamentals, Methodologies, and Industrial Applications; American Chemical Society: Washington, DC, USA, 2021; pp. 1–19

19. James A.O. and Akaranta O. (2011). Inhibition of Corrosion of Corrosion of Zinc Hydrochloric

20. Acid Solution by Red Onion Skin Acetone Extract, Res. J. Chem. Sci., 1(1), 31-37

21. Lebrini, M, Robert. F, Lecanite, A, and Roos, C (2011). "Corrosion inhibition pof C38 steel in 1M hydrochloric acid medium by alkaloids extract from Oxandra asbecki plant". Corrosion science, 53(2): 687-695.

22. Loto, C.A, Loto, T.R., and Popoola, I.P.A. (2011, August 4). Corrosion and Plant Extracts

23. Inhibition of Mild Steel in HCL".International Journal of the Physical Sciences,

24. 6(15), 3616-3623.

25. Loto, T.R, Loto, C.A, Popoola, .I.P.A and Ranyaos, .M, (2012). Pyrimidine Derivatives as Environmentally-Friendly Corrosion Inhibitors: International Journal of The Physical

26. Sciences, 6(15), 3616-3623.A Review." 7(19), 2697-2705.

27. M. A. Abba-Aji, A. B. Muhammad and D. D. Onwe (2020). Corrosion inhibition of mild steel determined using blended bitter leaf (Vernonnia amygdalina) extract and honey in dilute H2SO4 and HCl acid solutions. AZOJETE,16(4):763-772. ISSN 1596-2490; e-ISSN 2545-5818

28. Monticelli, C. (2018). Corrosion Inhibitors, Editor(s): Klaus Wandelt, Encyclopedia of Interfacial Chemistry, Elsevier, Pages 164-171, https://doi.org/10.1016/B978-0-12-409547-2.13443-2.

29. Njoku, E.R, (1998). Effect of Inhibitors on Corrosion of Mild Steel in HCL Pickling

30. Solution. M.Sc Thesis Department of Metallurgical Engineering, ABU, Zaria Nigeria

31. Nigerian National Petroleum Corporation (NNPC). Annual Statistical Bulletin, 2020. https://nnpcgroup.com/

32. Nigerian Extractive Industries Transparency Initiative (NEITI). 2019 Oil and Gas Industry Audit Report. https://eiti.org/documents/nigeria-2019-eiti-report-oil-and-gas

33. Nwigbo, V. N. Okafor and A. O. Okewale (2012). Comparative Study of Elaeis Guiniensis Exudates (Palm Wine) as a Corrosion Inhibitor for Milod Steel in acidic and Basic Solutions, Research Journal of Applied Science Engineering and Technology, 4(9), 1035 – 1039.

34. Owate, I. O., Nwadiuko, O. C., Dike, I. I., Isu, J. O., and Nnanna, L. A. (2014). Inhibition of Mild Steel Corrosion by Aspilia africana in Acidic Solution, American Journal of Materials Science, 4(3) 144–149.

35. Okewale A. O. and Olaitan A. (2017). The Use of Rubber leaf Extract as a Corrosion Inhibitor for Mild Steel in Acidic Solution. International Journal of Materials and Chemistry 2017, 7(1): 5-13, DOI: 10.5923/j.ijmc.20170701.02

36. Ostovari, A., Hoseinieh, S. M., Peikari, M., Shadizadeh, S. R. and Hashemi, S. J. corrosion inhibition of mild steel in 1 M HCl., Corros. Sci . 51, 1935-1949(2009).

37. Parangusan, H., Sliem, M. H., Abdullah, A. M., Elhaddad, M., Al-Thani, N., Bhadra, J. (2025).

38. Plant extract as green corrosion inhibitors for carbon steel substrate in different environments: A systematic review, International Journal of Electrochemical Science, Vol. 20(4),

39. Paul, O.A, Ladan, M and Takuma, S, (2012). Corrosion Inhibition and Adsorption Behaviour for Mild Steel by Ficus Glumosa Gum in H2SO4 Solution. African Journal of Pure and Applied Chemistry, 6(7), 100-106.

40. Popova, A. and Christov, M, corros. Sci., 48,3208(2006). L.L Shreir., Third Edition., Elsevier B.V., (1), 89-100, (2010).

41. Presuel-Moreno, F.; Jakab, M.A.; Tailleart, N.; Goldman, M.; Scully, J.R. (2008). Corrosion-resistant metallic coatings. Mater. Today, 11, 14–23.

42. Prithiba, A., Leelavathi, S. and Rajalakshmi, R. (2014). Application of Natural Products as Corrosion Inhibitors in Different Steel and Media, Chemical Science Review and Letters, 3, 177–187

43. Rajeev, P., Surendranathan, A.O. and Murthy, C.S.N. (2012). Corrosion mitigation of the oil well steels using organic inhibitors – A review: Journal of Material Environment Science, 3(5), 856–869.

44. Rani, B.E., and Bharathi Bai, J.B. (2012).Green Inhibitors for Corrosion Protection of Metals and Alloys: An Overview. Int. J. Corros., 380217

45. Wang, X., Chen, L., Yang, F., Xiang, Q., & Liu, J. (2023). Corrosion inhibition mechanism and extraction technology of plant corrosion inhibitors: a review. Journal of Adhesion Science and Technology, 37(21), 2919–2943. https://doi.org/10.1080/01694243.2023.2172993

46. Umoren, A.S, (2009). Polymers as Corrosion Inhibitors for Metals in different Media – A Review". The Open Corrosion Journal, 2, 175-188.

47. Uwah, IE, Okafor, PC, Ebiekpe, VE (2013) Inhibitive action of ethanol extracts from Nauclea latifolia on the corrosion of mild steel in H2SO4 solutions and their adsorption characteristics. Arab J Chem 6(3):285–293

48. Zhou X, Yang H, Wang F (2012) Investigation on the inhibition behavior of a pentaerythritol glycoside for carbon steel in 3.5% NaCl saturated Ca(OH)2 solution. Corrosion Sci 54:193–200