IKR Publishers

IKR Journal of Engineering and Technology (IKRJET)
Journal homepage: https://ikrpublishers.com/ikrjet/
Volume-2, Issue-6 (November-December) 2026

OPEN ACCESS
ISSN: 3107-7331 (Online)

Evaluation of Lemon Leaf Extract (*Citrus limon*) as a Green Corrosion Inhibitor for Mild Steel in Pineapple Juice

Chukwunonso Samson Nebechi[1*], Christopher Mbah[2], Nwachi Emmanuel Oko[3], Onyia Chikezie Walter[4] & Okoro Alexander[5]

[1,2,3,4]Department of Metallurgical and Materials Engineering, Enugu State University of Science and Technology, Enugu, Nigeria
[5]Department of Civil Engineering, Enugu State Polytechnic, Iwollo, Enugu State

DOI: *10.5281/zenodo.24403250*

ARTICLE INFO

Article history:
Received : 01-11-2026
Accepted : 08-11-2026
Available online : 20-11-2026

Copyright © 2026 The Author(s): This is an open-access article distributed under the terms of the Creative Commons Attribution-NonCommercial **4.0 International License (CC BY-NC 4.0),** which permits non-commercial use, sharing, and reproduction in any medium, provided the original author(s) and source are appropriately credited.

Citation: Nebechi, C. S., Mbah, C., Oko, N. E., Walter, O. C., & Alexander, O. (2026). Evaluation of Lemon Leaf Extract (*Citrus limon*) as a Green Corrosion Inhibitor for Mild Steel in Pineapple Juice. *IKR Journal of Engineering and Technology (IKRJET), 2*(6), 32-38.

ABSTRACT **Original Research Article**

Corrosion of mild steel in the acid medium during fruit processing can result in poor resistance of the equipment and cost growth connected with the maintenance of it. The present research was carried out to evaluate the lemon leaf extract (Citrus limon) as natural green corrosion inhibitors for mild steel in the pineapple juice. The pineapple juice was mechanically extracted and filtered, while, lemon leaves were dried, pulverized and extracted in ethanol with the help of Soxhlet apparatus. Corrosion inhibition was studied by weight loss method with different concentration of the extract and immersion time. Analysis of chemical composition of the extract by gas chromatography mass spectrometry (GC-MS) method was performed. Initial pH value of the pineapple juice was 3.24. The efficiency of corrosion inhibition reached 77.6% at the extract concentration of 0.50 g/L for 72 hours due to the decrease in corrosion rate from 4.90 to 1.29 mm/year. The different phytochemical components such as D-limonene (38.40%), citral (15.55%), linalool (16.10%), γ-terpinene (14.50%), terpinen-4-ol (9.20%) and 3-carene have been revealed by GC-MS analysis. These components are likely to inhibit corrosion because of their adsorption on the surface of mild steel and hydrophobic film formation. These findings demonstrate the potential of lemon leaf extract as a plant-derived corrosion inhibitor for mild steel in fruit-processing environments.

Keywords: Citrus Limon, Green Corrosion Inhibitor, Mild Steel, Pineapple Juice, Weight-Loss Method, GC–MS, Corrosion Rate.

**Corresponding author: Chukwunonso Samson Nebechi*
Department of Metallurgical and Materials Engineering, Enugu State University of Science and Technology, Enugu, Nigeria

Introduction

The use of mild steel in industrial processes is widespread because of its affordability, availability, mechanical strength, and ease of workability. These properties make the mild steel suitable to be used in manufacturing machines, tanks, piping systems, structural parts, and other applications in the manufacturing industry and food processing industry (Callister & Rethwisch, 2018). Despite the number of good properties that are exhibited by the mild steel, it is highly susceptible to corrosion in unfriendly environments, leading to wastage of material, increased maintenance costs, poor reliability, and premature wear out of the machines. The corrosion process is electrochemical in nature and involves the dissolution of the metal in the anode and cathode reactions, whose rate depends on several factors like pH of the environment, temperature, oxygen content, electrolyte concentration, and the period of exposure (Emmanuel, 2024; Revie & Uhlig, 2008; Roberge, 2008).

In fruit processing settings, there is a possibility of contact between metal surfaces and organic acids, dissolved salts, water, and organic matter contained in fruit juices (Fouda et al., 2014). This can affect the electrochemistry of the exposed metals and lead to their corrosion provided that proper conditions prevail. Pineapple juice, in particular, is pertinent

to this study due to the potential for its acidity leading to the corrosion of iron from uncoated mild steel. However, this is influenced not only by its pH but also by the types of organic acids present, the dissolved components, oxygen levels, temperature, and the time of exposure (Roberge, 2008). Studying the corrosion of mild steel in pineapple juice will help to obtain relevant information regarding material corrosion and inhibitors performance in fruit processing conditions.

These inhibitors could function either through interrupting the electrochemical reactions or protecting the metal surface by a film layer at the solution-metal interface. The environmental and health hazards posed by certain compounds in the conventional corrosion inhibitors have prompted the use of plant-based corrosion inhibitors (Holla et al., 2024; Zakeri et al., 2022). The effectiveness of the inhibitor depends on the inhibitor compound composition, concentration, metal used, and corrosive medium (Revie & Uhlig, 2008; Roberge, 2008). Although traditional inhibitors are known for their ability to inhibit metal corrosion effectively, the harmfulness of some formulations has promoted studies in alternative formulations based on renewable biological resources (Quraishi et al., 2017). Extracts from plant sources have received much attention because they consist of organic chemicals that may react with metals under appropriate experimental conditions and prevent corrosion (Verma et al., 2018; Zakeri et al., 2022).

Corrosion inhibition properties of plant extracts, especially those obtained from citrus plants, such as citrus limon (lemon), are known to be effective due to presence of biologically active phytochemicals in their compositions such as flavonoids, alkaloids, tannins, and polyphenols, and such properties of plant extracts are usually linked with the presence of organic compounds which contain heteroatoms (oxygen and nitrogen), aromatic structures, as well as other electron-rich functional groups, which act as an active adsorbent, allowing for creation of protective, hydrophobic barrier film on the surface of metals (Prabakaran et al., 2016; Zarger et al., 2024). Despite the existence of research work on the extraction of the extract of Citrus limon and other citrus fruits in mineral acid and salt solutions (Riaz et al., 2022; Iyobosa & Ikponmwosa, 2023), there is no sufficient research work that will prove the efficacy of the extract in organic acid solutions (such as raw pineapple juice). Weight loss measurement using gravimetry is the most popular method of corrosion analysis because it calculates the weight loss of the metal sample over a certain period. The corrosion rate and efficiency of inhibition are measured through the comparison between weight loss in untreated samples of mild steel and other samples subjected to the same corrosive condition with different concentrations of the inhibitor. The advantage of using gravimetry as a method of corrosion assessment is its ability to estimate corrosion during a long exposure period and the efficiency of inhibitors under controlled conditions (ASTM International, 2017; Revie & Uhlig, 2008). GC-MS in plant extract analysis gives the composition of the chemicals involved in corrosion inhibition.

Despite the above-stated advantages of the plant extract, the use of it as the corrosion inhibitor for a particular industry has not yet been confirmed by experiments. The experiment aimed to determine the effect of a lemon leaf extract on the corrosion of mild steel in pineapple juice has to be performed. Consequently, the purpose of the current study is to investigate the inhibitive performance of ethanolic lemon leaf extract as a green corrosion inhibitor of mild steel in mechanically extracted pineapple juice. The present study would involve the process of pineapple juice extraction, determination of its pH value, preparation of the extract using ethanolic Soxhlet extraction, determination of the corrosion rates of mild steel in the absence and presence of different amounts of the extract for some period of time through gravimetric weight loss method, calculation of the inhibition efficiency depending on the obtained corrosion rates values, and characterization of the extract using GC-MS.

Materials and Methods

Sample Collection and Preparation

The Composition of mild steel in terms of weight percent (wt.%) was as follows: C, 0.15; Mn, 1.26; V, 0.017; Si, 0.035; S, 0.008; Cr, 0.036; Ni, 0.03; Al, 0.083; Cu, 0.038 and Fe (balance). This analysis was done in the Metallurgical Laboratory, Research and Development Centre (R&Dc), Kaduna State. The chemical composition of the sample was analyzed using Spectromax spectrometer (Model MAXxLMF14) which is a tool used for chemical analysis. The Mild steel Sheets (MS) were collected from Mechenical Village, Nsukka, Enugu State, Nigeria. Mild steel sheets were cut into coupons of dimensions 2 x 3 x 0.25 cm. A hole of about 0.1 cm diameter was drilled at one of the ends of each coupon to make it possible to suspend it by means of nylon thread. The Mild steel coupons were polished with different grades of emery paper ranging from coarse to the finest grade (1200) to make the surface smooth. The coupons were brushed gently, washed with distilled water, rinsed in acetone and dried in air before being used in the experimental study. (Mbah et al., 2023).

Preparation of Pineapple Juice Extract

The fruits of Ananas comosus (pineapple) were collected from New Market, Enugu while the extraction of pineapple juice was carried out at Enugu State Polytechnic, Iwollo, Enugu, Nigeria. These fruits were first washed with clean water to ensure that there are no contaminants in it. The fruits were peeled and chopped into smaller sizes. Pineapple juices were extracted in mechanical means without heating at room temperature. This was due to the fact that thermal treatment could cause a modification of organic acids and other chemical compounds in the juice. The use of non-heated

pineapple juice would not make any impact on the characteristics of the corrosive solution. The filtration of pineapple juice was done using mesh filter of 250 µm in order to prevent fibers materials from it. The pH value of the pineapple juice was measured by the electronic meter whereby the calibration of the meter was done based on the processes stated in ASTM G51-95 (2012). It could be noted that the pH value was 3.24 which makes the juice an acid and can serve as the corrosive solution for mild steel studies (Ofoegbu, 2021).

Plant Sample Collection, Preparation and Extraction

The Lemon leaves were harvested from a garden within the compound of the Enugu State Polytechnic. The process of extraction was done at the Divine Chemical and Analytical Laboratory, Nsukka. Fresh lemon leaves were first washed with distilled water and left to dry at room temperature (25 ± 2^0C) for 14 days after which they were ground into powder. The powdered lemon leaves were taken to the laboratory (Divine Chemical and Analytical Laboratory, Nsukka) where extraction was done (Mbah, et al., 2023). 500g of powdered lemon leaves was placed in the thimble, which was then placed in a soxhlet extractor. 250mL of analytical grade ethanol was poured into a round bottom flask attached to a soxhlet extractor and condenser, and placed on an isomantle. The side arm of the soxhlet extractor was lagged with glass wool. The solvent was heated at 60^0C. As the ethanol vapour passed through the side arm to the condenser, it condensed and dropped back into the sample in the thimble, the ethanol soluble components dissolved and were siphoned back into the flask. The extraction process was therefore permitted to run for 3 hours. Following the extraction process, the flask containing the extract was separated and the extract concentrated under the temperature of 40^0C until ethanol was evaporated off, leaving behind a gel that was then cooled in a desiccator and weighed. The final yield of extract was 38.2 g.

Weight Loss Method

The initial masses of the mild steel coupons (W_1) were measured before the coupons were suspended with nylon thread and completely immersed in 100 mL of either uninhibited or inhibited pineapple juice. After the designated time intervals, the mild steel samples were removed, soft brushed, washed with distilled water, rinsed with acetone, air-dried. Mild steel samples were again weighed and the masses values were recorded as (W_2). The weight loss (ΔW) was calculated as the difference between the initial and final masses from equation (1). The weight loss recorded at each exposure interval was considered the cumulative weight loss.

$$\Delta W = W_1 - W_2 \quad (1)$$

The corrosion rate CR (mm/yr) of the mild steel coupons in uninhibited and inhibited media, percentage of surface coverage (θ) and efficiency of inhibition (IE%), were determined by use of equations 2, 3 and 4 respectively;

$$\text{Corrosion Rate (mm/yr)} = \frac{K \times \Delta W}{A\rho t} \quad (2)$$

$$\text{Inhibition efficiency(I.E\%)} = \frac{CR_{(uninhib)} - CR_{(inhib)}}{CR_{(uninhib)}} \times 100\%$$

$$\theta = \frac{CR_{(uninhib)} - CR_{(inhib)}}{CR_{(uninhib)}} \quad (4)$$

Where ΔW is the difference between initial masses (W_1) and final masses (W_2), A is area of the sample specimen in cm^2, ρ is theoretical density of the mild steel = 7.85 g/cm^3 (Frederick et al., 2020), K is constant (87600), t is the exposure time, $CR_{(uninhib)}$ and $CR_{(inhib)}$ are the corrosion rate of mild steel without and with inhibitor at the same process conditions.

Effect of Immersion Time

The mild steel coupons were immersed in open beakers filled with 100 mL of uninhibited and inhibited solutions of pineapple juice separately, at room temperature (25 ± 2^0C) with various concentrations of inhibitor (0.1, 0.3, and 0.5 g/L). The mild steel coupons were removed from the solutions at intervals of 12, 24, 48, and 72 hours (Aliyu and Ibrahim., 2021).

Characterization

GC-MS Analysis

The GC-MS analysis was conducted in order to identify the chemical and active components of the LLE. This was done in the Central Laboratory of the University of Nigeria, Nsukka using the Agilent Technologies Model 2014 GC-MS apparatus. In the sample preparation stage, 1g of crude plant extract was dissolved in 10 ml of ethanol, followed by an hour's wait in order to facilitate the dissolution of the plant extract components. The prepared solution was then introduced into the GC-MS system for chromatographic separation and mass-spectral identification. The chromatographic peaks was identified by comparison of their mass spectra with appropriate spectral-library data. The identified compounds were subsequently considered in interpreting the possible contribution of phytochemical constituents to corrosion inhibition (Fatma et al., 2019).

Results and Discussion

Effect of Immersion Time on Corrosion Rate

Gravimetric weight loss of weight loss data was utilized in determining the effectiveness of the corrosion inhibition of LLE on mild steel in pineapple juice in 12-72 hours exposure time periods. Weight Loss (WL), Corrosion Rate (CR), Inhibition Efficiency (IE%) and Surface Coverage (θ) are measurements that are used in conducting a detailed analysis of green corrosion inhibitors (ASTM International, 2017; Revie & Uhlig, 2008). The study uses ASTM G1-03 standards for specimen preparation for corrosion tests. It

could be observed that the corrosion rate decreases with increasing exposure time and with the increase in concentration of the inhibitors. The corrosion rate decreased and inhibition efficiency increased in 0.5g/L dosage of LLE after 72 hours.

Figure 1 depicts the variation in corrosion rate of blank sample as a function of exposure time (12-72 hours), which was reduced from 18.58 to 4.90mm/yr. The addition of 0.1 g/L of lemon leaf extract (LLE) into medium resulted in a considerable drop in the corrosion rate from 12.05 to 2.06mm/yr within the same period of exposure. If the concentration of LLE increased to 0.3 g/L, then there was another reduction in corrosion rate to 1.55mm/yr (from 9.69mm/yr). Figure 1 shows that at 72 hours, the corrosion rate was reduced from 18.58 mm/yr in the control (blank) test to 1.29 mm/yr when 0.5 g/L of LLE was added. From these results, it revealed that the increase in the time of exposure of the mild steel to the corrosive medium caused the gradual reduction in the dissolution rate, especially when inhibitors were present. Generally, there were a trend of reduction in corrosion rate with time in all systems. The reduction in corrosion rate with the increase in the time of exposure could be related to the gradual buildup of corrosion products and adsorption of inhibitor molecules on the metal surface, making the contact of the corrosive medium with the metal less effective. In this case, the metal surface was becoming increasingly protected with the passing time, hence the decrease in the corrosion rate.

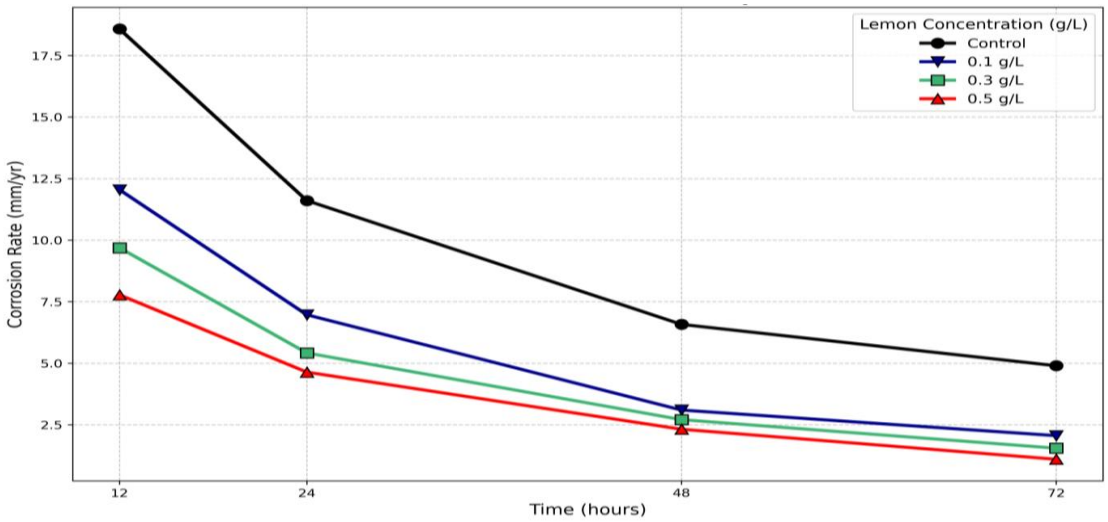


Figure 1: Effect of LLE concentration and exposure time on the corrosion rate of mild steel in pineapple juice.

Effect of Inhibition Efficiency (IE%) and Time (hours)

Figure 2 showed the inhibition efficiency (IE%) of the lemon leaf extract (LLE) at different concentrations and different exposure times. The IE% of the inhibitor concentration of 0.1 g/L increased from 35.10% after 12 hours to 58.0% after 72 hours. When the inhibitor concentration increased to 0.3 g/L, the IE% rose from 47.80% after 12 hours to 70.8% after 72 hours. At a high inhibitor concentration of 0.5 g/L, the IE% was 77.6%.

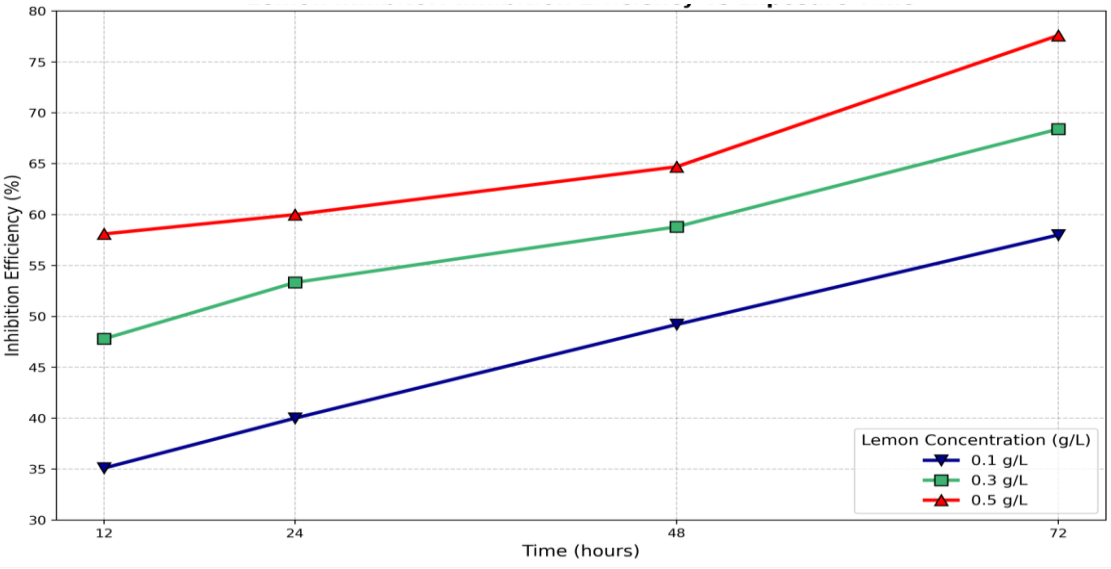


Figure 2: Effect of LLE concentration and exposure time on the inhibition efficiency of mild steel in pineapple juice.

Due to the increasing inhibition efficiency with regard to the inhibitor concentration and time of immersion, the adsorption of active components of the LLE on mild steel surfaces may become an important parameter for corrosion inhibition. An increase in IE% with increasing immersion time (12 to 72 hours) indicates the stability and compaction of adsorbed layer which was as a result of molecular reorganization and strong interactions of molecules with the surface. This proves that an inhibiting layer was formed which reduces the reaction rate of corrosion and the dissolution of metal. Similarly, Hassan et al. (2016) observed the inhibition efficiency of 89% for Citrus aurantium leaf extract at 1 M H_2SO_4 at 10 mL.

The relatively lower efficiency observed for LLE in the present study may therefore be associated with the nature of the corrosive environment. Unlike the mineral-acid media used in most published Citrus-inhibitor studies, the present investigation employed fresh pineapple juice, which contains organic acids and other constituents that could participated in the corrosion process. The complex composition of a food-processing medium may influence both the aggressiveness of the environment and the adsorption behaviour of phytochemicals on the mild steel surface. Nevertheless, achieving 77.6% inhibition under these conditions indicates that LLE has considerable potential as a green corrosion inhibitor for mild steel in food-processing environments.

Characterization

Qualitative analysis for determining the active phytochemical components found in LLE was carried out through GC-MS on the basis of retention times and intensity of peaks. The Total Ion Chromatogram (TIC) results were shown in Fig. 4.1. The height and area of the peaks indicate the relative abundance of the compounds identified. The identified phytochemical components were known to possess functional groups with adsorption activity capable of acting as corrosion inhibitors of mild steel in an acidic pineapple juice medium (Nyoman et al., 2024).

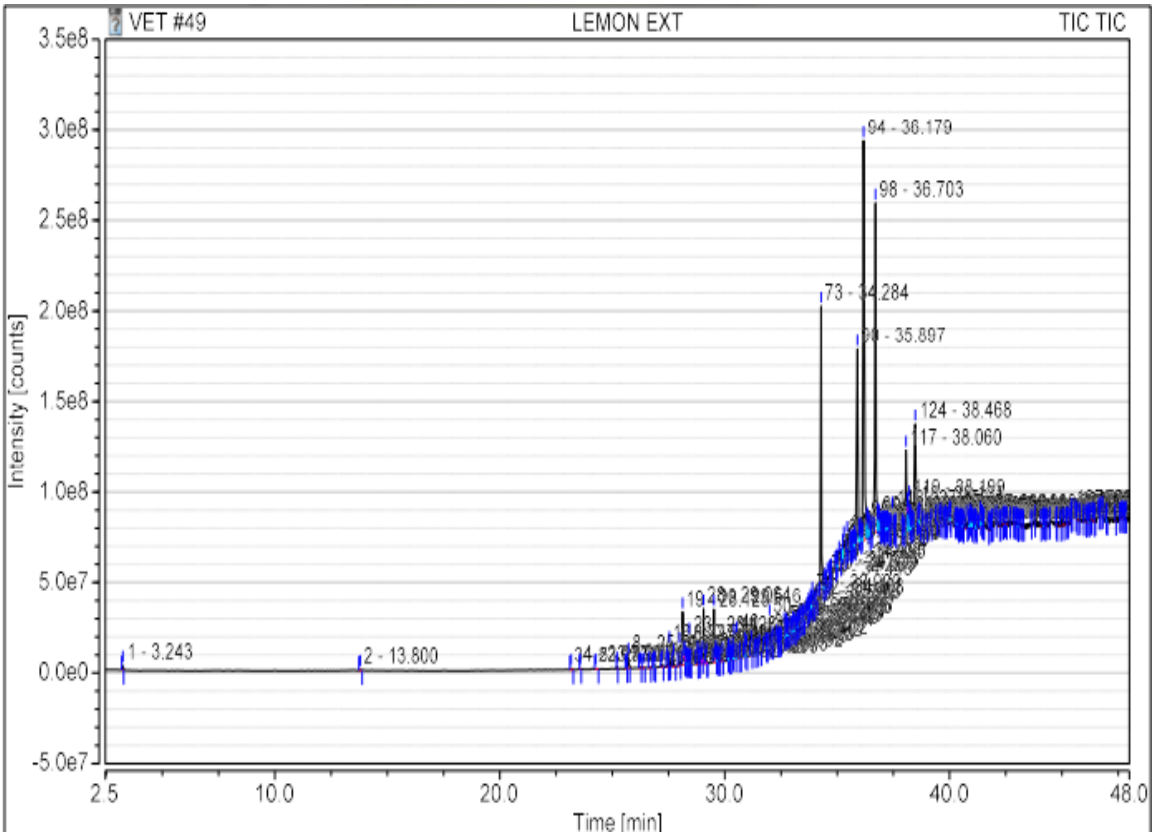


Figure 3: Chromatography of lemon leaf extract

From the chromatographic profile of lemon leaf ethanolic extract (figure 3) indicates the presence of a variety of volatile phytochemicals in the extract, consisting mainly of terpenes and terpenoids. The retention times vary between 3.24 and 38.46 minutes as illustrated in figure 3. It reflects effective separation of the phytochemicals depending on their volatilization and polarity properties. The ethanolic extract consists mainly of monoterpenes and oxygenated monoterpenes, which were effective as corrosion inhibitors due to their capability of adsorption on the mild steel surface in acidic medium like pineapple juice (Al-Amiery et al., 2014). The aggressive medium in this case was acidic pineapple juice (due to citric acid and other organic acids), which corrodes mild steel aggressively. The inhibitory efficacy of the extract was directly related to the adsorption of its phytochemical components onto the steel surface. This forms a protective barrier that mitigates electrochemical corrosion reactions (Umoren et al., 2019; Verma et al., 2018).

In the early retention region, small peaks that appeared between 3 and 13 min were associated to light monoterpenes like α-pinene (0.85%) and β-pinene (0.40%). These monoterpenes donate π electrons due to the presence of double bonds, leading to the phenomenon of physisorption of these compounds on the steel surface (Al-Amiery et al., 2014). A group of clustered peaks, appearing between 24 and 33 min, indicates the existence of terpene hydrocarbons in low concentrations of: sabirene + β-myrcene + 3-carene + α-terpinene + β-ocimene + 1,3,6-octatriene, 3,7-dimethyl in amounts between 0.5–2.5% each. Clearly visible are the main peaks: γ-terpinene (34.28 min), terpinen-4-ol (35.86 min), D-limonene (36.17 min), and linalool/α-terpineol (36.70 min) with concentrations 14.50%, 9.20%, 38.40%, and 16.10%, respectively. D-Limonene (38.40%) is the major component. Unsaturation in the structure of the monoterpenes makes it possible to have π-electrons that were capable of interacting strongly with d orbitals of iron, and this was crucial in corrosion inhibition through adsorption and the formation of hydrophobic layers (Eddy & Ebenso, 2010), while oxygen containing derivatives like terpinen-4-ol and linalool could help in adsorption through donation of oxygen lone pairs, resulting in a mixed type of inhibition (Verma et al., 2018; Eddy & Ebenso, 2010). In addition, several oxygenated monoterpenes were observed in between 35 and 38 minutes. They include linalool or α-terpineol at 36.70 minutes (16.10%), citral isomers were present with z-citral (neral) at 38.06 minutes (8.25%), geraniol at 38.16 minutes (1.05%), and e-citral (geranial) at 38.47 minutes (7.30%), with a total content of citral being approximately 15.55%. Oxygenated monoterpenes have functional groups such as Oxygenated monoterpenes have functional groups such as hydroxyl (-OH), Carbonyl (C=O), and aldehyde (-CHO) groups, enhance their ability to adsorb onto metal surfaces. The phenomenon of adsorption creates a protective layer that minimizes the reactions between the metal surface and the corrosive environment. The molecules contain conjugated C=C and C=O bonds, which favor chemisorption and complexation through stable Fe-inhibitor complexes, thus inhibiting the anodic dissolution (Singh et al., 2016). Generally, the lemon leaves extract was abundant in terpenes, whereby the major terpenes in the extract were found to include D-limonene (38.40%), linalool/α-terpineol (16.10%), γ-terpinene (14.50%), terpinen-4-ol (9.20%) and citral (15.55%), while 3-carene, sabinene and other minor terpenes were present in the extracts. The chemical analysis of the plant extracts was similar to that of lemon leaf extracts determined by earlier researchers (Mohammad & Hassan, 2017; Mohsen et al., 2020). Due to the presence of hydrocarbon monoterpenes (adsorption of π-electrons) and oxygenated terpenoids (chemisorption of heteroatoms), the adsorption process involved both physisorption and chemisorption processes (Verma et al., 2018). This implied that the extract of lemon leaves consisted of components such as D-limonene (38.40%), Citral (15.55%), linalool (16.10%), γ-terpinene (14.50%), terpinen-4-ol (9.20%) and 3-Carene, and this made it possible to form a hydrophobic layer to prevent aggressive ions from attacking the surface of mild steel in pineapple juice (Halambek et al., 2013; Saxena et al., 2021). This proves its enormous capacity as a green corrosion inhibitor.

Conclusion

In this study, the effect of lemon leaf extract (LLE) as a green inhibitor of corrosion of mild steel in pineapple juice containing acid media was examined using weight loss technique. According to the results of the experiment, it was revealed that the lemon leaf extract was an effective green inhibitor of corrosion of mild steel in the medium. As the concentration increases, there was a marked improvement in the performance of the inhibitor at all concentrations. The maximum value of inhibition efficiency of 77.6% was observed at 0.5 g/L LLE for 72 hours; corrosion rate decreased from 4.90 mm/year in pineapple juice without inhibitor to 1.29 mm/year in the inhibited medium.

The result from GC-MS study reveals that the inhibitory action of extracts was attributed to the presence of D-limonene, citral, linalool, γ-terpinene, terpinen-4-ol and 3-Carene that create a hydrophobic film and inhibit the attack of aggressive ions to the surface of mild steel in pineapple juice.

References

1. Aliyu, M., & Ibrahim, M. B. (2021), Adsorption and Thermodynamic Studies of Watermelon Seed Ethanol Extract on the Corrosion Inhibition of Zinc in Nitric Acid. *ChemSearch Journal 12*(2): 101 – 112.
2. Al-Amiery, A. A., Kadhum, A. A. H., Alobaidy, A. H. M., Mohamad, A. B., & Hoon, P. S. (2014). Novel corrosion inhibitor for mild steel in HCl. Materials, 7(2), 4335–4348.
3. ASTM. (2012). ***Standard practice for conducting laboratory immersion corrosion tests on metals*** (ASTM G51-95). ASTM International.
4. ASTM International. (2017). ***ASTM G1-03(2017): Standard practice for preparing, cleaning, and evaluating corrosion test specimens***. ASTM International.
5. Callister, W. D., & Rethwisch, D. G. (2018). *Materials science and engineering: An introduction* (10th ed.). John Wiley & Sons.
6. Eddy, N. O., & Ebenso, E. E. (2010). Adsorption and quantum chemical studies on the inhibition potentials of some plant extracts for the corrosion of mild steel in acidic medium. International Journal of Electrochemical Science, 5, 731–750.
7. Emmanuel, J. K. (2024). Corrosion protection of mild steel in corrosive media, a shift from synthetic to natural corrosion inhibitors: A review. Bulletin of the

National Research Centre, 48, Article 26. https://doi.org/10.1186/s42269-024-01181-7

8. Fatma M. Mahgoub, Ahmed M. Hefnawy, Eman H. Abd Alrazzaq.,(2019). Corrosion inhibition of mild steel in acidic solution by leaves and stem extract of Acacia nilotica. Desalination and Water Treatment.doi: 10.5004/dwt.24681
9. Frederick O. O., Thelma E. A., Osariemen E., & Joy, E.A O. (2020), Green corrosion inhibition of mild steel using prunusdulcis seeds extract in an acidic medium. *Journal of pure and applied sciences vol.* 26, 171-178
10. Halambek, J., Žutinić, A., & Berković, K. (2013). Ocimum basilicum L. oil as corrosion inhibitor for aluminium in hydrochloric acid solution. International Journal of Electrochemical Science, 8(9), 11201–11214.
11. Holla, B. R., Mahesh, R., Manjunath, H. R., & Anjanapura, V. R. (2024), Plant extracts as green corrosion inhibitors for different kinds of steel: A review. ***Heliyon,*** ***10***(14), e33748. https://doi.org/10.1016/j.heliyon.2024.e33748
12. Hassan, K.H., Khadom A.A., & Kurshed N.H. (2016), ***Citrus aurantium*** leaves extracts as a sustainable corrosion inhibitor of mild steel in sulfuric acid. *South African Journal of Chemical Engineering*, *1*(22), 1-5. https://doi.org/10.1016/j.sajce.2016.07.002
13. Iyobosa, G. O., & Ikponmwosa, S. O. (2023). Citrus sinensis peel extract as corrosion inhibitor for mild steel in hydrochloric acid solution. ***GSC Biological and Pharmaceutical Sciences, 23***(3), 198–202.
14. Mbah, C.N., Nebechi, C.S., Oko, N.E., Onyeabor, D.C., Nnakwo, K.C, Eze I.N, (2023), Green corrosion inhibition performance of orange leaves extract on mild steel sheet buried in an acidified soil. *International Journal of Research in Advanced Engineering and Technology 9*(2), 24-27
15. Mohsen Asker, Souad E. El-gengaihi, Emad M. Hassan, Mona A. Mohammed and Sayeda A. Abdelhamid (2020). Phytochemical constituents and antibacterial activity of Citrus lemon leaves. https://doi.org/10.1186/s42269-020-00446-1
16. Mohammad Hojjati, Hassan Barzegar (2017). Chemical Composition and Biological Activities of Lemon (*Citrus limon*) Leaf Essential Oil. Nutrition and Food Sciences Research.
17. Nyoman Arsana, I., Juliasih, N. K. A., & Widyantari, A. A. A. S. S. (2024). GC-MS analysis of bioactive compounds in lime leaf ethanol extract (Citrus amblycarpa (Hassk.) Ochse), and its potential as a traditional medicine agents. Journal of Research in Science Education. https://doi.org/10.29303/jppipa.v10i4.3735
18. Ofoegbu, S.U. (2021), Comparative Gravimetric Studies on Carbon Steel Corrosion in Selected Fruit Juices and Acidic Chloride Media (HCl) at Different pH. *Materials, 14*, 4755. https://doi.org/10.3390/ma14164755
19. Oguzie, E. E. (2008). Corrosion inhibitive effect and adsorption behaviour of Hibiscus sabdariffa extract on mild steel in acidic media. Portugaliae Electrochimica Acta, 26(3), 303–314. https://doi.org/10.4152/pea.200803303
20. Prabakaran, M., Kim, S.-H., Hemapriya, V., & Chung, I.-M. (2016). Evaluation of polyphenol composition and anti-corrosion properties of *Cryptostegia grandiflora* plant extract on mild steel in acidic medium. *Journal of Industrial and Engineering Chemistry, 37***,** 47–56.
21. Quraishi, M. A., Sharma, D., & Verma, C. (2017). *Green corrosion inhibitors: Theory and practice*. John Wiley & Sons.
22. Revie, R. W., & Uhlig, H. H. (2008). Corrosion and corrosion control (4th ed.). John Wiley & Sons.
23. Riaz, M., Aslam, J., & Khan, M. A. (2022). Antioxidant and phytochemical potential of *Citrus limon* extracts. *Journal of Plant Biochemistry and Biotechnology*, *31*(2), 245–254. https://doi.org/10.1007/s13562-021-00712-3
24. Roberge, P. R. (2008). *Corrosion engineering: Principles and practice*. McGraw-Hill.
25. Saxena, A., Prasad, D., Haldhar, R., Singh, G., & Kumar, A. (2021). Use of Asparagus racemosus extract as green corrosion inhibitor for mild steel in 0.5 M H_2SO_4. *Journal of Materials Science*, *56*(3), 2590-2602.
26. Singh, A. K., Mohapatra, S., & Pani, B. (2016). Corrosion inhibition effect of *Aloe vera* gel: Gravimetric and electrochemical study. *Journal of Industrial and Engineering Chemistry*, *33*, 288–297. https://doi.org/10.1016/j.jiec.2015.10.014 MDPI
27. Umoren, S. A., Solomon, M. M., Obot, I. B., & Suleiman, R. K. (2019). A critical review on the recent studies on plant biomaterials as corrosion inhibitors for industrial metals. Journal of Industrial and Engineering Chemistry, 76, 91–115.
28. Verma, C., Eno E. Ebenso, M.A. Quraishi, and Chaudhery Mustansar Hussain. (2018), Recent developments in sustainable corrosion inhibitors: Design, performance and industrial scale applications. *Materials Advances*, *2*, 3806–3850. https://doi.org/10.1039/D0MA00681E
29. Zarger, M. S. S., et al. (2024). Eco-friendly corrosion inhibition of mild steel using fruit peel extracts in acidic medium. *Cuestiones de Fisioterapia*, *53*(3), 1396–1400.
30. Zakeri, A., Bahmani, E., & Aghdam, A. S. R. (2022), Plant extracts as sustainable and green corrosion inhibitors for protection of ferrous metals in corrosive media: A mini-review. *Corrosion Communications*, *5*, 25–38. https://doi.org/10.1016/j.corcom.2022.03.002