World Journal of Advanced Research and Reviews
eISSN: 2581-9615 CODEN (USA): WJARAI
Cross Ref DOI: 10.30574/wjarr
Journal homepage: https://wjarr.com/

(RESEARCH ARTICLE)

Phytochemical, Weight-Loss, and Scanning Electron Microscopy Studies of *Ficus ottoniifolia* leaf extract as a green corrosion inhibitor for mild steel

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World Journal of Advanced Research and Reviews, 2026, 29(01), 206-213

Publication history: Received on 24 November 2025; revised on 31 December 2025; accepted on 05January 2026

Article DOI: https://doi.org/10.30574/wjarr.2026.29.1.4297

Abstract

Bio-based materials like plant extracts, natural polymers, gums, Agricultural waste, amino acids, and carbohydrates, because of their natural origin, biodegradability, and non-accumulative properties serve as excellent sustainable substitutes to many inorganic corrosion inhibitors that pose toxicity concerns. This study investigated the phytochemical composition, corrosion inhibition performance, and surface protective behavior of *Ficus ottoniifolia* leaf aqueous extract as a green corrosion inhibitor for mild steel in 0.5 M HCl. Fresh leaves were collected, authenticated, air-dried, pulverized, and extracted in hot distilled water. The Phytochemical screening revealed eight major classes of bioactive constituents, with terpenoids and flavonoids occurring in the highest concentrations, supported by saponins, glycosides, alkaloids, phenols, steroids, and tannins. Weight-loss measurements for over four weeks, showed a consistent decrease in corrosion rate with increasing inhibitor volume (5 - 20 mL) and immersion time, with the 20 mL extract achieving the strongest inhibitory effect. Peak inhibition efficiency occurred between 300 and 350 hours, attributed to excellent formation and stabilization of an adsorbed protective film, after which a gradual decline was observed due to film weakening. SEM analysis revealed severe surface degradation on uninhibited steel, while samples exposed to 20 ml extract exhibited smooth morphology, minimal corrosion, and sustained protection even after 672 hours immersion. These findings positions *Ficus ottoniifolia* extract as a viable alternative to synthetic inhibitors owing to its long-term efficacy in acidic environments.

Keywords: *Ficus ottoniifolia*; Corrosion; inhibitor; Phytochemical; Adsorption mechanism

1. Introduction

The gradual pervasive and irreversible degradation process occurring when materials like metals interact with their environment is known as corrosion, it often leads to material deterioration and environmental contamination (Elmsellem *et al.*, 2014; Lahiri *et al.,* 2017; Harsimran *et al.,* 2021). Most structural alloys/Mild steel is naturally prone to corrosion especially when exposed to moisture in the atmosphere or in their environment (Banerjee *et al.,* 2022), and the rate at which this deterioration occurs can increase significantly in acidic condition (Mohammed *et al.,* 2022). Mild steel remains one of the most widely used engineering materials due to its favorable mechanical properties, fabrication ease, and low cost (Yan *et al.,* 2014; Qiao *et al.,* 2023). Nevertheless, its susceptibility to rapid corrosion in aggressive media, especially mineral acids, limits its long-term performance in industrial operations (Avdeev & Kuznetsov, 2022). Corrosion can occur uniformly across a surface or appear in localized forms such as in pitting or cracking (Böhni, 2020). This is because; it is a diffusion controlled process occurring on exposed surfaces. But, the good

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news is that, with the development of effective protection strategies including the use of inhibitors, corrosion can be controlled.

These substances, Corrosion inhibitors are when introduced in aggressive environments suppress or reduce the rate of corrosion by slowing chemical or electrochemical reactions (Răuță, *et al.,* 2025), forming protective barriers on metal surfaces. They are commonly applied in acidic environments, such as those encountered in industries involved in pickling or acidification of oil wells (Goyal *et al*., 2018). With the limiting of corrosive attacks on metallic materials, inhibitors help to prevent structural damage and material loss (Rajeev *et al*., 2012; Dehghani *et al*., 2020). The mechanism of inhibition generally involves adsorption onto the metallic surface to create a protective film, reaction with corrosive ions to form complex compounds, or the promotion of oxide film formation that shields the base metal (Wei, *et al.,* 2020; Ma, *et al*., 2022; Salim *et al.,* 2024). Many conventional inhibitors are synthetic and toxic, posing environmental hazards and health risks (Heakal and Elkhol, 2017). In view of this fact, as a matter of significant attention, together with what other researchers are doing, we are considering in this study, plant - derived extracts as green corrosion inhibitors. These eco-friendly alternatives offer biodegradability, cost-effectiveness, and safety advantages over traditional chemicals (Eddy, 2022). Rich in diverse phytochemicals such as alkaloids, flavonoids, tannins, and saponins containing heteroatoms (Christian *et al.,* 2022), plant extracts can adsorb onto metal surfaces; forming protective films that inhibit metal dissolution. Numerous studies have confirmed their high inhibition efficiencies comparable to synthetic inhibitors, promoting sustainable corrosion control (Al Amiery *et al*., 2023).

In this paper, we used extract from *Ficus ottonifolia,* in English Hedge fig leaf, locally known as "ekwo ogbu" in southeastern Nigeria, because of its rich phytochemical composition. We investigated the efficacy of the extract as a corrosion inhibitor for mild steel in 0.5 M Hydrochloric acid environment. We identified the phytochemical constituents of the extract, measured corrosion rates with and without the inhibitor using weight-loss methods and assessed the surface morphology of the coupons through Scanning Electron Microscopy. The application of renewable plant resources as alternatives to conventional synthetic inhibitors, many of which are toxic and non-biodegradable makes the study a significant one as it provides a sustainable and environmentally friendly approach to corrosion control, a way to minimize environmental pollution and health hazards associated with industrial corrosion inhibitors.

2. Experimental Details

The equipment and apparatus used for this study were obtained from the laboratory unit, Department of Biochemistry, University of Nigeria, Nsukka. At first, Fresh leaves of *Ficus ottoniifolia* were collected, authenticated (identified by an expert), and air-dried to fine powder. Extraction was performed by heating 10 g of the powder in 100 mL distilled water at 85 °C for two hours with continuous stirring, followed by filtration and storage of the extract for subsequent phytochemical constituents analysis using spectrophotometer. We used weight-loss method in determining Corrosion rate. Mild steel rods were procured locally and cut into coupons (2.1 × 0.58 cm), polished with silicon carbide abrasive paper, degreased with acetone, and dried. Varying volumes of *Ficus ottoniifolia* leaf aqueous extract, 5 to 20 mL were added to the different beakers that contain the HCL solutions, while the control samples were maintained without inhibitors. The dried coupons were immersed in 200 mL of 0.5 M hydrochloric acid (HCl) solutions prepared by appropriate dilution and dissolution of concentrated reagents, respectively. The steel coupons remained immersed for four weeks and periodically retrieved for cleaning and weighing to calculate mass loss. Corrosion rate (mm/yr) and inhibition efficiency (%) were computed using standard formulae based on weight loss, exposure time, specimen surface area, and steel density. We also examined the surface microstructure of the coupons through Scanning Electron Microscopy (SEM). All experiments were performed in triplicate to ensure reproducibility and statistical reliability.

2.1. Weight Loss Measurement

During the experiment, after the expiration of each immersion time considered, coupons were removed, cleaned, rinsed with distilled water, degreased with acetone, dried, and reweighed. The weight loss (ΔW) was calculated using the equation 1,

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

Where ΔW = weight loss, W_i = initial weight, W_f = final weight

2.2. Corrosion Rate Determination

The corrosion rate (CR) in millimeters per year (mm/yr) was determined using equation 2,

$$CR = \frac{K * \Delta_w}{\rho * A * T} \quad 2$$

where:

Δ_w = weight loss (g), A = exposed surface area of coupon (cm^2), ρ = density of mild steel (7.86 g/cm^3), T = exposure time (hours), and K = unit conversion constant (8.76 x 10^4)

The surface area of each cylindrical coupon was calculated using the relation,

$$\text{Area (A)} = 2\pi r^2 (r + l) \quad 3$$

Where, l = length of the coupon = 2.1cm, r = radius of specimen = 0.29cm, A = Total surface area of the coupon.

2.3. Inhibition Efficiency Determination

The inhibition efficiency (IE %) was evaluated as given in the equation 4,

$$IE\ \% = \frac{CR_0 - CR}{CR_0} * 100 \quad 4$$

Where, CR and CR_0 are the corrosion rates with and without inhibitor, respectively.

3. Results and Discussion

3.1. Phytochemical Analysis of the Leaf Extract

The phytochemical analysis of the aqueous *ficus ottoniifolia* leaf extract is as presented in figure1.

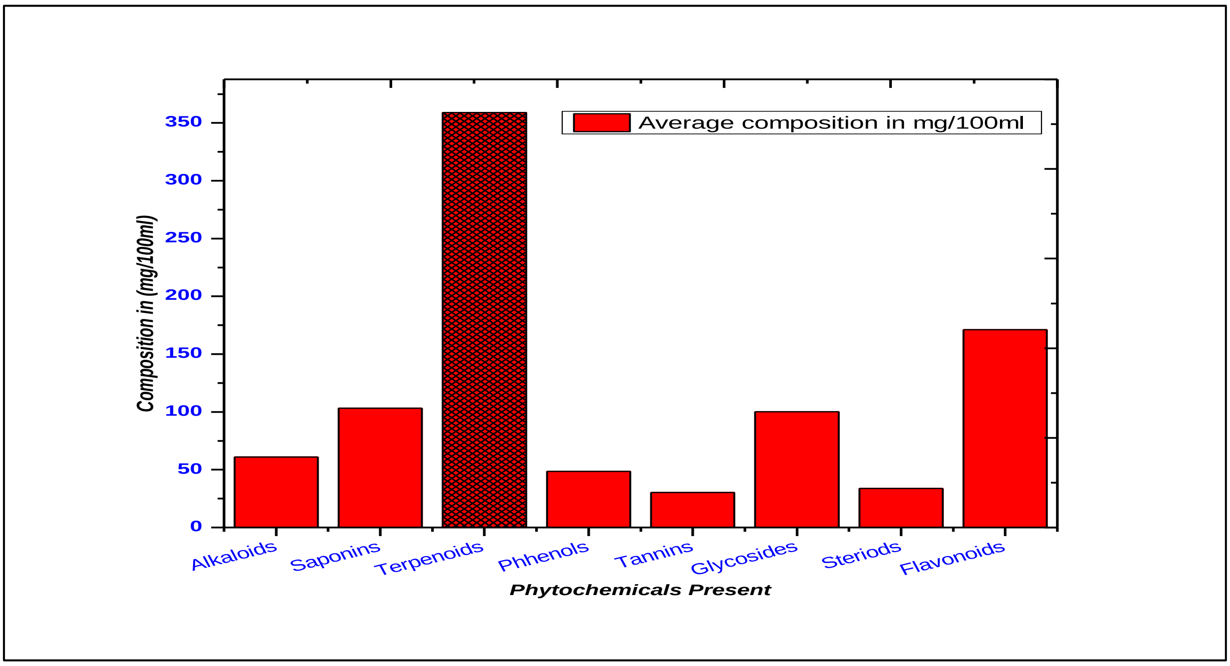

Figure 1 Column Chart of the Phytochemical composition of the leaf extract

The chart showed that Terpenoids and flavonoids are present in the highest concentrations. These two has the ability to adsorb onto the steel surface through their electron-rich structures, forming a protective barrier that blocks HCL attack and reduces anodic dissolution (Verma *et al.,* 2024). Flavonoids specifically contribute through chelation with metal ions and hydrophobic shielding, while terpenoids enhance film stability via van der Waals forces. Saponins support this by creating a surfactant-like layer that improves extract dispersion and coverage on the metal (Jafari *et al.,* 2024). Glycosides and alkaloids aid inhibition through polar functional groups that promote physisorption and mixed-type inhibition (anodic/cathodic). Phenols and tannins provide antioxidant effects to prevent oxidative corrosion, while steroids add to the hydrophobic film (Proenca *et al.,* 2022). Related *Ficus* species extracts confirm this synergy, achieving up to 80% inhibition efficiency in acidic media (Verma *et al.,* 2024).

3.2. Corrosion Rate of Mild Steel in Hydrochloric Acid (HCl) Environment:

Figure 2 is the graphical illustration showing how the corrosion rate of mild steel in 0.5 M HCl environment changes with different volumes of *Ficus ottoniifolia* leaf extract (Inhibitor) and time of immersion of the coupons.

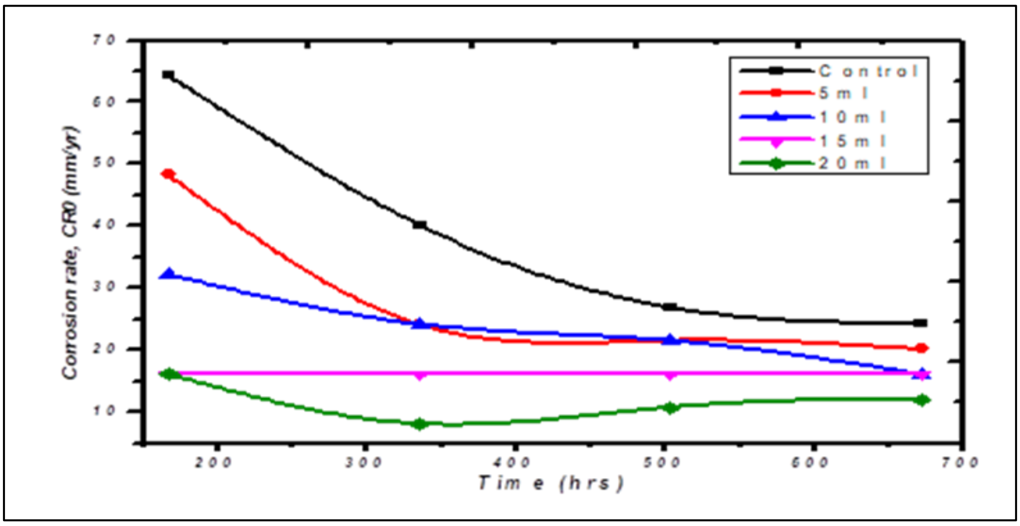

Figure 2 Variation of Corrosion Rate with Various Volumes of *Ficus ottoniifolia* Leaf Extract and time

3.3. Inhibition Efficiency (IE%) of *Ficus ottoniifolia* Leaf Extract in 0.5 M HCl

It is clear from the figure 2 that the corrosion rate consistently decreases as the immersion time increases for all inhibitor volumes tested. Additionally, increasing the volume of the leaf extract from 5 ml to 10ml, 15ml and 20 ml leads to a further reduction in the corrosion rate, with the 20 ml volume showing the most significant inhibitory effect throughout the immersion period.

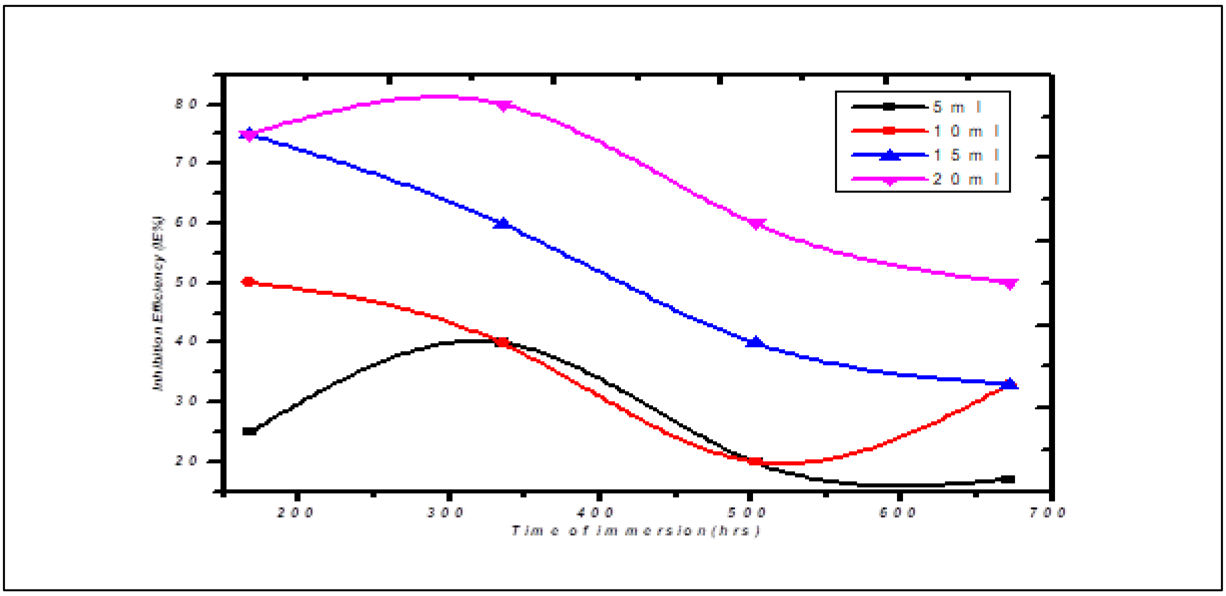

Figure 3 Variation of Inhibition Efficiency (IE%) with time and various volumes of Extract in 0.5 M HCl

This decrease results from enhanced adsorption of phytochemicals like terpenoids and flavonoids, forming a denser protective film on the coupons that blocks HCl ions through Langmuir isotherm mechanisms. Prolonging immersion time would further promote film thickening and stabilization, enhancing surface coverage and reducing anodic/cathodic reactions for peak inhibition at higher volumes. This observed trend is in agreement with (Patni *et al.,* 2013; Fazal *et al.,* 2022)

Figure 3 presents the variation of inhibition efficiency with time and volumes of the *ficus ottoniifolio* leaf extract. It confirms that the inhibition efficiency reaches its peak between 300 to 350 hours of immersion time, which is likely due to the excellent formation and stabilization of the protective phytochemical film on the mild steel surface during this period. Beyond this time, the efficiency decreases as the inhibitor film may begin to degrade, allowing corrosive agents to penetrate and reduce the overall protection across all inhibitor volumes. This decrease in inhibition efficiency with time is in line with the findings of other researchers such as (Al-Amiery *et al.,* 2021).

3.4. Scanning Electron Microscopy (SEM):

The results obtained from surface characterization of the mild steel after 168 and 672 hours of immersion in the absence (Control) and presence of 20 ml leaf extract of *ficus ottoniifolia* are presented in figures 4 to 7.

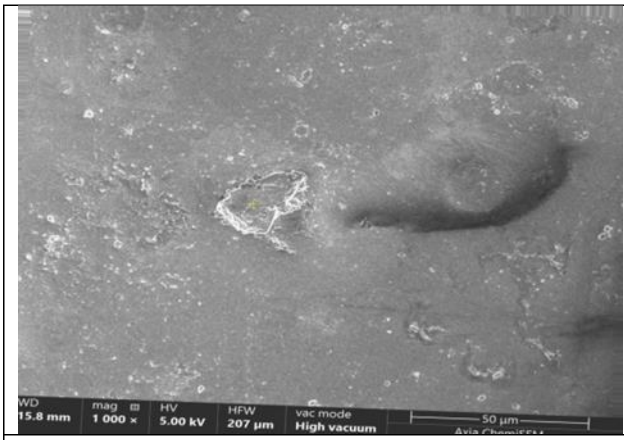

Figure 4 0.5 M HCl as deposited (control) after 168 hrs at 1,000 magnifications

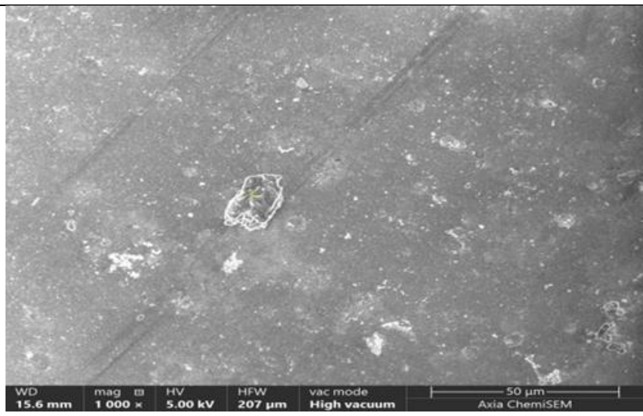

Figure 5 0.5 M HCl + 20 ml *ficus ottoniifolia* leaf extract after 168 hrs at 1,000 magnifications

In contrast, surfaces treated with *Ficus ottoniifolia* extract display smooth, uniform morphology with visible grinding marks, minimal isolated pits, and a thin protective film, maintaining integrity and effective shielding even after prolonged immersion. The SEM micrographs reveal stark differences between uninhibited and inhibited mild steel surfaces in 0.5 M HCl.

Figure 6 0.5 M HCl as deposited (control) after 672 hrs at 1,000 magnifications

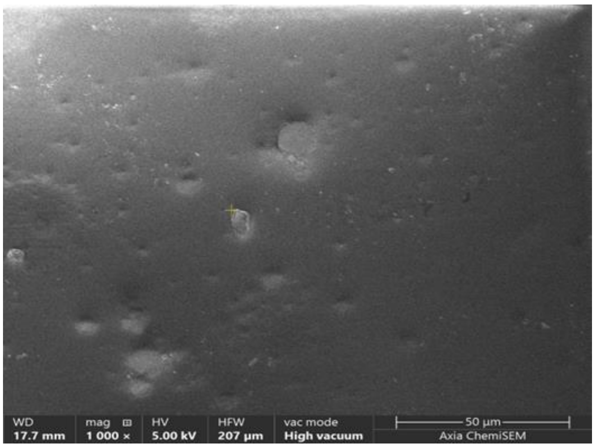

Figure 7 0.5 M HCl + 20 ml *ficus ottoniifolia* leaf extract after 672 hrs at 1,000 magnifications

The unprotected control (figures 4 and 6) exhibits severe degradation with thick, porous, cracked corrosion product layers, deep pits, and obscured polishing marks due to aggressive acid attack and ongoing dissolution, worsening over 672 hours with multilayered deposits.

4. Conclusion

This study has demonstrated that *Ficus ottonifolia* leaf extract is a highly effective green inhibitor for mild steel corrosion in 0.5 M HCl, owing to the strong adsorption and protective film formation by its rich phytochemical constituents. The Weight-loss and SEM analyses confirmed significant reduction in corrosion rate and surface degradation, establishing the extract to be good eco-friendly alternative to synthetic inhibitors.

Compliance with ethical standards

Acknowledgements

The authors extend their appreciation to Ebonyi State Government for funding this research through the State Scholarship Scheme with a Grant Number: EBSU/PG/Ph.D/2022/11619

Statement of Ethical Approval

This study did not involve human participants/animal experimentation and therefore did not require formal ethical approval. All procedures involving data handling and analysis were conducted responsibly in accordance with standard academic and institutional guidelines.

Disclosure of conflict of interest

The authors of this work declare no conflicts of interest.

Data Availability Statement

The data supporting this study can be obtained from the first author upon reasonable request.

References

[1] Al-Amiery, A. A., Isahak, W. N. R. W., & Al-Azzawi, W. K. (2023). Corrosion inhibitors: natural and synthetic organic inhibitors. Lubricants, 11(4), 174. https://doi.org/10.3390/lubricants11040174

[2] Al-Amiery, A. A., Shaker, L. M., Kadhum, A. H., & Takriff, M. S. (2021). Exploration of furan derivative for application as corrosion inhibitor for mild steel in hydrochloric acid solution: Effect of immersion time and temperature on efficiency. Materials Today: Proceedings, 42, 2968-2973.https://doi.org/10.1016/j.matpr.2020.12.807

[3] Avdeev, Y. G., & Kuznetsov, Y. I. (2022). Acid corrosion of metals and its inhibition. A critical review of the current problem state. International Journal of Corrosion and Scale Inhibition, 11(1), 111-141. https://elibrary.ru/item.asp?id=48249072

[4] Banerjee, P., Hasda, R., Murmu, M., & Hirani, H. (2022). MgO as corrosion inhibitor. In Inorganic Anticorrosive Materials (pp. 183-210). Elsevier. https://doi.org/10.1016/B978-0-323-90410-0.00011-8

[5] Böhni, H. (2020). Localized corrosion. In Corrosion mechanisms (pp. 285-327). CRC Press. https://www.taylorfrancis.com/chapters/edit/10.1201/9781003065678-6/localized-corrosion-hans-b%C3%B6hni

[6] Christian, N. I., Ekuma, A. P., & Osondu, N. (2022). Phytochemical, Optical and FTIR Studies of ZnSe Thin Films for Solar Energy Applications. IOSR Journal of Applied Physics (IOSR-JAP), 14(01), 25-29. https://scholar.google.com/scholar?hl=en&as_sdt=2007&q=Phytochemical%2C+Optical+and+FTIR+Studies+of+ZnSe+Thin+Films+for+Solar+Energy+Applications&btnG

[7] Dehghani, A., Ramezanzadeh, B., Poshtiban, F., & Bahlakeh, G. (2020). Construction of a highly-effective/sustainable corrosion protective composite nanofilm based on Aminotris (methylphosphonic acid) and trivalent cerium ions on mild steel against chloride solution. Construction and Building Materials, 261, 119838. https://doi.org/10.1016/j.conbuildmat.2020.119838

[8] Eddy, N. O., Ibok, U. J., Garg, R., Garg, R., Iqbal, A., Amin, M., ... & Galal, A. M. (2022). A brief review on fruit and vegetable extracts as corrosion inhibitors in acidic environments. Molecules, 27(9), 2991. https://doi.org/10.3390/molecules27092991

[9] Elmsellem, H., Youssouf, M. H., Aouniti, A., Ben Hadda, T., Chetouani, A., & Hammouti, B. (2014). Adsorption and inhibition effect of curcumin on mild steel corrosion in hydrochloric acid. Russian Journal of Applied Chemistry, 87(6), 744-753. https://link.springer.com/article/10.1134/S1070427214060147

[10] Fazal, B. R., Becker, T., Kinsella, B., & Lepkova, K. (2022). A review of plant extracts as green corrosion inhibitors for CO2 corrosion of carbon steel. npj Materials Degradation, 6(1), 5. https://www.nature.com/articles/s41529-021-00201-5

[11] Finšgar, M., and Jackson, J. (2014). Application of corrosion inhibitors for steels in acidic media for the oil and gas industry: A review, Corr. Sci. 86, 17-41 Lahiri, A. K. (2017). Material degradation. In Applied Metallurgy and Corrosion Control: A Handbook for the Petrochemical Industry (pp. 177-267). Singapore: Springer Singapore. https://link.springer.com/chapter/10.1007/978-981-10-4684-1_8

[12] Goyal, M., Kumar, S., Bahadur, I., Verma, C., & Ebenso, E. E. (2018). Organic corrosion inhibitors for industrial cleaning of ferrous and non-ferrous metals in acidic solutions: A review. Journal of Molecular Liquids, 256, 565-573. https://doi.org/10.1016/j.molliq.2018.02.045

[13] Harsimran, S., Santosh, K., & Rakesh, K. (2021). Overview of corrosion and its control: A critical review. Proc. Eng. Sci, 3(1), 13-24. https://doaj.org/article/d4c85301cacb491290fe901f9113ca6d

[14] Heakal, F. E. T., & Elkholy, A. E. (2017). Gemini surfactants as corrosion inhibitors for carbon steel. Journal of Molecular Liquids, 230, 395-407. https://doi.org/10.1016/j.molliq.2017.01.047

[15] Jafari Pour, M., Manshad, A. K., Zargar, G., & Akbari, M. (2024). Application of Alkali-Novel Green Extracted Surfactant (AS) for Sustainable Chemical Enhanced Oil Recovery (CEOR) in Carbonate Petroleum Reservoirs. Energy & Fuels, 38(3), 1744-1765. https://pubs.acs.org/doi/abs/10.1021/acs.energyfuels.3c03584

[16] Ma, I. W., Ammar, S., Kumar, S. S., Ramesh, K., & Ramesh, S. (2022). A concise review on corrosion inhibitors: types, mechanisms and electrochemical evaluation studies. Journal of Coatings Technology and Research, 19(1), 241-268. https://link.springer.com/article/10.1007/s11998-021-00547-0

[17] Mohammed, H. K., Jafar, S. A., Humadi, J. I., Sehgal, S., Saxena, K. K., Abdullah, G. H., ... & Abdullah, W. S. (2023). Investigation of carbon steel corrosion rate in different acidic environments. Materials Today: Proceedings. https://doi.org/10.1016/j.matpr.2023.03.792

[18] Patni, N., Agarwal, S., & Shah, P. (2013). Greener approach towards corrosion inhibition. Chinese Journal of Engineering, 2013(1), 784186. https://doi.org/10.1155/2013/784186

[19] Proença, C. S., Serrano, B., Correia, J., & Araújo, M. E. M. (2022). Evaluation of tannins as potential green corrosion inhibitors of aluminium alloy used in aeronautical industry. Metals, 12(3), 508. https://doi.org/10.3390/met12030508

[20] Qiao, Y. X., Zheng, Z. B., Yang, H. K., Long, J., & Han, P. X. (2023). Recent progress in microstructural evolution, mechanical and corrosion properties of medium-Mn steel. Journal of Iron and Steel Research International, 30(8), 1463-1476. https://www.proquest.com/openview/a1d525ff8a450f653547378077d5f094/1?pq-origsite=gscholar&cbl=7435067

[21] Rajeev, P., Surendranathan, A. O., & Murthy, C. S. (2012). Corrosion mitigation of the oil well steels using organic inhibitors–a review. J. Mater. Environ. Sci, 3(5), 856-869.https://www.jmaterenvironsci.com/Document/vol3/vol3_N5/87-JMES-234-2012-Puthalath-review.pdf

[22] Răuță, D. I., Matei, E., & Avramescu, S. M. (2025). Recent Development of Corrosion Inhibitors: Types, Mechanisms, Electrochemical Behavior, Efficiency, and Environmental Impact. Technologies, 13(3), 103.https://www.mdpi.com/2227-7080/13/3/103

[23] Salim, R., Ech-chihbi, E., Ettahiri, W., Hammouti, B., Rais, Z., & Taleb, M. (2024). Industrial corrosion inhibitors: food waste as ideal substitutes. In Sustainable Food Waste Management: Anti-corrosion Applications (pp. 231-266). Singapore: Springer Nature Singapore. https://link.springer.com/chapter/10.1007/978-981-97-1160-4_11

[24] Verma, C., Chauhan, D. S., Aslam, R., Banerjee, P., Aslam, J., Quadri, T. W., ... & Rasheed, T. (2024). Principles and theories of green chemistry for corrosion science and engineering: design and application. Green Chemistry, 26(8), 4270-4357. https://pubs.rsc.org/en/content/articlehtml/2024/gc/d3gc05207a

[25] Wei, H., Heidarshenas, B., Zhou, L., Hussain, G., Li, Q., & Ostrikov, K. K. (2020). Green inhibitors for steel corrosion in acidic environment: state of art. Materials Today Sustainability, 10, 100044. https://doi.org/10.1016/j.mtsust.2020.100044

[26] Yan, J. B., Liew, J. R., Zhang, M. H., & Wang, J. Y. (2014). Mechanical properties of normal strength mild steel and high strength steel S690 in low temperature relevant to Arctic environment. *Materials & Design*, *61*, 150-159. https://doi.org/10.1016/j.matdes.2014.04.057