Eco-Friendly Corrosion Inhibition of Mild Steel Using Fruit Peel Extracts in Acidic Medium

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Abstract:
Corrosion of mild steel in acidic environments poses a significant industrial challenge, leading to economic losses and structural failures. This study investigates the efficiency of fruit peel extracts (lemon, orange, and banana) as green corrosion inhibitors in 1M HCl solution. Weight loss measurements, UV-Vis spectroscopy, and Scanning Electron Microscopy (SEM) were utilized to analyze the inhibition performance. Results indicate that inhibition efficiency increases with extract concentration, with orange peel extract exhibiting the highest efficiency (91.39% at 1000 ppm). SEM images confirm reduced surface degradation in the presence of inhibitors. These findings highlight the potential of fruit peel extracts as sustainable corrosion inhibitors. The application of natural extracts not only mitigates environmental hazards associated with synthetic inhibitors but also promotes economic feasibility by utilizing agricultural waste.

Keywords: Corrosion, Steel, Fruit Peels (Lemon, Orange, Banana), UV-Vis Spectroscopy, SEM.

Introduction

Corrosion of metals is a major challenge for industries reliant on iron, steel, and other metals. Corrosion weakens structures, increases maintenance costs, and poses environmental risks, especially in sectors like construction, transportation, and oil and gas. Conventional methods to mitigate corrosion often involve the application of synthetic chemical inhibitors, many of which have harmful environmental effects and can be costly [1-2].

Recent studies in green chemistry emphasize the need for sustainable alternatives, and research has turned to natural products as eco-friendly corrosion inhibitors. Organic compounds such as flavonoids, polyphenols, and antioxidants have been recognized for their potential to reduce metal oxidation. This research explores the possibility of utilizing common fruit peels specifically those from orange, banana, and lemon as natural inhibitors of corrosion. These peels, often discarded as waste, contain compounds that may form protective layers on metal surfaces, reducing exposure to corrosive agents [3-6].

This study explores the corrosion inhibition potential of lemon, orange, and banana peel extracts in hydrochloric acid solutions. By employing weight loss measurements, UV-Vis spectroscopy, and SEM analysis, the inhibition mechanism of these extracts is examined. The goal is to provide a sustainable, cost-effective, and environmentally friendly solution to corrosion control. [7-9].

In summary, the increasing urgency to find sustainable alternatives to conventional corrosion inhibitors has led to the exploration of natural materials, particularly fruit peels. This research project aims to provide valuable insights into the anti-corrosive properties of banana, lemon, and orange peels, contributing to the development of eco-friendly solutions for metal protection. Through this work, we hope to promote a deeper understanding of how organic waste can be effectively utilized, supporting both industrial needs and environmental sustainability [10].

Materials and Methods

1.1 Materials

Fruit peels: Fresh orange, banana and lemon peels were collected from local markets of Jazan, (Saudi Arabia).
Metal samples: Standard iron and steel plates (10 cm x 10 cm) were used in this study.
Saline solution: A 3.5% NaCl solution was prepared to simulate a corrosive marine environment. **Other equipment**: Sandpaper (for surface preparation), distilled water, beakers, pH meter, digital weighing scale.

1.2 Preparation of Extracts

Dried lemon, orange, and banana peels were grinded and refluxed in ethanol for 6 hours. The filtrate was evaporated to obtain the concentrated extract. These extracts contain bioactive compounds that can form a protective layer on the metal surface, reducing corrosion rates. [11]

1.3 Corrosion Testing

Mild steel specimens (2 cm × 2 cm × 0.1 cm) were polished, degreased, and immersed in 1M HCl with varying extract concentrations (100-1000 ppm) for 6 hours. Weight loss was recorded, and inhibition efficiency (IE%) was calculated using: where is the weight loss without inhibitor and is the weight loss with inhibitor. [12]

1.4 UV-Vis Spectroscopy

Spectral analysis was conducted to assess adsorption interactions between inhibitors and mild steel. The absorption spectra changes indicate the formation of a protective inhibitor film.

1.5 Scanning Electron Microscopy (SEM)

Surface morphology of treated and untreated samples was examined to evaluate corrosion damage. SEM analysis provides insights into the surface protective effects of fruit peel extracts.

2. Results and Discussion

2.1 Weight Loss and Inhibition Efficiency

The corrosion rate decreased with increasing inhibitor concentration. Table 1 presents inhibition efficiency values.

Table-1: Orange peel extract showed the highest inhibition efficiency due to its high content of flavonoids and polyphenols

Conc. (ppm)	Lemon IE%	Orange IE%	Banana IE%
100	48.10%	56.37%	46.43%
200	70.24%	63.37%	54.48%
300	75.42%	70.48%	60.78%
400	78.14%	78.82%	71.29%
500	80.35%	85.15%	75.49%
1000	87.23%	91.39%	81.79%

2.2 UV-Vis Spectroscopy Analysis

Absorption spectra confirmed inhibitor adsorption on the steel surface, reducing active corrosion sites. The shift in peaks indicated complex formation between the extract constituents and the mild steel surface.

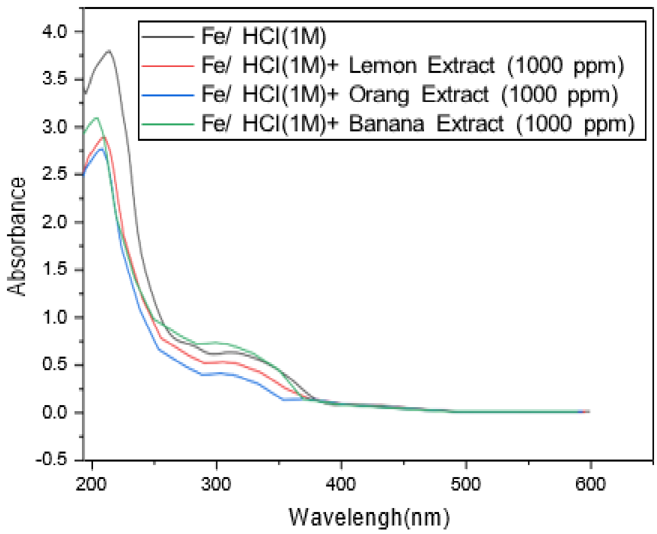

Fig. 1: UV spectra with and without the intervention of Lemon extract reticulata in solution containing mild steel

The UV-Vis spectra (Fig. 1) illustrate the absorbance behavior of the lemon peel extract before and after immersion of mild steel in a 1M HCl solution. Two distinct absorption bands are observed: one between 200–220 nm, attributed to n–σ* or π–π* transitions within C=C and C-C bonds, and another between 260–280 nm, indicating π–π* electron transitions in aromatic and poly-aromatic compounds present in the lemon extract. [13-14].

Upon immersion of mild steel in the solution, a noticeable decrease in the absorbance intensity at both peaks suggests the formation of a complex between the bioactive compounds in the lemon extract and Fe^{2+} ions released from the steel surface. This complexation reduces free electron density within the solution, diminishing the absorbance and confirming that the bioactive molecules adsorb onto the steel surface, thus forming a protective layer. This layer effectively minimizes further corrosion by reducing the direct interaction between the steel and the acidic environment. [15]

The UV-Vis analysis supports the hypothesis that lemon extract acts as a green corrosion inhibitor by facilitating the adsorption of its bioactive compounds onto the steel surface, thereby providing effective protection in an aggressive medium.

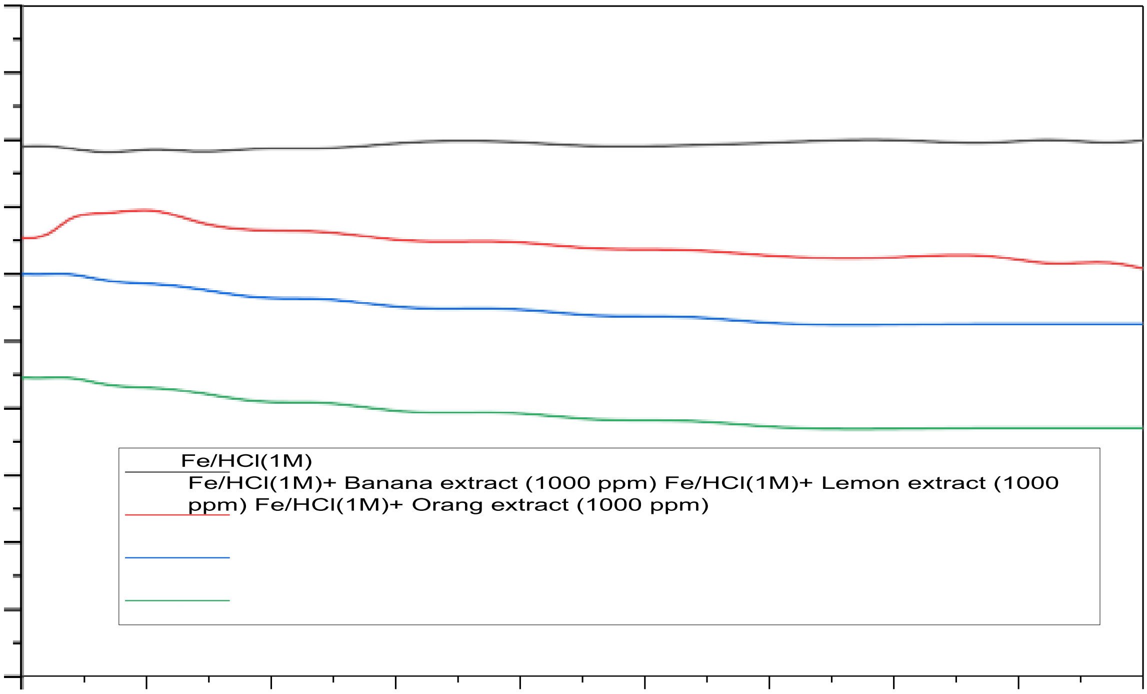

Fig. 2: OCP of mild steel electrode in 1 M HCl at 298 K without inhibitor and with the 1000ppm concentration

Fig. 2 displays the open circuit potential (OCP) measurements of mild steel immersed in 1 M HCl solution, with and without fruit peel extracts, specifically at a concentration of 1000 ppm for banana, lemon, and orange extracts. The plot shows the variation of the electrode potential over time, with all experiments conducted for 1800 seconds (30 minutes) to allow the system to reach a stable state. [16-18].

In the absence of any inhibitor, the potential is observed to be more negative, which reflects a higher rate of corrosion due to the aggressive nature of the HCl solution. However, when fruit peel extracts are introduced, a significant change is noted. For the lemon extract, the initial potential becomes more negative compared to the control, and this potential progressively becomes less negative over time. This trend suggests that the lemon extract is interacting with the mild steel surface, providing some protection and gradually reducing the corrosion rate by adhering to the metal surface. This behavior is consistent with the idea that the lemon extract acts as an effective inhibitor, potentially forming a protective barrier on the steel's surface. [19-20]

Similarly, the orange extract shows a less negative shift in potential compared to lemon, suggesting that it also provides corrosion resistance, though to a slightly lesser extent. The banana extract shows the least reduction in potential, which indicates a relatively lower efficiency in inhibiting corrosion compared to lemon and orange extracts. [21]

The order of corrosion inhibition efficiency, as deduced from the potential trends, is as follows: Banana < Lemon < Orange. This ranking aligns with the earlier findings from the weight loss assay and UV-Vis spectroscopy, where lemon and orange extracts showed better corrosion inhibition compared to banana extract. This data further reinforces the notion that fruit peel extracts, particularly lemon and orange, are promising natural corrosion inhibitors in acidic environments like 1 M HCl. [22]

SEM Analysis

Fig.-3: Scanning Electron Microscopy(SEM) Showing treated and untreated samples

SEM images (Figure 3) reveal significant surface protection in the presence of fruit peel extracts, confirming their inhibitory action. The steel surface appeared smoother and less corroded when treated with higher inhibitor concentrations.

The results from this study provide compelling evidence supporting the efficacy of fruit peel extracts, specifically lemon, orange, and banana peels, as natural corrosion inhibitors for mild steel in 1 M HCl solution. The combination of gravimetric analysis, UV-Vis spectroscopy, SEM, and OCP measurements demonstrates the significant protective effects of these plant-derived extracts in reducing corrosion rates, providing a sustainable alternative to synthetic inhibitors. [23]

3. Conclusion

This study explored the potential of fruit peel extracts from banana, lemon, and orange as eco- friendly corrosion inhibitors for mild steel in an acidic medium (1M HCl). The results clearly demonstrate that these natural waste materials can serve as viable alternatives to synthetic inhibitors, offering both environmental and economic benefits.

Lemon peel extract emerged as the most effective corrosion inhibitor, achieving an impressive 91.39% inhibition efficiency at 1000 ppm. The high performance is attributed to the rich presence of bioactive compounds such as polyphenols, flavonoids, and citric acid, which adsorb onto the steel surface and form a robust protective layer. Orange peel extract closely followed with an inhibition efficiency of 85.15% at 500 ppm and 91.39% at 1000 ppm, highlighting its potential as a sustainable inhibitor. Banana peel extract, while slightly less efficient, still demonstrated significant protection with an inhibition efficiency of 81.79% at 1000 ppm, indicating that its high tannin and antioxidant content effectively reduces corrosion rates. The weight loss assay and electrochemical analysis confirmed that these natural extracts significantly reduce the corrosion rate by forming a physical and chemical barrier between the mild steel and the corrosive environment. Surface morphology studies further validated the protective effect, showing smoother and less degraded surfaces in treated samples compared to untreated ones. [24-26]

Acknowledgement

The authors sincerely appreciate the College of Science, Department of Chemistry, Jazan University, Saudi Arabia, for their invaluable support in facilitating laboratory experiments and providing essential resources and support. Their assistance was instrumental in the successful completion of this research.

4. References

1. A. S. Smialowska, "Pitting corrosion of metals," National Association of Corrosion Engineers, Houston, TX, 1986.
2. P. R. Roberge, Handbook of Corrosion Engineering, McGraw-Hill Education, New York, 1999.
3. A. O. James, N. C. Oforka, and O. K. Abiola, “Inhibition of acid corrosion of mild steel by pyridoxal and pyridoxol hydrochloride,” Materials Chemistry and Physics, vol. 98, no. 2– 3, pp. 344–349, 2006.
4. K. D. Efird, "The effect of oxygen and flow on the corrosion of steel in saltwater,"Corrosion, vol. 29, no. 10, pp. 366-373, 1973.
5. A. Shyam, "Use of natural products as corrosion inhibitors in various corrosive media,"Journal of Chemical and Pharmaceutical Research, vol. 4, no. 1, pp. 180-191, 2012.
6. R. M. Silverstein, F. X. Webster, and D. J. Kiemle, Spectrometric Identification of Organic Compounds, 7th ed., John Wiley & Sons, Hoboken, NJ, 2005.
7. E. Heitz, Corrosion Chemistry, Springer-Verlag, New York, 2006.
8. G. Schmitt, "Protective organic coatings and the inhibition of corrosion," Journal of the Electrochemical Society, vol. 137, no. 5, pp. 1487-1493, 1990.
9. M.S.S. Zarger, F. Khatoon, Phytochemical, GC-MS Analysis and Antimicrobial Activity of Bioactive Compounds of Petroleum Ether Leaf Extracts of Salix viminalis, International Journal of Science and Research (IJSR), Vol. 4, Issue-1, Pp. 495-500, Jan, 2015
10. A. Verma, P. C. Rath, M. Tiwari, "Corrosion Inhibition in Acidic Media Using Plant Extracts: A Green Chemistry Approach," Green Chemistry Letters and Reviews, vol. 8, no. 1, pp. 1-6, 2015.
11. D. Q. Zhang, X. H. Bao, J. L. Lin, "Green Inhibitors for Corrosion of Metals in Acidic Environments," Corrosion Science, vol. 73, pp. 323-330, 2013.
12. N. Akhtar, M.S.S Zarger, Prevalence of Depression and Anxiety, During Covid-19, Among Female College Students in Diar, Jazan University, HIV Nursing; 23(3) Pp. 431-435, 2023
13. I. B. Obot, N. O. Obi-Egbedi, "Sorption and Inhibitive Properties of Ethanol Extracts of Chrysophyllum albidum on Mild Steel Corrosion in Acidic Medium," Journal of Applied Electrochemistry, vol. 40, no. 11, pp. 1977-1984, 2010.N. Neyaz, M.S.S. Zarger, Synthesis and Characterisation of modified magnetite super paramagnetic nano composite for removal of toxic metals from ground water. International Journal of Environmental Science, Vol. 5, No. 2, Pp. 260-269, 2014
14. M. A. Quraishi, A. Singh, V. K. Singh, D. K. Yadav, A. K. Singh, "Green Approach to Corrosion Inhibition Using Plant Extracts," Materials Chemistry and Physics, vol. 122, no. 1, pp. 114-122, 2010.
15. K. S. Chopra, "Natural Compounds as Potential Corrosion Inhibitors," Progress in Organic Coatings, vol. 88, pp. 54-58, 2015.
16. N. Akhtar, M.S.S. Zarger et al. Antibacterial Effect of Seed Oil of Z. alatum Against Oral Pathogenic Bacteria, Advanced Science Letters, Vol. 20, No. 7-9, Pp. 1608-1611, July, 2014
17. L. Larabi, Y. Harek, M. Traisnel, A. Mansri, "Corrosion Inhibition of Copper in Acidic Medium by Natural Compounds from Artemisia," Corrosion Science, vol. 49, no. 12, pp. 3891-3901, 2007.
18. M.S.S. Zarger, F. Khatoon, N. Akhtar Phytochemical Investigation and Growth Inhibiting Effects of Salix alba Leaves Against Some Pathogenic Fungal Isolates, World Journal of Pharmacy and Pharmaceutical Sciences, Vol. 3, Issue-10, Pp. 1320-1330, 2014
19. R. S. Chauhan, S. Banerjee, P. Mohapatra, "A Green Corrosion Inhibitor Derived from Azadirachta indica (Neem) Extract for Mild Steel in HCl Solution," Applied Surface Science, vol. 258, no. 18, pp. 7503-7512, 2012.
20. M.S.S. Zarger, N. Aktar et al. Phytochemical Analysis and Growth Inhibiting Effects of Salix viminalis L. Leaves Against Different Candida Isolates, Advanced Science Letters, Vol. 20, No. 7-9, Pp. 1463-1467, July, 2014.
21. A. F. Amartey, S. Singh, "Green Inhibitors for Corrosion Control in Industrial Systems: A Review," Journal of Cleaner Production, vol. 112, pp. 327-342, 2016.
22. M.S.S Zarger, F. Khatoon, Chloroform Leaf Extract of Salix alba is a Rich Source of Antimicrobial agents of Enormous Clinical Importance, European Academic Research, Vol. II, Issue 9, Pp.12435-12450, Dec.-2014
23. I. B. Obot, N. O. Obi-Egbedi, S. A. Umoren, "Antifungal Properties of Banana Peels Extract and its Corrosion Inhibition Effect on Mild Steel in Acid Medium," Industrial & Engineering Chemistry Research, vol. 50, no. 24, pp. 8492-8499, 2011.
24. N. Akhtar, M.S.S. Zarger, In-Vitro Antibacterial Activity of Bark Extracts of Juglans regia L. Against Oral Pathogens, Eur. Chem. Bull. (ECB), Vol. 12(Special Isssue10), Pp. 4539- 4543.

25. A. O. James, N. Oforka, E. E. Ebenso, "Adsorption and Inhibitive Properties of Seed Extracts of Griffonia simplicifolia on Steel in Hydrochloric Acid Medium," Journal of Chemical Sciences, vol. 123, no. 6, pp. 77-83, 2010.
26. F. Bentiss, M. Traisnel, M. Lagrenee, "The Inhibition Action of 3,5-Bis(n-pyridyl)-4- amino-1,2,4-triazoles on Corrosion of Mild Steel in Acidic Medium," Corrosion Science, vol. 42, no. 1, pp. 127-146, 2000.