Volume 2, Issue 1

Innovation Series Quarterly

hthttps://journal.academicapress.org/aps/index.php/isq

Research Article

Green Corrosion Inhibitor from Kitchen Waste for Acidic Environments

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Keywords:
Eggshell
Corrosion
Acidic
Weight loss
FTIR

Abstract: *Natural corrosion inhibitors containing calcium carbonate have gained attention due to their performance. Eggshells are promising inhibitors because of their high $CaCO_3$ content, making their effect on mild steel corrosion important to study. Eggshell waste was extracted using ethanol in a Soxhlet extraction and concentrated by rotary evaporation. Inhibitor solutions of 1–15 g were prepared. FTIR and XRD were used to characterize the inhibitor. Corrosion behavior was evaluated by weight loss tests in 1.0 M HCl for 3, 5, and 7 days. Results showed increased $CaCO_3$ adsorption on steel surfaces, reducing corrosion rate and improving inhibition efficiency under acidic conditions.*

1. INTRODUCTION

Corrosion is the degradation of materials caused by environmental interactions, leading to major economic losses worldwide. Mild steel, widely used in construction, transportation, pipelines, and industrial equipment, is especially vulnerable to corrosion in acidic environments such as industrial effluents(Alias et al., 2024). Chloride ions significantly accelerate corrosion, increasing maintenance and replacement costs(Honarvar Nazari et al., 2020). Although chemical inhibitors are effective, many are toxic and environmentally harmful(Giraudo et al., 2020). Eggshells, a calcium carbonate rich waste material, offer a sustainable alternative(Sanni et al., 2023). This study investigates eggshells as a natural corrosion inhibitor for mild steel using Ftir and weight loss analysis, aiming to reduce corrosion while providing economic and environmental benefits(Baitule & Manivannan, 2021).

2. LITERATURE REVIEW

Previous studies have widely investigated the use of organic and waste derived corrosion inhibitors for steel protection in aggressive environments(KM et al., 2024). Research has shown that eggshell waste extract is an effective organic inhibitor for AISI 1020 and 1020 steels in acidic media, particularly in HCl and H_2SO_4 solutions, as evaluated using weight loss and electrochemical techniques(Alias et al., 2024). Other studies have explored commercial organic coatings and plant-based inhibitors, such as apple pomace extract, in chloride-rich environments like NaCl solutions(Honarvar Nazari et al., 2020). These studies consistently highlight that organic inhibitors can significantly reduce corrosion rates by forming protective films on steel surfaces, demonstrating their potential as low-cost and environmentally friendly alternatives to conventional chemical inhibitors.

3. METHODOLOGY

3.1 Samples and Solution Preparation

Mild steel specimens were prepared for corrosion studies by cutting them into uniform dimensions of 50 mm × 25 mm × 2 mm and polishing the surfaces to ensure consistency. The natural corrosion inhibitor was produced from waste eggshells collected from household and supermarket sources. The eggshells were washed, boiled to remove membranes and contaminants, and dried using sunlight and oven heating to eliminate moisture. The dried shells were ground into fine powder and sieved to obtain uniform particle size. The powder was further purified through ethanol reflux extraction using a Soxhlet apparatus, followed by vacuum filtration and final oven drying. The resulting eggshell powder was stored in sealed containers and used as an eco-friendly corrosion inhibitor for mild steel studies.

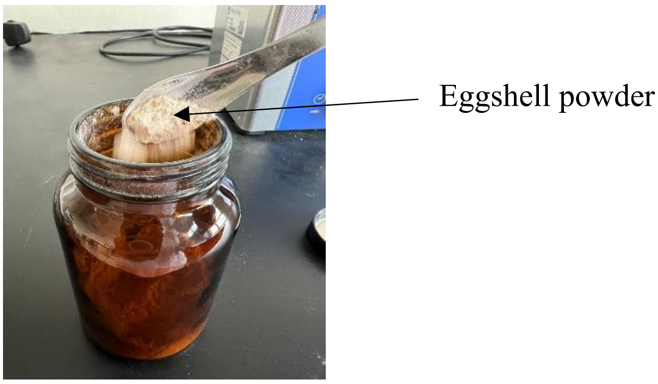

Figure 1. Eggshell powder

3.2 Characteristics Testing

FTIR is a technique used effectively to identify chemical composition and functional groups in a substance. The procedure measures the infrared absorption or transmittance of a sample by its wavelength or frequency. The different chemical bonds existing absorb IR radiation at different characteristic frequencies, which creates a distinct spectrum called the molecular fingerprint for that material. This study performed the FTIR analysis using the VERTEX 70 FTIR spectrometer, a high-performance instrument manufactured by Bruker. This machine is known for its precision, wide spectral range, and high sensitivity. It is suitable for solid and powder samples, such as prepared eggshell powder or corrosion-inhibited mild steel surfaces.

3.3 Weight Loss Testing

This experimental procedure evaluates the corrosion inhibition performance of eggshell powder using the weight loss method. Initially, different amounts of eggshell powder are accurately weighed using a digital analytical balance to prepare varying inhibitor concentrations(Alfattah et al., 2025). Each amount is added to 250 mL of 1 M hydrochloric acid, creating a highly corrosive medium suitable for testing inhibitor effectiveness. The beakers are clearly labelled to avoid confusion, and the mixtures are stirred thoroughly to ensure uniform suspension of the eggshell powder in the acid solution. Mild steel specimens are suspended in each solution using cable ties, ensuring full immersion without contact with the beaker walls or base. The beakers are then placed in a temperature-controlled water bath at 30 °C, 40 °C, and 50 °C to study the effect of temperature on corrosion and inhibitor performance. The steel samples are immersed for 3, 5, and 7 days to evaluate both short-term and long-term corrosion behavior. After immersion, the steel specimens are removed, washed with distilled water, gently cleaned, and dried completely. Each sample is weighed before and after immersion to determine weight loss. Corrosion rates are calculated using the standard weight loss formula, and inhibitor efficiency is determined by comparing corrosion rates or weight loss values with and without inhibitor. The results are tabulated to identify the optimal eggshell concentration and conditions for effective corrosion protection.

4. FINDINGS

4.1 Ftir Result

FTIR analysis of eggshell powder (1–15 g) confirmed that it is mainly composed of calcium carbonate, with absorption bands similar to industrial $CaCO_3$. Key bands include O–H stretching (3230–3500 cm^{-1}), C–H stretching (2960–2970 cm^{-1}), asymmetric CO_3^{2-} stretching (1410–1420 cm^{-1}), and out-of-plane bending (875 cm^{-1}). These functional groups and carbonate ions enable the powder to adsorb onto mild steel, forming a protective layer that enhances corrosion inhibition.

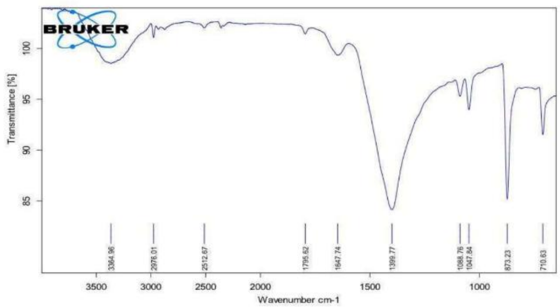

Figure 2. FTIR Result For Eggshell

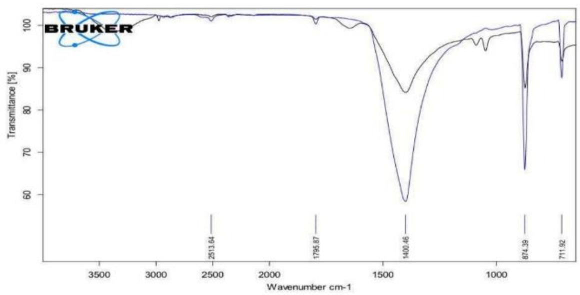

Figure 3. FTIR Result For Eggshell VS CaCO3 Industry

4.2 Weight Loss Result

Corrosion behaviour of mild steel was evaluated using the weight loss method at eggshell concentrations of 0–15 g and immersion periods of 3, 5, and 7 days in 1.0 M HCl. Results for corrosion rate and inhibition efficiency are presented , while the relationship between corrosion rate and eggshell concentration is illustrated. The highest corrosion rate (3.6965 mm/y) was observed in the sample without eggshell after 3 days of immersion. The addition of 1 g of eggshell significantly reduced the corrosion rate to 0.5748 mm/y, achieving over 84% reduction compared to the uninhibited sample. Increasing the eggshell concentration up to 15 g .

Table 1. Weight loss Result

Concentration	Corrosion rate (mm/year)	Inhibitor Efficiency (%)	Corrosion rate (mm/year)	Inhibitor Efficiency (%)	Corrosion rate (mm/year)	Inhibitor Efficiency (%)
	3 days	3 days	5days	5 days	7 days	7 days
Raw	3.6965	0	6.812	0	9.2227	0
1	0.5748	84.4511	1.2944	64.9838	1.9849	90.8036
3	0.397	89.2606	1.206	67.3737	1.05	95.1353
5	0.3997	89.198	0.5197	85.9398	0.9249	95.6981
7	0.3075	91.6804	0.4975	86.7314	0.8598	96.0162
9	0.2617	92.9201	0.3597	84.8593	0.6118	97.1656
11	0.196	94.6975	0.2886	92.1932	0.443	97.9475
13	0.1353	96.3406	0.1139	96.9181	0.4222	98.0439
15	0.1347	96.3555	0.0939	97.4608	0.0559	99.7408

5. DISCUSSION

The corrosion results clearly show the influence of immersion time and eggshell concentration on the corrosion behavior of mild steel in 1.0 M HCl. For the 5-day immersion period, the control sample without eggshell inhibitor (0%) exhibited severe corrosion, with a high corrosion rate of 6.812 mm/y. When eggshell powder was added, the corrosion rate decreased significantly, dropping to 1.2944 mm/y at 1 g, 0.3597 mm/y at 9 g, and reaching a very low value of 0.0939 mm/y at 15 g. A similar trend was observed for the 7-day immersion period, where the blank sample showed the highest corrosion rate of 9.2227 mm/y due to prolonged exposure to aggressive HCl ions. However, increasing eggshell concentration again resulted in substantial corrosion reduction, with rates decreasing to 1.9849 mm/y at 1 g, 0.6118 mm/y at 9 g, and 0.0559 mm/y at 15 g.

Overall, longer immersion times increased corrosion severity in the absence of inhibitor, confirming the strong corrosive action of HCl on mild steel. In contrast, higher eggshell concentrations consistently improved inhibition efficiency, reaching values above 96%. This improvement is attributed to enhanced adsorption of calcium carbonate–rich eggshell particles on the steel surface, forming a protective layer that limits metal–acid interaction. These findings confirm the effective and stable inhibition performance of eggshell extract over extended immersion periods.

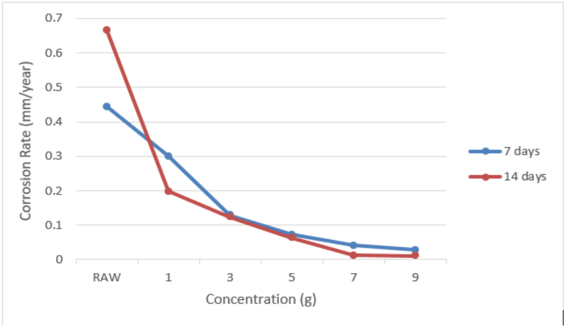

Figure 4. Corrosion rate against difference concentration

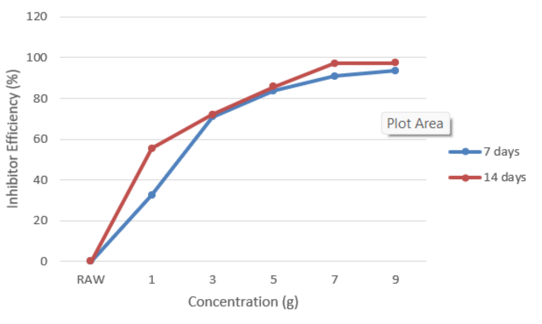

Figure 5. Inhibitor efficiency against difference concentration

6. CONCLUSION

This study investigates eggshell extract as a sustainable natural corrosion inhibitor for mild steel in a 1.0 M HCl environment(Darmawan & Leman, 2020). FTIR and XRD analyses confirmed the presence of high calcium carbonate content in eggshell powder, which plays a key role in corrosion reduction(Khadija et al., 2024). Weight loss tests showed that increasing eggshell concentration significantly decreased corrosion rates, with the highest inhibition efficiency of 99.74% achieved at 15 g after 7 days. Although longer immersion increased overall corrosion, it enhanced inhibitor efficiency by allowing a stable protective layer to form. Overall, the results demonstrate that waste eggshells are an eco-friendly, low cost, and effective alternative to synthetic corrosion inhibitors(Ahlstrøm & Skrede, 2020).

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