

The Study of Corrosion Inhibition of Mild Steel in 1 M HCl Using *Moringa oleifera* Extract: Electrochemical Evaluation, Adsorption Behaviour, and Surface Morphology Analysis

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Structured Abstract

Background: Mild steel is widely used in industrial applications for its excellent mechanical strength and affordability. However, its high susceptibility to corrosion in acidic environments, such as 1.0 M hydrochloric acid (HCl), poses serious economic and environmental challenges. While synthetic corrosion inhibitors are effective, they often pose environmental risks. Therefore, this study explores the use of *Moringa oleifera* (MO) extract as a sustainable and eco-friendly corrosion inhibitor for mild steel in acidic media.

Methods: MO extract solutions were prepared at 100, 200, 300, and 400 ppm by dissolving moringa powder in 1.0 M HCl. Mild steel specimens were cut, polished, and cleaned to ensure uniformity before immersion in 1.0 M HCl, both with and without the MO extract. Electrochemical tests were carried out using Electrochemical Impedance Spectroscopy (EIS) across frequencies from 10^5 to 10^{-2} Hz and Linear Polarization Resistance (LPR) with a ± 10 mV potential range to evaluate corrosion behaviour and inhibition efficiency. Post-testing, surface morphology was analyzed using Field Emission Scanning Electron Microscopy (FESEM), while elemental composition and inhibitor adsorption were assessed using Scanning Electron Microscopy with Energy Dispersive X-ray (SEM-EDX).

Results: This study shows that MO extract significantly reduces the corrosion of mild steel in 1.0 M HCl. EIS revealed increased charge-transfer resistance and decreased double-layer capacitance at higher extract concentrations, achieving an inhibition efficiency of up to 85.54% at 400 ppm. LPR results supported this, with corrosion current density and rate substantially reduced, confirming mixed-type inhibition. Adsorption studies followed the Langmuir isotherm model with a ΔG_{ads} value of -4.74 kJ/mol, indicating spontaneous physical adsorption. Surface analysis using FESEM and SEM-EDX revealed smoother, less-damaged steel surfaces in the presence of MO, confirming the formation of a protective organic layer.

Conclusion: The findings of this study indicate that the MO extract demonstrated significant potential as a green corrosion inhibitor for mild steel in 1.0 M HCl. The findings confirm its effectiveness in reducing corrosion through adsorption and protective film formation, offering an eco-friendly alternative to conventional synthetic inhibitors for industrial applications.

Keywords: Corrosion inhibition, *Moringa oleifera*, mild steel, electrochemical analysis, green inhibitor

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