IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.311 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 5, May 2026
DOI: 10.17148/IARJSET.2026.13559

GREEN CORROSION INHIBITORS IN AQUEOUS SYSTEMS: BRIDGING SURFACE CHEMISTRY AND ENVIRONMENTAL SAFETY

Satyendra Sharma

Assistant Professor, P. G Department of Chemistry, Sri Arvind Mahila College, Patna,

Patliputra University, Patna, India

Abstract: Corrosion remains a major challenge in industrial systems involving metals exposed to aqueous environments. Conventional corrosion inhibitors, although effective, often exhibit toxicity, poor biodegradability, and ecological hazards. Green corrosion inhibitors derived from plant extracts, natural polymers, amino acids, and biodegradable compounds have emerged as sustainable alternatives. This research paper examines the role of green corrosion inhibitors in aqueous systems, with an emphasis on adsorption mechanisms, surface chemistry, electrochemical behaviour, and environmental safety. The study also discusses inhibitor efficiency, adsorption isotherms, surface analytical methods, and ecological assessment. Experimental trends reported in literature indicate that green inhibitors can achieve inhibition efficiencies above 85–90% under optimized conditions while maintaining environmental compatibility. The paper bridges the gap between corrosion science and sustainability by evaluating both protective performance and environmental impact.

Keywords: Green corrosion inhibitors, aqueous systems, adsorption, electrochemistry, environmental safety, plant extracts, sustainable chemistry.

1. INTRODUCTION

Corrosion is an electrochemical degradation process that affects metallic structures exposed to aggressive environments such as acidic, saline, or alkaline aqueous media. Industrial sectors, including petroleum refining, marine engineering, transportation, and power generation, experience enormous economic losses due to corrosion-related failures. Traditional inhibitors such as chromates, phosphates, and nitrites are highly effective but pose serious environmental and health concerns because of their toxicity and persistence.

The growing emphasis on sustainable industrial practices has accelerated research into environmentally friendly corrosion inhibitors. Green corrosion inhibitors are generally biodegradable, renewable, low-toxic, and derived from natural sources, including plant extracts, gums, amino acids, biopolymers, and ionic liquids. These compounds protect metal surfaces primarily through adsorption mechanisms involving heteroatoms such as nitrogen, oxygen, sulfur, and phosphorus.

The effectiveness of green inhibitors depends strongly on surface chemistry, molecular structure, concentration, pH, and temperature. Advanced characterization techniques such as scanning electron microscopy (SEM), electrochemical impedance spectroscopy (EIS), X-ray diffraction (XRD), and density functional theory (DFT) have significantly improved the understanding of inhibitor-metal interactions.

This paper aims to provide a comprehensive overview of green corrosion inhibitors in aqueous systems by integrating corrosion science with environmental sustainability principles.

2. CORROSION IN AQUEOUS SYSTEMS

2.1 Fundamentals of Corrosion

Corrosion is a spontaneous electrochemical process involving anodic metal dissolution and cathodic reduction reactions.
For iron in an acidic medium:

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.311 ⁜ Peer-reviewed & Refereed journal ⁜ Vol. 13, Issue 5, May 2026
DOI: 10.17148/IARJSET.2026.13559

Anodic Reaction

$$Fe \rightarrow Fe^{2+} + 2e^-$$

Cathodic Reaction

$$2H^+ + 2e^- \rightarrow H_2$$

Overall corrosion rate depends on:

- Electrolyte composition
- Dissolved oxygen
- Temperature
- Metal microstructure
- Presence of aggressive ions such as chloride

In saline systems, chloride ions penetrate oxide layers and accelerate localized corrosion such as pitting.

3. GREEN CORROSION INHIBITORS

3.1 Definition and Characteristics

Green corrosion inhibitors are environmentally acceptable substances capable of reducing corrosion rates without causing ecological damage.

Important Characteristics

- Biodegradable
- Renewable source
- Low toxicity
- Cost-effective
- High inhibition efficiency
- Eco-compatible

4. CLASSIFICATION OF GREEN CORROSION INHIBITORS

Table 1: Classification of Green Corrosion Inhibitors

Type of Inhibitor	Source	Active Components	Typical Metals Protected
Plant extracts	Leaves, roots, seeds	Alkaloids, flavonoids, tannins	Steel, copper, aluminum
Natural gums	Gum rabic, guar gum	Polysaccharides	Mild steel
Amino acids	Glycine, cysteine	Amino and carboxyl groups	Stainless steel
Biopolymers	Chitosan, cellulose	Hydroxyl and amino groups	Iron alloys
Essential oils	Clove, neem oil	Phenolics, terpenes	Copper, steel
Ionic liquids	Bio-based salts	Organic cations/anions	Multi-metal systems

5. SURFACE CHEMISTRY OF GREEN CORROSION INHIBITORS

5.1 Adsorption Mechanism

Adsorption is the primary mechanism by which inhibitors protect metal surfaces.

Types of Adsorption

1. **Physisorption**
    - Electrostatic attraction
    - Weak interaction
    - Reversible
2. **Chemisorption**
    - Coordinate covalent bonding
    - Strong adsorption
    - High stability

The adsorption behavior commonly follows the Langmuir adsorption isotherm:

$$\frac{C}{\theta} = \frac{1}{K_{ads}} + C$$

DOI: 10.17148/IARJSET.2026.13559

Where:

- C = inhibitor concentration
- θ = surface coverage
- K_{ads} = adsorption equilibrium constant

6. ELECTROCHEMICAL EVALUATION METHODS

6.1 Potentiodynamic Polarization

Used to determine:

- Corrosion current density
- Corrosion potential
- Tafel slopes

Reduction in corrosion current indicates inhibitor effectiveness.

6.2 Electrochemical Impedance Spectroscopy (EIS)

EIS evaluates:

- Charge transfer resistance
- Double-layer capacitance
- Surface film stability

Higher impedance implies stronger protective film formation.

7. SURFACE CHARACTERIZATION TECHNIQUES

Table 2: Surface Analysis Techniques

Technique	Purpose	Information Obtained
SEM	Surface morphology	Pitting and surface damage
AFM	Surface roughness	Nanostructure of inhibitor film
FTIR	Functional groups	Adsorption interactions
XPS	Surface composition	Chemical bonding states
XRD	Crystal structure	Corrosion products
EDX	Elemental analysis	Presence of inhibitor elements

8. ENVIRONMENTAL SAFETY ASSESSMENT

8.1 Toxicity Considerations

Traditional inhibitors like chromates are carcinogenic and environmentally persistent. Green inhibitors reduce environmental hazards due to:

- Natural origin
- Low bioaccumulation
- Rapid biodegradation

According to environmental guidelines, eco-friendly inhibitors should exhibit:

- Biodegradability >60% within 28 days
- Low aquatic toxicity
- Low octanol-water partition coefficient

9. PERFORMANCE OF SELECTED GREEN INHIBITORS

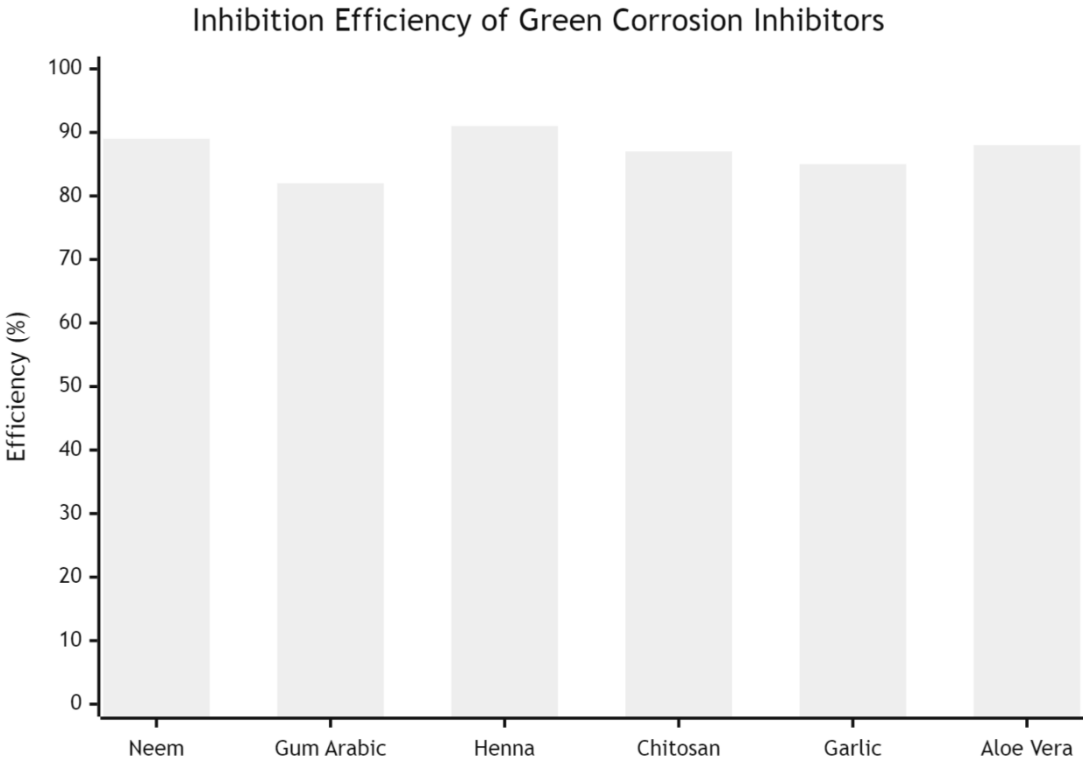
Table 3: Reported Inhibition Efficiencies

Green Inhibitor	Metal	Medium	Efficiency (%)
Neem extract	Mild steel	1M HCl	89
Gum arabic	Steel	NaCl solution	82
Henna extract	Aluminum	Acidic medium	91
Chitosan	Copper	Saline water	87
Garlic extract	Mild steel	Sulfuric acid	85
Aloe vera extract	Steel	Hydrochloric acid	88

IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588
International Advanced Research Journal in Science, Engineering and Technology
Impact Factor 8.311 ⁙ Peer-reviewed & Refereed journal ⁙ Vol. 13, Issue 5, May 2026
DOI: 10.17148/IARJSET.2026.13559

10. GRAPHICAL REPRESENTATION OF INHIBITION EFFICIENCY

Graph 1: Inhibition Efficiency of Green Corrosion Inhibitors



11. MECHANISM OF CORROSION PROTECTION

Green inhibitors protect metallic surfaces through:

- Surface adsorption
- Barrier film formation
- Blocking active anodic/cathodic sites
- Chelation with metal ions
- Hydrophobic layer generation

Functional groups responsible for inhibition include:

- –OH
- $–NH_2$
- –COOH
- Aromatic π-electrons

These groups donate electrons to vacant metal orbitals, forming stable protective complexes.

12. COMPUTATIONAL AND THEORETICAL APPROACHES

Density Functional Theory (DFT) and Molecular Dynamics (MD) simulations are increasingly used to study inhibitor adsorption.

Important theoretical parameters include:

- HOMO energy
- LUMO energy
- Dipole moment
- Energy gap

Lower HOMO-LUMO energy gaps generally indicate higher adsorption tendency and stronger inhibition performance.

DOI: 10.17148/IARJSET.2026.13559

13. CHALLENGES AND LIMITATIONS

Despite promising performance, green inhibitors face several challenges:

- Variability in plant composition
- Poor thermal stability
- Limited long-term durability
- Difficult extraction standardization
- Industrial scalability issues

Further studies are needed to improve:

- Purification techniques
- Molecular optimization
- Hybrid green formulations
- Nanotechnology integration

14. FUTURE PERSPECTIVES

Future developments may include:

- Nanoengineered green inhibitors
- Smart self-healing coatings
- AI-assisted inhibitor design
- Hybrid biopolymer composites
- Sustainable industrial formulations

Integration of corrosion science with environmental toxicology and life-cycle analysis will be critical for large-scale industrial adoption.

15. CONCLUSION

Green corrosion inhibitors represent a sustainable and environmentally responsible alternative to conventional toxic inhibitors in aqueous systems. Their effectiveness is largely governed by adsorption behavior, surface chemistry, and molecular interactions with metallic substrates. Plant extracts, natural gums, amino acids, and biopolymers have demonstrated significant corrosion inhibition efficiencies in acidic and saline environments.

The combined use of electrochemical techniques, surface characterization methods, and computational simulations has enhanced understanding of inhibition mechanisms. In addition to corrosion protection, environmental compatibility remains a major advantage of green inhibitors. However, challenges associated with standardization, durability, and industrial implementation still require extensive research.

Bridging surface chemistry with environmental safety will play a key role in developing next-generation sustainable corrosion protection technologies.

REFERENCES

[1]. Peter, A., Obot, I.B., & Sharma, S.K. "Use of Natural Gums as Green Corrosion Inhibitors." *International Journal of Industrial Chemistry*, Vol. 6, No. 3, 2015, pp. 153–164.

[2]. Sheydaei, M. "The Use of Plant Extracts as Green Corrosion Inhibitors: A Review." *Surfaces*, Vol. 7, No. 2, 2024, pp. 215–238.

[3]. Madrid, F.M.G., et al. "Green Corrosion Inhibitors for Metal and Alloys Protection in Contact with Aqueous Saline." *Materials*, Vol. 17, No. 5, 2024, pp. 1021–1045.

[4]. Bandeira, R.M., et al. "The Green Plant-Based Corrosion Inhibitors." *Surface Science and Technology*, Vol. 12, No. 1, 2025, pp. 55–79.

[5]. "Comprehensive Review of Green Corrosion Inhibitors." *Discover Electrochemistry*, Vol. 3, No. 1, 2025, pp. 1–28.

[6]. "Green Guardians: Environmentally Friendly Corrosion Inhibitors." *Progress in Organic Coatings*, Vol. 198, 2025, Article 108923.

[7]. Xhanari, K., et al. "Green Corrosion Inhibitors for Aluminium and Its Alloys." *RSC Advances*, Vol. 7, 2017, pp. 44606–44630.

DOI: 10.17148/IARJSET.2026.13559

[8]. Buchweishaija, J. "Phytochemicals as Green Corrosion Inhibitors." *Tanzania Journal of Science*, Vol. 35, No. 1, 2009, pp. 77–92.

[9]. Verma, C., Ebenso, E.E., Bahadur, I., & Quraishi, M.A. "An Overview on Plant Extracts as Environmental Sustainable and Green Corrosion Inhibitors for Metals and Alloys in Aggressive Corrosive Media." *Journal of Molecular Liquids*, Vol. 266, 2018, pp. 577–590.

[10]. Raja, P.B., & Sethuraman, M.G. "Natural Products as Corrosion Inhibitor for Metals in Corrosive Media—A Review." *Materials Letters*, Vol. 62, No. 1, 2008, pp. 113–116.

[11]. Umoren, S.A., & Solomon, M.M. "Synergistic Corrosion Inhibition Effect of Metal Cations and Organic Compounds." *Journal of Environmental Chemical Engineering*, Vol. 5, No. 1, 2017, pp. 246–273.

[12]. Quraishi, M.A., et al. "Corrosion Inhibition by Green Organic Compounds in Acidic Media." *International Journal of Corrosion*, Vol. 2013, Article ID 124256, 2013.

[13]. Gece, G. "Drugs: A Review of Promising Novel Corrosion Inhibitors." *Corrosion Science*, Vol. 53, No. 12, 2011, pp. 3873–3898.

[14]. Fouda, A.S., et al. "Corrosion Inhibition of Carbon Steel Using Plant Extracts in Hydrochloric Acid Solutions." *Chemical Science Review and Letters*, Vol. 3, No. 9, 2014, pp. 122–134.

[15]. Li, X., Deng, S., & Fu, H. "Inhibition Effect of Dendrocalamus Brandisii Leaves Extract on Aluminum in HCl Solution." *Corrosion Science*, Vol. 62, 2012, pp. 163–175.

[16]. El-Etre, A.Y. "Natural Honey as Corrosion Inhibitor for Metals and Alloys." *Corrosion Science*, Vol. 40, No. 11, 1998, pp. 1845–1850.

[17]. Eddy, N.O., Odoemelam, S.A., & Mbaba, A.J. "Inhibition of the Corrosion of Mild Steel in H_2SO_4 by Ethanol Extract of Aloe Vera." *African Journal of Pure and Applied Chemistry*, Vol. 2, No. 12, 2008, pp. 132–138.

[18]. Abdel-Gaber, A.M., Abd-El-Nabey, B.A., Sidahmed, I.M., El-Zayady, A.M., & Saadawy, M. "Inhibitive Action of Some Plant Extracts on the Corrosion of Steel in Acidic Media." *Corrosion Science*, Vol. 48, No. 9, 2006, pp. 2765–2779.

[19]. Obot, I.B., Macdonald, D.D., & Gasem, Z.M. "Density Functional Theory Investigation of Corrosion Inhibition Performance." *Corrosion Science*, Vol. 99, 2015, pp. 1–30.

[20]. Ebenso, E.E., Arslan, T., Kandemirli, F., Caner, N., & Love, I. "Quantum Chemical Studies of Some Rhodanine Azosulpha Drugs as Corrosion Inhibitors." *International Journal of Quantum Chemistry*, Vol. 110, No. 5, 2010, pp. 1003–1018.

