Eco-Friendly Approaches to Corrosion Inhibition: A Comprehensive Review of Recent Developments in Plant-Based Inhibitors

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Abstract:

Corrosion of metals and alloys poses significant challenges in industrial applications, leading to the deterioration of infrastructure and equipment. Conventional methods to mitigate this process have primarily relied on synthetic corrosion inhibitors, which, while effective, often introduce environmental and health hazards. Recent shifts in global priorities towards sustainability and environmental conservation have catalyzed the exploration of eco-friendly alternatives. This comprehensive review synthesizes findings from three pivotal studies, presenting an in-depth analysis of the advancements in plant-based corrosion inhibitors as viable and sustainable alternatives to their synthetic counterparts. This review emphasizes the importance of interdisciplinary approaches, combining insights from chemistry, materials science, and environmental science, to develop effective, sustainable, and eco-friendly corrosion inhibitors. By providing a comprehensive overview of recent advancements and highlighting areas for future research, this review aims to serve as a catalyst for further innovation in the field of corrosion inhibition. Here we have provided different type of corrosion inhibitors, Measurement techniques, research gap, and objectives, future techniques were discussed.

Keywords: Corrosion inhibition, Mild steel, Synthetic inhibitors, Environmental impact, Green chemistry.

1. Introduction:

Corrosion, a naturally occurring phenomenon, results in the gradual destruction of materials, particularly metals and alloys, through chemical or electrochemical reactions with the environment [1-5]. It presents a significant challenge across various industries, leading to substantial economic losses, safety hazards, and environmental issues [6-11]. Traditionally, corrosion inhibition has been achieved through the use of various synthetic chemicals. However, the environmental and health hazards associated with these synthetic inhibitors have led to an increasing demand for green and sustainable alternatives [12-15]. This review paper synthesizes insights from three recent studies to provide a comprehensive understanding of the advancements in plant-based corrosion inhibitors as eco-friendly alternatives to traditional methods [16-20].

The detrimental impact of synthetic corrosion inhibitors on the environment and human health cannot be overstated [21-24]. These compounds, while effective in mitigating corrosion, often contain toxic heavy metals and organic compounds that pose significant risks upon release into the environment [25-28]. The adverse effects range from soil and water contamination to detrimental impacts on aquatic life and human health [29-33]. Consequently, there's a growing imperative within the scientific community and industry to develop corrosion inhibitors that are not only effective but also environmentally benign and sustainable [34.

The shift toward green corrosion inhibitors is not merely a response to environmental concerns but also aligns with the broader paradigm of green chemistry and sustainability. Plant-based inhibitors, in particular, have garnered significant attention due to their wide availability, low cost, and minimal environmental footprint [35-37]. These natural inhibitors often contain a variety of organic compounds, including tannins, alkaloids, and flavonoids, which have shown promising inhibitory effects against corrosion. The first study under review offers a detailed exploration of the types and mechanisms of both synthetic and natural organic corrosion inhibitors, providing a foundational understanding of how these substances interact with metal surfaces to prevent corrosion [38-40].

This review paper builds upon the insights from these studies to present a cohesive understanding of the current landscape of green corrosion inhibitors. It aims to highlight the potential of plant-based inhibitors in replacing traditional synthetic chemicals, address the challenges and limitations in their application, and identify future directions for research and development in this field. By doing so, this paper contributes to the ongoing discourse on sustainable and environmentally friendly approaches to corrosion inhibition, aligning with global efforts towards a more sustainable and ecologically conscious industrial future [41-43].

2. Corrosion measurement techniques

Corrosion measurement techniques are vital for understanding the extent of corrosion and evaluating the effectiveness of inhibitors. The three reviewed articles discuss a variety of methods used to measure and analyze corrosion rates and the inhibitory effects of various substances. Here's a synthesis of the corrosion measurement techniques based on the insights from the articles:

3. Weight Loss Measurements:

This is one of the most straightforward and common methods for assessing corrosion rates. It involves exposing a metal specimen to a corrosive environment for a predetermined period, then cleaning and weighing it to determine the loss of mass. The rate of corrosion is inferred from the weight loss over time. This technique was mentioned across all three studies as a primary method for evaluating the performance of corrosion inhibitors [44-46].

3.1 Electrochemical Techniques:

Potentiodynamic Polarization (PDP): This technique involves varying the potential of the metal specimen in a corrosive solution and measuring the resulting current to understand the corrosion kinetics. It helps in determining the corrosion potential, corrosion current, and Tafel slopes, which are crucial for evaluating the efficiency of corrosion inhibitors.

Electrochemical Impedance Spectroscopy (EIS): EIS is a non-destructive technique that measures the impedance of a metal surface over a range of frequencies. The impedance data is used to model the corrosion process and understand the behavior of corrosion inhibitors. It provides insights into the protective film formation and the adsorption behavior of inhibitors.

Linear Polarization Resistance (LPR): LPR measures the polarization resistance of the metal by applying a small perturbation to the system's rest potential and measuring the resulting current. It's an effective method for quickly estimating the corrosion rate without significantly disturbing the system [47].

3.2 Surface Analysis Techniques:

Scanning Electron Microscopy (SEM): SEM is used to visualize the surface morphology of the corroded metal. It provides detailed images of the corrosion products, pits, and any protective films formed by inhibitors.

Atomic Force Microscopy (AFM): AFM provides a 3D surface profile and detailed topographical data for the metal surface, allowing for the examination of the effects of corrosion and the protective action of inhibitors at a nanoscale level.

X-ray Photoelectron Spectroscopy (XPS): XPS is used to analyze the surface chemistry of the corroded metal and the composition of any protective layers formed by corrosion inhibitors. It helps in understanding the nature of the inhibitor's interaction with the metal surface.

4. Gravimetric Analysis:

Similar to weight loss measurements, gravimetric analysis involves weighing the metal specimen before and after exposure to a corrosive environment. It provides a quantitative measure of the corrosion rate and is often used in conjunction with other methods to provide a more comprehensive analysis [48].

Gasometry and Thermometry: These methods involve measuring the volume of gas evolved (gasometry) and the change in temperature (thermometry) during the corrosion process. They are particularly useful for studying the kinetics of corrosion reactions and the influence of inhiitors.

4.1 Computational Modeling and Simulation: Theoretical approaches, including Density Functional Theory (DFT) and molecular dynamics simulations, are increasingly used to understand the behavior of corrosion inhibitors at the molecular level. These methods help in predicting the adsorption behavior, efficiency, and potential mechanism of action of inhibitors.

Each of these techniques offers unique insights into the corrosion process and the effectiveness of inhibitors. Often, a combination of methods is used to obtain a comprehensive understanding of corrosion behavior and to evaluate the performance of corrosion inhibitors under various conditions. The choice of technique depends on the specific requirements of the study, the type of metal, the corrosive environment, and the nature of the inhibitor being tested [49].

5. Corrosion control Methods

Corrosion control is essential for extending the life of materials and ensuring safety and reliability, especially in industries where metals are extensively used. The three articles reviewed provide insights into various corrosion control methods, with a focus on the use of natural products as corrosion inhibitors. Here's a synthesis of the types of corrosion control methods discussed in the context of these studies:

5.1 Use of Inhibitors: Natural Corrosion Inhibitors: Derived from plant extracts, these inhibitors offer an eco-friendly alternative to synthetic chemicals. They contain active organic compounds such as tannins, alkaloids, and flavonoids that form a protective layer on the metal surface, reducing the rate of corrosion. These inhibitors can be applied in various forms, such as coatings, solutions, or as part of smart release systems.

Synthetic Corrosion Inhibitors: Traditional inhibitors often contain inorganic compounds or organic compounds with specific functional groups that retard the corrosion process. While effective, their environmental and health impacts are a growing concern, leading to a shift towards greener alternatives.

Cathodic Protection: Sacrificial Anode Method: This involves attaching a more reactive metal (sacrificial anode) to the metal that needs protection. The sacrificial anode corrodes instead of the protected metal, thereby preventing corrosion.

Impressed Current Method: An external power source applies a current to counteract the corrosive electrochemical process. This method is often used for large structures like pipelines and ships.

Coatings and Linings: Protective Coatings: Applying paints, varnishes, or other coatings to metal surfaces can prevent exposure to corrosive environments. Advanced coatings may include corrosion inhibitors or be designed to heal themselves when damaged.

Linings: Metal surfaces can be lined with non-metallic materials like rubber, plastic, or ceramics to provide a barrier against corrosive substances.

Material Selection and Design:Corrosion-Resistant Materials: Using materials inherently resistant to corrosion, such as stainless steel, or materials with a protective oxide layer, like aluminum, can prevent or reduce corrosion.

Design Considerations: Designing structures to avoid crevices, ensuring proper drainage, and minimizing contact with corrosive environments can significantly reduce the risk of corrosion.

Environmental Control:Control of Exposure: Reducing the exposure of metals to corrosive environments, such as by controlling humidity, temperature, or chemical exposure, can significantly decrease corrosion rates.

pH Adjustment: Adjusting the pH of the environment can make it less corrosive. For example, neutralizing an acidic environment can reduce the corrosion rate of certain metals.

Maintenance and Monitoring: Regular Inspection: Routine inspection and maintenance can identify early signs of corrosion and allow for timely corrective measures.

Corrosion Monitoring Tools: Tools like corrosion coupons, probes, and electronic monitoring systems can provide ongoing assessment of corrosion rates and the effectiveness of control methods.

Advanced Techniques:

Nanotechnology: Incorporating nanoparticles in coatings or as part of inhibitors can enhance protection and provide new mechanisms for corrosion control [50-51.

Smart Release Systems: These systems can detect the onset of corrosion and release inhibitors precisely when and where they are needed.

6. Types of corrosion:

Here we have given the insights of different types of corrosion and its features

Uniform Corrosion: Description: This is the most common type of corrosion and occurs uniformly over the entire surface of a metal.

Characteristics: It results in a uniform loss of material, which can be predicted and measured easily. This type is often seen in acids and bases or under atmospheric conditions.

Pitting Corrosion: Description: Pitting corrosion causes small, localized areas of metal loss, typically in passive metals like stainless steel.

Characteristics: These pits can be hard to detect and can lead to failure with minimal overall material loss. It's often caused by localized chemical or mechanical damage to the protective oxide layer.

Galvanic Corrosion: Description: This occurs when two different metals are in electrical contact in a corrosive environment. The more active metal (the anode) corrodes faster while the more noble metal (the cathode) is protected.

Characteristics: Common in mixed-metal joints and structures, its rate can be predicted based on the galvanic series and the size of the anodic and cathodic areas.

Crevice Corrosion: Description: Similar to pitting, crevice corrosion occurs in confined spaces where the solution becomes stagnant and the metal ion concentration changes.

Characteristics: Common areas include under gaskets, washers, bolt heads, and lap joints. It can be prevented by design alterations to eliminate crevices.

Intergranular Corrosion: This type attacks the grain boundaries of metals, often leaving the grains themselves relatively untouched.

Characteristics: Commonly associated with sensitization in stainless steels and can be prevented by proper alloy selection and heat treatment.

Stress Corrosion Cracking (SCC): Stress corrosion cracking is the growth of crack formation in a corrosive environment. It can lead to unexpected sudden failure of normally ductile metals.

Characteristics: It's influenced by the tensile stress in the metal and the corrosive environment. Common in metals under tensile stress in the presence of certain corrosive media.

Erosion Corrosion: Caused by the rapid flow of any turbulent fluid on a metal surface, leading to increased corrosion due to mechanical wear and increased activity.

Characteristics: Common in pumps, pipes, and valves and can be minimized by reducing turbulence and using materials resistant to both corrosion and erosion.

Hydrogen Embrittlement: This occurs when hydrogen atoms diffuse into the metal and result in cracking and loss of ductility and toughness.

Characteristics: Common in high-strength steels and can be prevented by minimizing hydrogen ingress through proper material selection and surface treatments.

Microbiologically Influenced Corrosion (MIC): Caused by microorganisms in biofilms on the metal surface. These organisms can produce substances that induce or accelerate corrosion.

Characteristics: Common in environments where water is present, such as pipes and marine structures. Control strategies include biocides and material selection.

Fretting Corrosion: Occurs at the interface of two contacting surfaces under slight relative motion due to vibration or other forces.

Characteristics: The constant motion wears away the protective oxide layer, leading to increased corrosion. Common in machinery and moving parts.

7. Research Gap:

Consistency and Reproducibility: There is a need for more systematic studies that ensure the consistency and reproducibility of results when using plant-based inhibitors. Variations in plant species, extraction methods, and environmental conditions can lead to significant differences in inhibitor performance.

Mechanistic Understanding: While many studies demonstrate the effectiveness of natural inhibitors, the detailed mechanisms at the molecular level are often not fully understood. More research is needed to elucidate the exact pathways through which these inhibitors protect against corrosion.

Long-Term Stability and Performance: The long-term stability and performance of natural corrosion inhibitors under various environmental conditions are not well-documented. Understanding how these inhibitors behave over extended periods is crucial for their practical application.

Economic and Scalability Aspects: Few studies address the economic viability and scalability of extracting and applying natural corrosion inhibitors. Research is needed to evaluate the feasibility of large-scale production and application.

Comprehensive Comparative Studies: There is a lack of comprehensive studies comparing the performance, cost, and environmental impact of natural inhibitors with traditional synthetic inhibitors.

Future Prospective:

Advanced Isolation and Characterization Techniques: Utilizing advanced techniques for the isolation and characterization of active compounds in natural extracts can lead to the discovery of more effective and specific corrosion inhibitors.

Nano-technology Integration: Incorporating nanotechnology to enhance the delivery and effectiveness of natural corrosion inhibitors could provide new pathways for protection mechanisms.

Hybrid Inhibitors: Developing hybrid inhibitors that combine the best features of both synthetic and natural inhibitors could lead to more effective and environmentally friendly solutions.

Smart Coatings: Research into smart coatings that release inhibitors in response to environmental triggers could provide targeted corrosion protection and reduce the overall amount of inhibitor needed.

Environmental Impact Studies: Conducting detailed studies on the environmental impact and biodegradability of natural inhibitors will be crucial for their acceptance and widespread use.

8. Objectives of the Review Paper:

Consolidating Current Knowledge: To synthesize current knowledge on the use of natural products as corrosion inhibitors, highlighting their advantages, limitations, and the range of techniques used to evaluate their effectiveness.

Identifying Research Gaps: To clearly identify the existing research gaps and areas where further investigation is needed to advance the field of green corrosion inhibition.

Guiding Future Research: To provide a roadmap for future research by suggesting potential areas of study, such as mechanistic understanding, long-term performance, and economic feasibility.

Promoting Green Chemistry: To advocate for the continued exploration and adoption of environmentally friendly corrosion inhibitors as part of a broader move towards sustainable and green chemistry practices.

Bridging Interdisciplinary Gaps: To encourage collaboration between chemists, materials scientists, environmental scientists, and industry professionals to address the complex challenge of corrosion in a holistic and sustainable manner [52-53].

9. Conclusion:

The shift towards green chemistry and sustainable industrial practices has catalyzed the exploration of natural products as viable alternatives to traditional synthetic corrosion inhibitors. This review has synthesized findings from three recent studies, highlighting the potential of plant-based substances in mitigating corrosion effectively while minimizing environmental and health hazards. Natural inhibitors, derived from a variety of plants, oils, and extracts, have demonstrated considerable promise in various corrosive media, offering a range of organic compounds with inhibitory properties.

Despite the promising advancements, significant research gaps remain. The consistency and reproducibility of natural inhibitors, their long-term stability, and the detailed understanding of their inhibitory mechanisms require further exploration. Additionally, the economic viability and scalability of these inhibitors for industrial applications pose challenges that need to be addressed. Future research should focus on these areas to ensure the practical applicability and effectiveness of natural corrosion inhibitors.

The review also underscores the need for comprehensive comparative studies to evaluate the performance, cost, and environmental impact of natural inhibitors against their synthetic counterparts. Advanced isolation techniques, integration of nanotechnology, development of hybrid inhibitors, and the formulation of smart coatings are prospective areas that could revolutionize the field of corrosion inhibition.

Furthermore, it's imperative to conduct detailed environmental impact studies to understand the ecological implications of deploying these natural substances on a large scale. Bridging the gap between various disciplines, including chemistry, materials science, environmental science, and engineering, is crucial for developing innovative, effective, and eco-friendly corrosion mitigation strategies.

In conclusion, the exploration of natural products as corrosion inhibitors aligns with the global trajectory towards sustainability. While promising, the journey from laboratory research to industrial application is complex and requires concerted efforts from researchers, industry professionals, and policymakers. As we advance, it is hoped that this review will serve as a catalyst for further innovation, collaboration, and implementation of green corrosion inhibition strategies, paving the way for a more sustainable future.

References:

[1] A. Yurt, A. Balaban, S. U. Kandemir, G. Bereket & B. Erk,"Investigation on some Schiff base as HCl Corrosion inhibitors for carbon steel", Materials Chemistry and Physics, 85,420-426,2004.

[2] H.F. Finely & N. Hackerman, "Effect of adsorption of polar organic compounds on the reactivity of steel", Journal of Electrochemical Society, 107,259-263, 1960.

[3] A.S. Fouda, G.Y. Elewady, A. El-Askalani & K. Shalabi, "Inhibition of aluminum corrosion in hydrochloric acid media by three Schiff base compound", Zastita Materijala, 51,205-219,2009.

[4] R.W.Bosch, Hubrecht,W.F.Bogaerts & B.C.Syrett, "Electrochemical frequency modulation: A new electrochemical technique for online corrosion monitoring",Corrosion,57,60-70,2001.

[5] Nik, W. W., Hajar, H. M., Suriani, M. J., Sabri, M. G. M., & Ghazali, M. J. (2017). Development of anti-corrosive paint incorporated with henna extract as natural inhibitor. *Journal of Mechanical Engineering and Sciences*, *11*(4), 3179.

[6] Obot, I.B.; Macdonald, D.D.; Gasem, Z.M. Density functional theory (DFT) as a powerful tool for designing new organic corrosioninhibitors. Part 1: An overview. Corros. Sci. 2015, 99, 1–30.

[7] Nik, W. W., Sulaiman, O., Giap, S. E., & Rosliza, R. Evaluation of inhibitive action of sodium benzoate on corrosion behaviour of AA6063 in seawater. *International Journal of Technology*, *1*(1), 20-28. 2010.

[8] Verma C, Ebenso EE, Quraishi MA. Corrosion inhibitors for ferrous and non- ferrous metals and alloys in ionic sodium chloride solutions: A review, J Mol Liq., 2017, 248, 927-42.

[9] Kelly RG., Scully JR., Shoesmith D., Buchheit RG. Electrochemical Techniques in Corrosion Science and Engineering, Taylor and Francis eBook, 2002.

[10] Kamaruzzaman, W. M. I. W. M., Fekeri, M. F. M., Nasir, N. A. M., Hamidi, N. A. S. M., Baharom, M. Z., Adnan, A. & Ghazali, M. S. M. (2021). Anticorrosive and microbial inhibition performance of a coating loaded with Andrographis paniculata on stainless steel in seawater. *Molecules*, *26*(11), 3379.

[11] Bentiss F., Lagrenee M., Traisnel M., Hornez JC. The corrosion inhibition of mild steel in acidic media by a new triazole derivative, Corros Sci., 1999, 41(4), 789- 803.

[12] Sanyal B. Organic compounds as corrosion inhibitors in different environments - A review, Prog Org Coat., 1981, 9(2), 165-236.

[13] Goyal M., Kumar S., Bahadur I., Verma C., Ebenso EE. Organic corrosion inhibitors for industrial cleaning of ferrous and non-ferrous metals in acidic solutions: A review, J. Mol. Liq., 2018, 256, 565-73.

[14] Praveen BM. Venkatesha TV. Metol as corrosion inhibitor for steel, *Int. j. Elechem.* 4: (2013): 267-275.

[15] Raicheva SN, Aleksiev BV, Sokolova EI (1993) The effect of the chemical structure of some nitrogen- and sulfur-containing organic compounds on their corrosion inhibiting action. Corros Sci 34:343–350

[16] Haque, J., Zulkifli, M. F. R., Ismail, N., Quraishi, M. A., Mohd Ghazali, M. S., Berdimurodov, E., & Wan Nik, W. M. N. B. Environmentally benign water-soluble sodium L-2-(1-imidazolyl) alkanoic acids as new corrosion inhibitors for mild steel in artificial seawater. *ACS omega*, *8*(28), 24797-24812. 2023.

[17] Varadaraj, S., Pinto, T., Praveen, B. M., Devendra, B. K., Naveen Kumar, J. R., & Bin Wan Nik, W. M. N. Mechanical and corrosion properties of electrochemically deposited Ni-Nb_2O_5 composite coatings on mild steel for marine Applications. *Sensing Technology*, *1*(1), 2256215. 2023.

[18] Prasanna BM, Praveen BM, Hebbar Narayana, Venkatesha TV, Tandon HC (2014) Ketosulfone drug as a green corrosion inhibitor for mild steel in acidic medium. Ind Eng Chem Res 53:8436–8444

[19] Yaro AS., Khadom AA., Wael RK. Apricot juice as green corrosion inhibitor of mild steel in phosphoric acid, Alexandria Engineering Journal, 2013, 52(1), 129-35.

[20] Fontana M. Corrosion Engineering (Materials Science & Engineering), 3rd ed, McGraw-Hill, 1987.

[21] Gentil V. Corrosion. LTC. 2003. 18. Verma C., Olasunkanmi LO., Ebenso EE., Quraishi MA. Substituents effect on corrosion inhibition performance of organic compounds in aggressive ionic solutions: A review, J. Mol Liq., 2018, 251, 100- 18

[22] Hajar, H. M., Zulkifli, F., Suriani, M. J., Sabri, M. M., & Nik, W. W. (2016). Lawsonialnermis extract enhances performance of corrosion protection of coated mild steel in seawater. In *MATEC Web of Conferences* (Vol. 78, p. 01091). EDP Sciences.

[23] Stupnisek Lisac E, Podbrscek S, Soric T (1994) Non-toxic organiczinc corrosion inhibitors in hydrochloric acid. J Appl Electrochem 24:779–78

[24] Schmitt G, Bedbur K (1985) Investigations on structural and electronic effects of acid inhibitors by AC impedance. Werkst Korros36:273–280

[25] Shreevani, K., Narayana, B., Sarojini, B. K., Ganesha, A., Praveen, B. M., Devendra, B. K., & Sushmitha, C. H. Studies on characteristics and corrosion behaviour of chitosan/eudragit RS100 bilayer film coated Ti-6Al-4V. *Indian Journal of Chemical Technology (IJCT)*, *30*(4), 570-578. 2023

[26]Karthik, G., & Sundaravadivelu, M. (2016). Studies on the inhibition of mild steel corrosion in hydrochloric acid solution by atenolol drug. Egyptian J. Petrol. 25, 183 -191.

[27]Bull. Mater. Sci., Vol. 31, No. 1, February 2008, pp. 37–41. © Indian Academy of Sciences Chemical treatment of zinc surface and its corrosion inhibition studies S K RAJAPPA†, T V Venkatesha and B M Praveen. MS received 22 August 2007; revised 11 October 2007

[28]Devendra, B. K., Praveen, B. M., Tripathi, V. S., Nagaraju, D. H., Padaki, M., Nagaswarupa, H. P., & Krishna, R. H. Advanced strategies for hydrogen generation by Rhodium metal catalysts coated by the electrodeposition method. *Applied Surface Science Advances*, *12*, 100320. 2022.

[29]Bahaa Sami Mahdi Muna Khethier Abbass , Mustafa Khudhair Mohsin , Waleed Khalid Al-azzawi ,Mahdi M. Hanoon , Mohammed Hliyil Hafiz Al-kaabi Lina M. Shaker , Ahmed A. Al-amiery ,* ,Wan Nor Roslam Wan Isahak ,* , Abdul Amir H. Kadhum and Mohd S. Takriff

[30]Rosliza, R., Wan Nik, W. B., & Izman, S. Efficiency comparison of some natural products on corrosion inhibition of Al-Mg-Si Alloy. *Advanced Materials Research*, *328*, 1206-1209. 2011.

[31]International Scholarly Research Network ISRN Metallurgy Volume 2012, Article ID 940107, 7 pages doi:10.5402/2012/940107 Electrochemical Study of the Corrosion Behavior of Zinc Surface Treated with a New Organic Chelating Inhibitor R. A. Prabhu, T. V. Venkatesha, and B.M. Praveen

[32]Int J Ind Chem (2016) 7:9–19 DOI 10.1007/s40090-015-0064-6 Inhibition study of mild steel corrosion in 1 M hydrochloric acid solution by 2-chloro 3-formyl quinoline B. M. Prasanna B. M. Praveen Narayana Hebbar T. V. VenkateshaH. C. Tandon

[33]Chaouiki, A.; Chafiq, M.; Lgaz, H.; Al-Hadeethi, M.; Ali, I.; Masroor, S.; Chung, I. Green Corrosion Inhibition of Mild Steel by Hydrazone Derivatives in 1.0 M HCl. Coatings **2020**, 10, 640

[34]Anti-Corrosion Methods and Materials 63/1 (2016) 47–55 © Emerald Group Publishing Limited [ISSN 0003-5599] [DOI 10.1108/ACMM-05-2014-1388] *B.M. Prasanna, B.M. Praveen, Narayana Hebbar and T.V. Venkatesha Volume 63 · Number 1 · 2016 · 47–55*

[35]J Fail. Anal. and Preven. Anticorrosion Potential of Flectofenine on Mild Steelin Hydrochloric Acid Media: Experimental and Theoretical Study Narayana Hebbar . B. M. Praveen . B. M. Prasanna . H. P. Sachin

[36]Journal of Bio- and Tribo-Corrosion (2018) 4:21 Experimental and Theoretical Studies on Inhibition Effect of the *Praziquantel* on Mild Steel Corrosion in 1 M HCl B. M. Praveen· B. M. Prasanna· Narayana Hebbar· P. Shivakeshava Kumar M. R. Jagadeesh

[37]Journal of Bio- and Tribo-Corrosion (2020) 6:9 Synthesis, Characterization, and Anti-corrosion Behavior of Novel Mono Azo Dyes Derived from 4,5,6,7-Tetrahydro-1,3-benzothiazole for Mild Steel in Acid Solution N. M. Mallikarjuna 1· J. Keshavayya · B. M. Prasanna · B. M. Praveen · H. C. Tandon

[38]J Fail. Anal. and Preven. Electrochemical and Adsorption Studiesof 4-Chloro,8-(Trifluoromethyl)Quinoline (CTQ) for Mild Steel in Acidic Medium Narayana Hebbar . B. M. Praveen . B. M. Prasanna .P. Vishwanath

[39]Hajar, H. M., Zulkifli, F., Mohd Sabri, M. G., & Wan Nik, W. B. Protection against corrosion of aluminum alloy in marine environment by Lawsonia inermis. *International Journal of Corrosion*, *2016*. 2016.

[40]S.Aboul-Magd & M.Salah, "N.O. Eddy & S.A. Odoemelam," Inhibition of the corrosion of mild steel in acidic medium by Penicillin V Potassium". Advances in Natural and Applied Sciences, 2, 225-232, 2008.

[41]H.A. Abood, "The study of the inhibitory properties of Omeprazole on the corrosion of Aluminum 6063 in alkaline media", Basrah Journal of Scienec (C), 28, 74-93,2011.

[42]A.S. Fouda, A.M. El-Defrawy, & M.W. El-Sherbeni, "Lornoxicam & Tenoxicam drugs as green corrosion inhibitors for carbon steel in 1 M H_2SO_4 solution",Journal of Electrochemical Science and Technology 4, 47-56,2013.

[43]H. Adil, "Corrosion inhibition of zinc metal in 2M hydrochloric acid solution by using Guaifenesin drug as an inhibitor and theoretical calculations", Journal of Al- Nahrain University,18,60-65,2015.

[44]Praveen, B. M., Prasanna, B. M., Mallikarjuna, N. M., Jagadeesh, M. R., Hebbar, N., & Rashmi, D. Investigation of anticorrosive behaviour of novel tert-butyl 4-[(4-methyl phenyl) carbonyl] piperazine-1-carboxylate for carbon steel in 1M HCl. *Heliyon*, *7*(2). 2021.

[45]K.R. Ansari, M.A. Quraishi, Prashant & E.E. Ebenso, "Electrochemical and thermodynamic investigation of Diclofenac sodium drug as a potential corrosion inhibitor for mild steel in hydrochloric acid", International Journal of Electrochemical Science,8,12860-12873,2013.

[46]Devendra, B. K., Praveen, B. M., Tripathi, V. S., Nagaraju, G., Prasanna, B. M., & Shashank, M. Development of rhodium coatings by electrodeposition for photocatalytic dye degradation. *Vacuum*, *205*, 111460. 2022.

[47]I.A. Akpan & N.O. Offiong, "Electrochemical and gravimetric studies of the corrosion inhibition of mild steel in HCl medium by Cephalexin drug", American Journal of Chemistry and Materials Science, 1, 1-6, 2014.

[48]R. Kushwah & R.K. Pathak, "Inhibition of mild steel corrosion in 0.5 M sulphuric acid solution by Aspirin drug", International Journal of Emerging Technology and Advanced Engineering, 4,880-884, 2014.

[49]S.B. Ade, N.V. Shitole & S.M. Lonkar, "Antifungal drug‟s used as metal corrosion inhibitor in various acid medium", International Journal of ChemTech Research, 6, 3642-3650,2014.

[50]A.S.Fouda & H.E.Gadow, "Streptoquin and Septazole: Antibiotic drugs as corrosion inhibitors for copper in aqueous solutions", Global Journal of Researches inEngineering: C Chemical Engineering, 14,21-36,2014.

[51]R.S.A.Hameed, "Ranitidine drugs as non-toxic corrosion inhibitors for mild steel in hydrochloric acid medium", Portugaliae Electrochimica Acta, 29, 2011.

[52]N.Vaszilcsin, V.Ordadi & A.Borza, "Corrosion inhibitors from expired drugs", International Journal of Pharmaceutics, 15, 2012.

[53]Praveen, B. M., Alhadhrami, A., Prasanna, B. M., Hebbar, N., & Prabhu, R. Anti-corrosion behavior of olmesartan for soft-cast steel in 1 mol dm− 3 HCl. *Coatings*, *11*(8), 965. 2021.