Development of Sustainable Inhibitors for Corrosion Control

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Corrosion is a natural process which converts a refined metal into a more chemically stable oxide. It is the gradual deterioration of metals by chemical or electrochemical reaction with their environment[1, 2]. This reaction causes damage and disintegration of the metal starting from the portion of the metal exposed to the environment and spreading to the entire bulk of the metal. Corrosion is usually an undesirable phenomenon since it negatively affects the desirable properties of the metal[3, 4]

Corrosion is a spontaneous process playing a vital role in the economics and safety of alloys and metals. Changing the environment by adding corrosion inhibitors is considered as an efficient corrosion management method [5-8]. A corrosion inhibitor is a chemical substance which when added in a small concentration to the corrosive environment results in a significant reduction in the corrosion rate either by reducing the rate of attack or by reducing the probability of its occurrence or by both[9]. An efficient inhibitor should be economical, environment friendly, and inhibit the corrosion process when present in a small concentration. Corrosion prevention using inhibitors has some noticeable advantages such as low cost, simple control and operation, and non-requirement of special instruments[10]. Corrosion inhibition is achieved in two ways. In some cases, the inhibitor interacts with the metal surface and forms an inhibitive surface film at the metal/electrolyte interface. In other cases, the inhibitor can alter the corrosive environment into a less corrosive or noncorrosive environment, e.g. by chemically neutralizing dissolved acidic gases, chemically scavenging dissolved oxygen, etc

The addition of inhibitors containing lone pair and bond pair of electrons prevents the corrosion process by the synergistic interaction between the metal atom and the inhibitor molecule[11, 12]. Many organic and inorganic inhibitors are environmentally harmful and toxic. So, in the context of environmental pollution, the inhibitor should be environment friendly rather than application efficiency.

Green inhibitors for corrosion prevention

The search for green corrosion inhibitors was triggered by the environmental toxicity of organic corrosion inhibitors; these inhibitors are biodegradable and do not include heavy metals or other harmful substances[13]. Green inhibitors refer to the use of eco-friendly or sustainable corrosion inhibitors. These inhibitors are derived from natural sources or are biodegradable and are less toxic to the environment and human health compared to traditional inhibitors [34]. Green inhibitors have gained attention in recent years as there is a growing concern about the environmental impact of chemical inhibitors.

Examples of green inhibitors include plant extracts, Ionic liquids, surfactants, essential oils, chitosan, starch, cellulose, and other biopolymers. These inhibitors have been found to have good inhibitive properties and can be used as an alternative to traditional inhibitors. However, their effectiveness can be affected by factors such as the type of metal, environmental conditions, and inhibitor concentration.

Most of the green inhibitors adsorb on the metal surface by means of physical as well as chemical interactions. They contain heteroatom in their molecules. The free electrons on the heteroatom bond with the metal surface[14]. Some atoms in water ionize to release a proton; thus, the now negatively charged heteroatom helps to free an electron on the heteroatom and forms a stronger bond with the metallic electrons. These properties confer them good inhibition properties.

Research is ongoing to develop and optimize the use of green inhibitors as corrosion inhibitors in various applications, including in the oil and gas industry, marine industry, and construction industry.

It is abundantly clear from various methods like weight loss, electrochemical impedance, and potentio dynamic polarisation approaches that green inhibitors are highly effective at inhibiting steel corrosion.[15]

Plant extracts as green inhibitor

An extract is a solution composed by the active principles of a plant or its parts and a certain medium acting as solvent. The extraction yields depend on the polarity of the solvent used, in the techniques or methods (Soxhlet and maceration), among others. Most commonly, these extracts are recognised for their anti-inflammatory, antiviral, antioxidant, or antibacterial properties. Their corrosion inhibitory qualities can also be thought of as having synergic effects. Most often, extracts are made from the entire plant or the sections with the highest concentrations of active ingredients, or phytochemicals[16]. Plant products are cheap, accessible, and renewable in addition to being environmentally friendly and ecologically acceptable. Studies into the anti-corrosion properties of tannins, alkaloids, organic amino acids, and organic dyes derived from plants are interesting[17-19].

Many plant extracts could prevent the corrosion process as it contains complex mixtures of phytochemicals in their composition[20, 21]. However, researchers working in the corrosion area are dedicated to recognizing the active inhibitors in the plant extract by extraction and isolation of active inhibitors[22]. The current corrosion inhibition study of plant extracts is therefore focused on the isolation of the active compounds accountable for the corrosion inhibition performance of plant extracts.

Ionic liquids as corrosion inhibitors

Ionic liquids possess several captivating characteristics that render them excellent candidates for replacing traditional corrosion inhibitors, which often pose adverse effects on the environment and living organisms[23]. They stand out as the most promising and favorable category of environmentally friendly steel corrosion inhibitors when compared to alternatives. This is attributed to their numerous advantages, including a straightforward and cost-effective preparation process, an appealing array of physical-chemical properties, and their high thermal, chemical, and electrochemical stability. Furthermore, their green and sustainable nature adds to their appeal. Additionally, the tunable properties of ionic liquids contribute to the development of tailored solutions for specific tasks and materials. For instance, the anti-corrosion properties of ionic liquids can be designed at the molecular level to safeguard materials with specific compositions, thereby enhancing inhibition efficiency [24]].

Surfactants as corrosion inhibitors

The potential application of surfactants as corrosion inhibitors has garnered extensive attention in recent years. It is widely acknowledged that surfactants exhibit a propensity to associate with each other at interfaces and in solutions, forming aggregates [25]. The process of adsorption plays a crucial role in corrosion inhibition, with the primary function of the surfactant functional group being to adsorb onto the metal surface. The observed adsorption of surfactant molecules onto the metal surface has been identified as the key factor responsible for the corrosion inhibition of the metal[26]. This phenomenon is generally directly linked to the surfactant's ability to aggregate and form micelles. Consequently, gaining a deeper understanding of the relationship between the adsorption of surfactant molecules onto the metal surface and corrosion inhibition holds great significance for both theoretical and experimental purposes.

Addition of surfactants to acidic media is an efficient and quite cheap method for rust protection of metal surfaces. In past 20 years, research has focused on the scheming electrochemical reactions with surfactants as well as aggregate description through electrochemical methods. Surfactants were introducing in this research field to give a novel and useful dimension to these investigations. Very few investigations were found on the role of surfactants in surface modification of electrodes. Very recently, researchers were engaged in field of surfactants adsorbed from micellar solutions have paid attention on elucidating or utilizing, aggregate structures formed on the electrode. Surfactant molecules usually adsorb at the interface between two bulk phases such as air and water, oil and water or electrode and solution [27].

Amino acids as corrosion inhibitors

Amino acids offer a cost-effective and readily available alternative to conventionally used organic corrosion inhibitors. Their direct application as inhibitors streamlines the process, reducing the time and labor typically associated with preparing organic compound-based corrosion inhibitors[28]. Despite their abundance and biodegradability, the straightforward chemical structures of amino acids may limit their effectiveness as corrosion inhibitors for industrial purposes. To enhance inhibition efficiencies, a viable approach involves utilizing amino acid derivatives. These derivatives can feature varying carbon chain lengths, attached heteroatoms, heterocycles, phenyl rings, polar functional groups, and more, providing a method to optimize their potency for effective corrosion inhibition[29, 30].

References

[1] E. Bardal,(**2007**) Corrosion and protection, Springer Science & Business Media,

[2] J.R. Davis, (**2000**)Corrosion: Understanding the basics, Asm International.

[3] K.K. Alaneme, S.J. Olusegun, (**2012**)Corrosion inhibition performance of lignin extract of sun flower (Tithonia diversifolia) on medium carbon low alloy steel immersed in H_2SO_4 solution, Leonardo Journal of Sciences, 20, 59-70.

[4] P.R. Ammal, M. Prajila, A. Joseph, (**2018**) Effect of substitution and temperature on the corrosion inhibition properties of benzimidazole bearing 1, 3, 4-oxadiazoles for mild steel in sulphuric acid: physicochemical and theoretical studies, Journal of environmental chemical engineering, 6, 1072-1085.

[5] S.A. Umoren, M.M. Solomon, I.B. Obot, R.K. Suleiman, (**2019**)A critical review on the recent studies on plant biomaterials as corrosion inhibitors for industrial metals, Journal of Industrial and Engineering Chemistry, 76, 91-115.

[6] M. Al-Otaibi, A. Al-Mayouf, M. Khan, A. Mousa, S. Al-Mazroa, H. Alkhathlan, (**2014**) Corrosion inhibitory action of some plant extracts on the corrosion of mild steel in acidic media, Arabian Journal of Chemistry, 7, 340-346.

[7] R.Y. Khaled, A. Abdel-Gaber, H. Holail, (**2016**)Electrochemical studies of the inhibition effect of 4, 6-dichloro-2-(methylthio) pyrimidine on the corrosion of AISI type 321 stainless steel in 1.0 M hydrochloric acid, Int. J. Electrochem. Sci, 11, 2790-2798.

[8] P.K. Bhowmik, M. Hossain, J.A. Shamim, (**2012**)Corrosion and its control in crude oil refining process, in: 6th International Mechanical Engineering & 14th Conference Annual Paper Meet (6IMEC&14APM), Dhaka, Bangladesh.

[9] P.B. Raja, M.G. Sethuraman, (**2008**)Natural products as corrosion inhibitor for metals in corrosive media—a review, Materials letters, 62, 113-116.

[10] J.M. Gaidis, (**2004**) Chemistry of corrosion inhibitors, Cement and Concrete Composites, 26 , 181-189.

[11] M. ElBelghiti, Y. Karzazi, A. Dafali, B. Hammouti, F. Bentiss, I. Obot, I. Bahadur, E.-E. Ebenso, (**2016**)Experimental, quantum chemical and Monte Carlo simulation studies of 3, 5-disubstituted-4-amino-1, 2, 4-triazoles as corrosion inhibitors on mild steel in acidic medium, Journal of Molecular Liquids, 218, 281-293.

[12] L.C. Murulana, M.M. Kabanda, E.E. Ebenso, (**2016**) Investigation of the adsorption characteristics of some selected sulphonamide derivatives as corrosion inhibitors at mild steel/hydrochloric acid interface: Experimental, quantum chemical and QSAR studies, Journal of Molecular Liquids, 215, 763-779.

[13] K. Azzaoui, E. Mejdoubi, S. Jodeh, A. Lamhamdi, E. Rodriguez-Castellón, M. Algarra, A. Zarrouk, A. Errich, R. Salghi, H. Lgaz, (**2017**) Eco friendly green inhibitor Gum Arabic (GA) for the corrosion control of mild steel in hydrochloric acid medium, Corrosion Science, 129, 70-81.

[14] M. Chevalier, F. Robert, N. Amusant, M. Traisnel, C. Roos, M. Lebrini, (**2014**)Enhanced corrosion resistance of mild steel in 1 M hydrochloric acid solution by alkaloids extract from Aniba rosaeodora plant: Electrochemical, phytochemical and XPS studies, Electrochimica Acta, 131, 96-105.

[15] H. Wei, B. Heidarshenas, L. Zhou, G. Hussain, Q. Li, K.K. Ostrikov, (**2020**) Green inhibitors for steel corrosion in acidic environment: state of art, Materials Today Sustainability, 10, 100044.

[16] A. Miralrio, A. Espinoza Vázquez, (**2020**) Plant extracts as green corrosion inhibitors for different metal surfaces and corrosive media: a review, Processes, 8, 942.

[17] B. Rani, B.B.J. Basu, (**2012**)Green inhibitors for corrosion protection of metals and alloys: an overview, International Journal of corrosion, 2012.

[18] N. Bhardwaj, P. Sharma, V. Kumar, (**2021**)Phytochemicals as steel corrosion inhibitor: an insight into mechanism, Corrosion Reviews, 39, 27-41.

[19] M. Dahmani, A. Et-Touhami, S. Al-Deyab, B. Hammouti, A. Bouyanzer, (**2010**) Corrosion inhibition of C38 steel in 1 M HCl: A comparative study of black pepper extract and its isolated piperine, Int. J. Electrochem. Sci, 5, 1060-1069.

[20] K. Anupama, K. Ramya, K. Shainy, A. Joseph, (**2015**) Adsorption and electrochemical studies of Pimenta dioica leaf extracts as corrosion inhibitor for mild steel in hydrochloric acid, Materials Chemistry and Physics, 167, 28-41.

[21] A. Thomas, M. Prajila, K. Shainy, A. Joseph, (**2020**) A green approach to corrosion inhibition of mild steel in hydrochloric acid using fruit rind extract of Garcinia indica (Binda), Journal of Molecular Liquids, 113369.

[22] K. Anupama, A. Joseph, (**2018**) Experimental and theoretical studies on Cinnamomum verum leaf extract and one of its major components, eugenol as environmentally benign corrosion inhibitors for mild steel in acid media, Journal of Bio-and Tribo-Corrosion, 4, 30.

[23] C. Verma, S.H. Alrefaee, M. Quraishi, E.E. Ebenso, C.M. Hussain, (**2021**) Recent developments in sustainable corrosion inhibition using ionic liquids: A review, Journal of Molecular Liquids, 321, 114484.

[24] B. Dilasari, Y. Jung, J. Sohn, S. Kim, K. Kwon, (**2016**) Review on corrosion behavior of metallic materials in room temperature ionic liquids, International Journal of Electrochemical Science, 11, 1482-1495.

[25] C. Verma, C.M. Hussain, M. Quraishi, A. Alfantazi, (**2022**)Green surfactants for corrosion control: Design, performance and applications, Advances in Colloid and Interface Science, 102822.

[26] M.A. Malik, M.A. Hashim, F. Nabi, S.A. Al-Thabaiti, Z. Khan, (**2011**) Anti-corrosion ability of surfactants: a review, Int. J. Electrochem. Sci, 6, 1927-1948.

[27] R. Aslam, M. Mobin, J. Aslam, A. Aslam, S. Zehra, S. Masroor, (**2021**)Application of surfactants as anticorrosive materials: A comprehensive review, Advances in Colloid and Interface Science, 295, 102481.

[28] A.P. Singh Raman, A.A. Muhammad, H. Singh, T. Singh, Z. Mkhize, P. Jain, S.K. Singh, I. Bahadur, P. Singh, (**2022**) A review on interactions between amino acids and surfactants as well as their impact on corrosion inhibition, ACS omega, 7, 47471-47489.

[29] K.C.d.S. de Lima, V.M. Paiva, D. Perrone, B. Ripper, G. Simoes, M.L.M. Rocco, A.G. da Veiga, E. D'Elia, (**2020**) Glycine max meal extracts as corrosion inhibitor for mild steel in sulphuric acid solution, Journal of Materials Research and Technology, 9, 12756-12772.

[30] L. Hamadi, S. Mansouri, K. Oulmi, A. Kareche, (**2018**) The use of amino acids as corrosion inhibitors for metals: A review, Egyptian Journal of Petroleum, 27, 1157-1165.