

Research Article

Synthesis of Disodium Salt of Sulfosuccinate Monoester from the Seed Oil of *Terminalia catappa* and Its Inhibitive Effect on the Corrosion of Aluminum Sheet in 1 M HCl

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Oil was extracted from the seed of *Terminalia catappa* and used to synthesize disodium salt of sulfosuccinate monoester using simple reaction mechanism. The disodium salt of sulfosuccinate monoester was applied as corrosion inhibitor of aluminum sheet in 1 M HCl via weight loss method. The adsorption was found to obey Langmuir isotherm. The results presented disodium salt of sulfosuccinate monoester as an efficient inhibitor of aluminum sheet corrosion in 1 M HCl.

1. Introduction

Corrosion is most commonly referred to as the degradation of a material due to its reaction with its environment. Such degradation may mean deterioration of the physical properties of the material which may be in form of weakening of the material due to loss of cross-sectional area, shattering due to hydrogen embrittlement, or cracking due to sunlight exposure. Corrosion is usually found in several materials but most especially in metals; these materials have both domestic and industrial uses but the existence of corrosion which can take place under acidic or alkaline medium has resulted in limitation to their use. Importance of protection against corrosion in acidic or alkaline solutions is known to be increased by the fact that metals are more susceptible to be attacked in aggressive media, most of which are the commonly exposed metals (such as mild steel) in industrial environments [1]. The corrosion process is usually slowed down in various ways one of which is the use of corrosion inhibitors which when added in small amounts to a corroding environment decreases the rate of attack by such environment on material [2–4].

Being the third most abundant element and the most abundant metal, aluminum has found several industrial

applications which may be due to its economical considerations and the fact that its corrosion falls into general attack [5]. Thermodynamically, aluminum is expected to have a low corrosion resistance. The high corrosion resistance is due to the presence of a thin, compact film of adherent aluminum oxide on the surface which is formed on exposure to either air or water. This aluminum oxide dissolves in some chemicals, notably strong acids and alkaline solutions. When the oxide film is removed, the metal corrodes rapidly by uniform dissolution. So study of aluminum sheet corrosion phenomena has become important particularly in acidic media because of the increased industrial applications of acid solutions [6–9].

In the past time, use of inhibitors has been one of the most common different protective means used to control corrosion. Most inhibitors reported are synthetic organic compounds containing heteroatoms, such as O, N, and S, and multiple bonds [10, 11]; these heteroatoms have been established to have high electron density that contributes to the inhibitory capacity of such organic compounds. Although these synthetic organic compounds are widely used, their use as corrosion inhibitor has limitations such as being expensive, being nonrenewable, and being toxic to both plant and animal in the environment [12, 13]. Some efforts have been made to

develop cheap and nontoxic corrosion inhibitors but quite a number of them have reduced inhibitory activity at low concentration or are toxic at high concentration when they get into the environment. Due to superb environmental stability, ease of sustainability, and low level of toxicity, several plant extracts have been considered and reported as corrosion inhibitors [14–16] but it has been established that their efficiency may be improved upon by simple modification in terms of chemical functionality. This has also shown the need for green corrosion inhibitors and their importance over synthetic chemical products. The use of plant extract with little modification is of much importance and economically viable because, aside from being ecofriendly, they are renewable, easy to modify, and inexpensive [17–20]. Thus, they can be used as feed stock for oleochemicals which can serve as green corrosion inhibitors. *Terminalia catappa* seed oil is an example of plant extract that can be utilized to achieve such purpose.

Terminalia catappa is a large tropical tree in the leadwood family, Combretaceae. It is commonly called almond, a small deciduous tree, growing 4–10 m (13–33 feet) in height, with trunk of up to 30 cm (12 inches) in diameter. The leaves are 3–5 inches long with a serrated margin and a 2.5 cm (1 inch) petiole. The flowers are white or pale pink, 3–5 cm (1–2 inches) diameter with five petals, produced singly or in pairs before the leaves in early spring [21]. The antioxidant property of the solvent extract of the leaves has been reported [22]. The almond fruit is about 3.5–6 cm long. The seed has been reported to contain 6% water, 31% lipid, 29% protein, 25% carbohydrate, 3% mineral, 2% vitamins, and 4% sugars; saturated fat (palmitic acid) was 6%, monosaturated fat (oleic acid) was 64%, and polyunsaturated fat (linoleic acid) was 26% while major minerals were Ca-14%, Mg-16%, P-27%, and K-42% [23]. The oil has been reported to contain high levels of unsaturated fatty acids, especially oleic and linoleic; thus *Terminalia catappa* oil can be classified in the oleic-linoleic acid group [24].

Apart from the domestic use of plant products, they have also found wide application as sources of oleochemicals [25]. Oleochemicals are completely biodegradable and so could replace a number of petrochemicals. Sulfosuccinate is an example of an oleochemical that is produced from a renewable source, biodegradable and environmentally friendly. Sulfosuccinates have been reported to exhibit compatibility with chromium and have no adverse effect on the textile strength of processed fibre with wide range of applications which includes household formulations, textiles, polymers, paints and coating, agriculture, and production of shampoos [26]. Sulfosuccinates are known with excellent wetting properties which suggest them as possible corrosion inhibitors. At present, there is no report on their use as corrosion inhibitors. Since they are biodegradable, ecofriendly, and relatively cheap with the presence of heteroatoms in their structure, it will be important to determine their anticorrosion capacity.

In continuation of our search for cheap oleochemicals that can be used as corrosion inhibitors, the present study synthesized disodium salt of sulfosuccinate monoester from *Terminalia catappa* seed oil and investigated its inhibiting

effect on aluminum sheet corrosion in strong acidic solution using weight loss method.

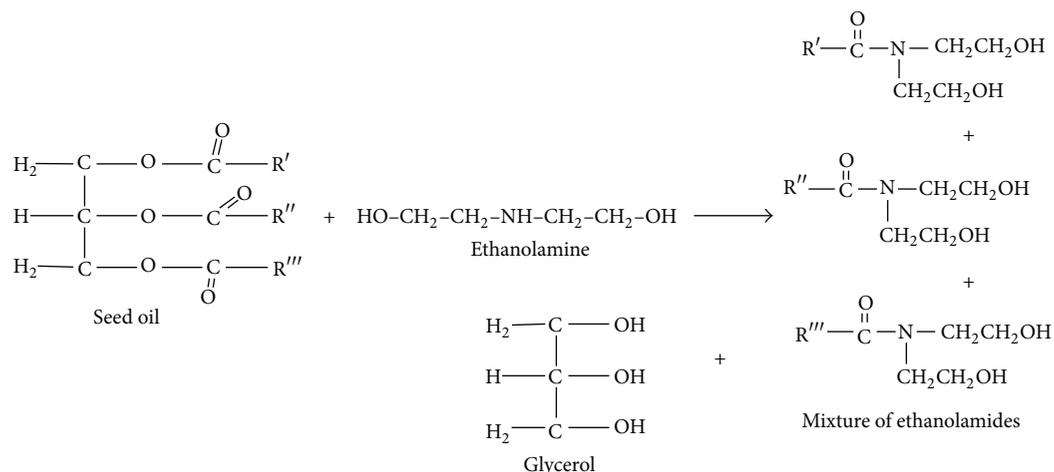
2. Materials and Methods

2.1. Materials. Seeds of *Terminalia catappa* were collected from the Botanical Garden, University of Ibadan. They were manually cracked, air-dried, and milled in a blender. The powdered seeds were finally extracted with hexane in a soxhlet extractor as described by Adewuyi and Oderinde [27].

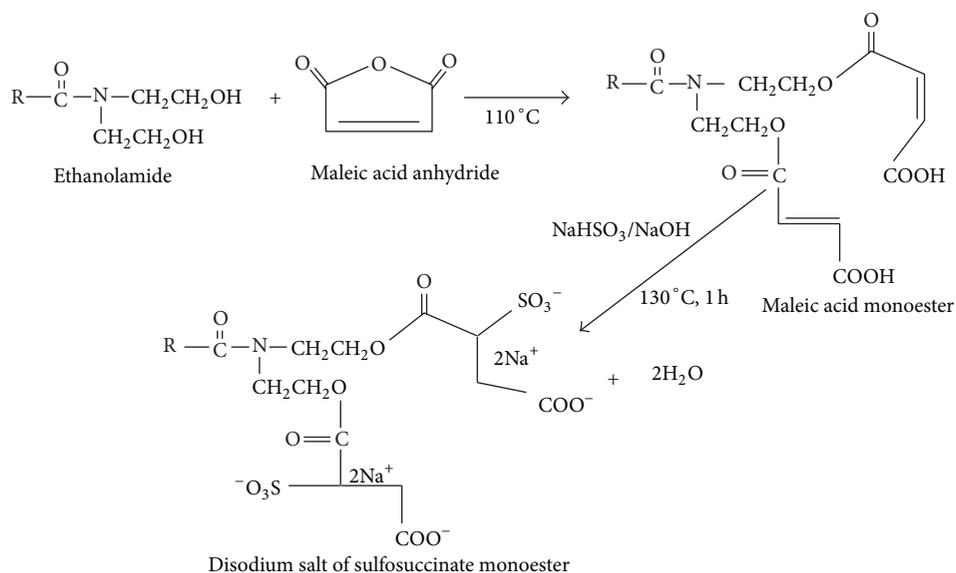
2.2. Synthesis of Fatty Ethanolamide from the Seed Oil of *Terminalia catappa*. This was achieved as previously described by Adewuyi et al. [28] with little modification. Briefly, the oil of *Terminalia catappa* was reacted with diethanolamine in ratio 1 (oil) : 3 (diethanolamine) in a 250 mL round bottom flask equipped with a magnetic stirrer, a thermometer, and a condenser. The flask was placed in an oil bath while the reaction temperature was gradually increased and maintained at 140°C. The reaction mixture was continuously stirred for 10 h to form fatty ethanolamide. At the end of the reaction, the mixture was concentrated on a rotary evaporator after which the product formed was dissolved in a mixture of methanol and chloroform [50/50 (v/v)]. The solvent was later removed in a rotary evaporator. Then, acetonitrile was added to the resultant solid and the solution was cooled in an ice bath. The amide precipitated out and was subsequently recovered by filtration using Whatman filter paper [29]. This is shown in Scheme 1.

2.3. Synthesis of Disodium Salt of Sulfosuccinate Monoester. The fatty ethanolamide synthesized was transferred into a round bottom flask and heated to 110°C while maleic acid anhydride (10 g, 0.1 mole) was gently added and stirred and the temperature was kept constant at 110°C. The reaction mixture was continuously stirred for 3 h while an aqueous solution of 30% sodium bisulphite (15.71 g, 0.1 mol) was added to the reaction mixture. The reaction temperature was gradually raised to 130°C with continuous stirring at this temperature for 1 h while the pH of the reaction mixture was adjusted using aq. NaOH. The product obtained was disodium salt of sulfosuccinate monoester as illustrated in Scheme 2. The synthesized disodium salt of sulfosuccinate monoester was purified by washing with petroleum ether for about 2 to 3 times. This removes any unwanted impurities and unreacted materials. The obtained product was filtered, dried, and analyzed using FTIR.

2.4. Corrosion Study. The corrosion inhibition study of disodium salt of sulfosuccinate monoester on aluminum sheet was carried out in 1 M HCl solution using weight loss measurement method. In this case, HCl was prepared to initiate the corrosion while disodium salt of sulfosuccinate monoester was used as the corrosion inhibitor. A cold rolled aluminum sheet of dimensions 5.0 cm by 5.0 cm with an area of 25.0 cm² was washed, dried, and accurately weighed. After weighing accurately, the aluminum sheets were immersed in a beaker which contained 1 M HCl with and without addition of



SCHEME 1: Synthesis of ethanolamide.



SCHEME 2: Synthesis of disodium salt of sulfosuccinate monoester.

disodium salt of sulfosuccinate monoester. The solution of acid without the disodium salt of sulfosuccinate monoester was used as the control in this study while the concentration of disodium salt of sulfosuccinate monoester in the other solution varied from 0.50 g/L to 3.00 g/L. All the aggressive acid solutions were opened to air for a period of 6 h and at an interval of 1 h; the aluminum sheets were taken out of solution, washed, dried, and reweighed accurately. The experiments were carried out in duplicate, and the average weight loss of the cold rolled aluminum sheets was obtained and recorded.

3. Results and Discussion

3.1. Synthesis of Disodium Salt of Sulfosuccinate Monoester. Figure 1 shows the peaks for the FTIR analysis carried out on the oil of *Terminalia catappa* (a), fatty ethanolamide

(b), and disodium salt of sulfosuccinate monoester (c) using Shimadzu FTIR-400S. It was observed that the *Terminalia catappa* oil, ethanolamide, and disodium salt of sulfosuccinate monoester showed characteristic absorption bands at 2924 cm⁻¹ and 2852 cm⁻¹ corresponding to the C-H stretching of methyl (-CH₃) and methylene (-CH₂) functional groups, respectively. The absorption band present at 721 cm⁻¹ in the oil, ethanolamide, and disodium salt of sulfosuccinate monoester spectra can be attributed to the rocking motion associated with -CH₂ groups in an open chain while 1465 cm⁻¹ suggests -CH₂ of bending vibrations of alkanes. The absorption bands representing the C=O stretching of ester occurred at 1745 cm⁻¹ in *Terminalia catappa* oil. This C=O stretching band of ester disappeared in the ethanolamide and disodium salt of sulfosuccinate monoester with the appearance of a new peak at 1634 cm⁻¹ corresponding to the C=O stretching of amide functional group. The -OH

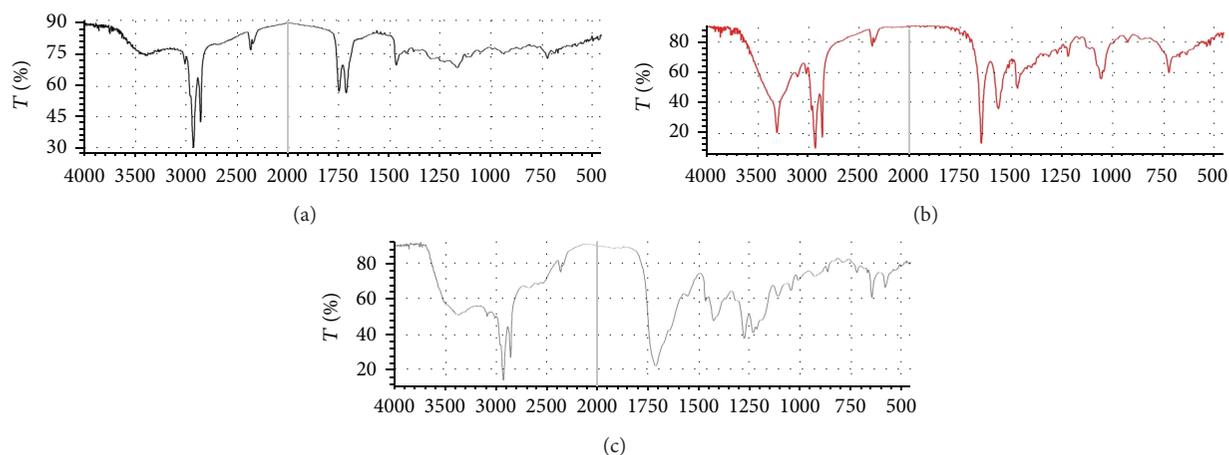


FIGURE 1: FTIR result of the oil (a), fatty ethanolamide (b), and disodium salt of sulfosuccinate monoester (c).

functional group vibrational frequency in the ethanolamide was found at 3296 cm^{-1} . The N-H stretching vibration was also observed at 3371 cm^{-1} . The C-H bending vibration of alkane was observed at 1454 cm^{-1} while the O-H stretching vibration was absent in the sulfosuccinate monoester indicating the formation of the product.

3.2. *Corrosion Study.* The corrosion rate was determined using the following expression [30]:

$$R = \frac{\Delta W}{At}, \quad (1)$$

where R ($\text{g cm}^{-2}\text{ h}^{-1}$) is the corrosion rate, ΔW is the average weight loss after immersion, A is the surface area of the aluminum sheet, and t is the total time (6 h) of immersion. The inhibition efficiency ($\%E_w$) was also calculated using the following equation [31]:

$$\%E_w = \left(R_o - \frac{R_t}{R_o} \right) \times 100, \quad (2)$$

where R_t and R_o are corrosion rates of aluminum sheet with and without inhibitor, respectively.

The corrosion rate of the aluminum sheet immersed into the blank (solution without the inhibitor) was faster than that of the solution with the inhibitor; this is shown in Figure 2.

At the initial stage, the weight loss of aluminum sheet in the blank was almost double that of the solution with the inhibitor but as time went on the weight loss of aluminum reduced in the blank but was still higher than what was observed in the case of the inhibitor. This observation may be due to the fact that corrosion started immediately on exposure of the aluminum sheet to the aggressive HCl solution but with time there may have been the formation of a protective covering on the surface of the aluminum sheet which reduced the rate but later lost its protective capacity

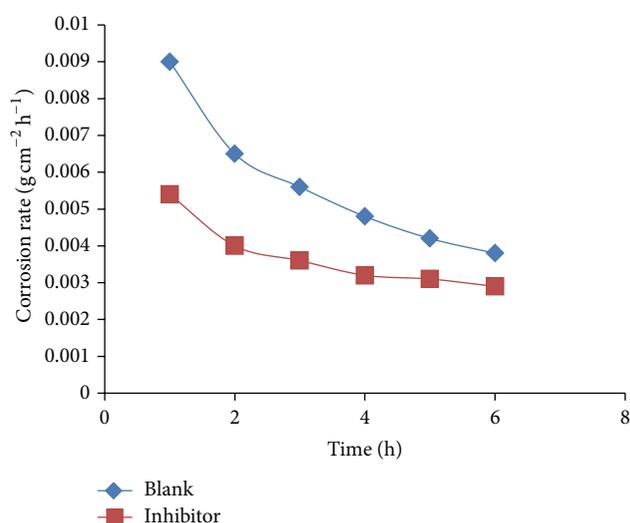
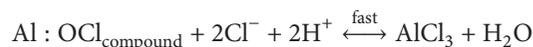
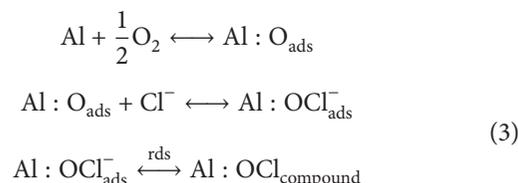


FIGURE 2: Corrosion rate versus time for both blank and inhibitor.

with time as shown in equation below with the formation of AlCl_3 [32]:



Corrosion inhibitors or a mixture of corrosion inhibitors have been reported to form a protective film as a result of the reaction of the aggressive solution with the corroding surface of which inhibitors may impede the anodic, the cathodic, or both electrochemical reactions [4]. Disodium salt of sulfosuccinate monoester used as inhibitor may have formed a protective covering on the surface of the aluminum sheet. As shown in Scheme 2, disodium salt of sulfosuccinate

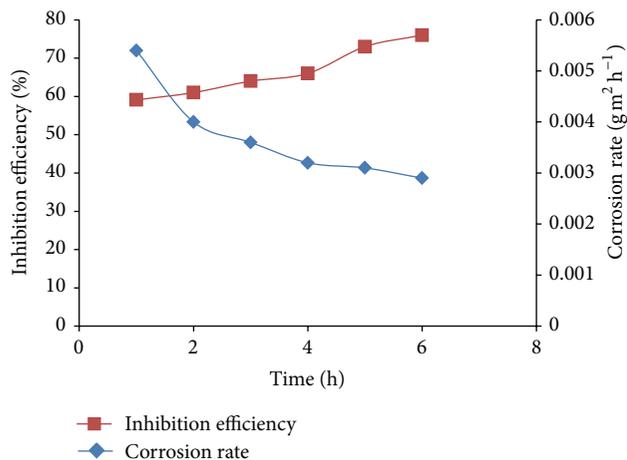


FIGURE 3: Comparison of the inhibition efficiency with corrosion rate over a period of time.

TABLE 1: Values of corrosion rate, inhibition efficiency, and surface covering.

Inhibitor (g/dm ³)	Surface coverage (θ)	IE (%)	Corrosion rate (gm ² h ⁻¹)
0.5	0.400	40.0	0.0054
1.0	0.588	58.8	0.0037
1.5	0.714	71.4	0.0026
2.0	0.794	79.4	0.0019
2.5	0.862	86.2	0.0012
3.0	0.909	90.9	0.0008

monoester has heteroatoms such as oxygen and nitrogen and also the presence of π (pie) electron systems which have been reported in the past to play active role in adsorption [33]. These heteroatoms and the π electron systems are rich in electrons and may have interacted with the surface of the aluminum via this electron density to form the protective covering at the surface of the aluminum sheet.

Figure 3 presents the correlations between the inhibition efficiencies and the corrosion inhibition rates over a period of 6 h for the inhibitor. The inhibition efficiency of disodium salt of sulfosuccinate monoester was found to increase with time while the corrosion rate reduced with time in the presence of disodium salt of sulfosuccinate monoester. This observation must have been due to the fact that the inhibitor adsorbed on the surface of aluminum and was able to reduce the interaction between the aluminum surface and the aggressive acid solution [34].

The different values of corrosion rate, inhibition efficiency, and surface covering at various concentrations of disodium salt of sulfosuccinate monoester are presented in Table 1.

It was observed that the inhibition efficiency increased just as the concentration of disodium salt of sulfosuccinate monoester increased. This was also noticed in the surface covering of the aluminum sheet which increased as the concentration of disodium salt of sulfosuccinate monoester

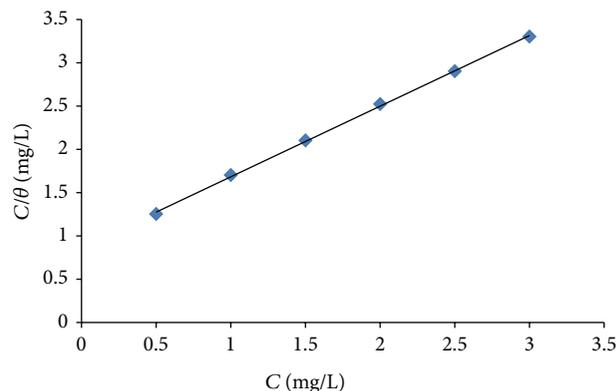


FIGURE 4: Langmuir adsorption plot for aluminum sheet in 1M HCl containing disodium salt of sulfosuccinate monoester.

in solution increased; this trend has also been reported by Wang et al. [35]. This may, apparently, be accounted for as the inhibitor interacting with the surface of the metal, thus blocking the active sites to form a barrier against infiltration of the aggressive electrolyte solution since the process of corrosion is considered to be electrolytic in nature [36, 37].

Attempt was made to fit the values of the surface coverage (θ) into different adsorption isotherms but the best fit was obtained with Langmuir adsorption isotherm using the following equation as proposed by Langmuir [38]:

$$\frac{C}{\theta} = \frac{1}{K_{\text{ads}}} + C, \quad (4)$$

where C is the concentration of the inhibitor and K_{ads} is the adsorptive equilibrium constant.

As shown in Figure 4, a plot of C/θ versus C gave straight lines with R^2 value of 0.999 which suggested a monolayer adsorption of the inhibitor at the surface of aluminum [34].

The essential characteristic of this isotherm can be expressed with the following equation:

$$K_R = \frac{1}{1 + K_{\text{ads}}C}, \quad (5)$$

where K_R is the equilibrium parameter, K_{ads} is the Langmuir constant, and C is the inhibitor concentration. K_R describes the type of the isotherm accordingly. If $K_R > 1$ the process is unfavourable, if $K_R = 1$, the process is linear, if $0 < K_R < 1$, the process is favourable, and when $K_R = 0$ the process is irreversible [39, 40]. In the present study, K_R value was found to be less than 1 and greater than 0 indicating that the adsorption process was favourable and reversible.

4. Conclusion

Disodium salt of sulfosuccinate monoester was synthesized from the seed oil of *Terminalia catappa* which was found to contain oleic acid as the most dominant fatty acid. The disodium salt of sulfosuccinate monoester had good inhibitive capacity against the corrosion of aluminum sheet in 1M HCl with inhibition efficiency increasing as the concentration of

disodium salt of sulfosuccinate monoester increased while the corrosion rate decreased.

Conflict of Interests

The authors declare that there is no conflict of interests regarding the publication of this paper.

Acknowledgments

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References

- [1] M. A. Amin, K. F. Khaled, Q. Mohsen, and H. A. Arida, "A study of the inhibition of iron corrosion in HCl solutions by some amino acids," *Corrosion Science*, vol. 52, no. 5, pp. 1684–1695, 2010.
- [2] D. A. Jones, "Coatings and inhibitors," in *Principles and Prevention of Corrosion*, A. D. Jones, Ed., pp. 477–512, Prentice Hall, Upper Saddle River, NJ, USA, 2nd edition, 1996.
- [3] M. A. Ash, *Handbook of Corrosion Inhibitors*, NACE International, Houston, Tex, USA, 2001.
- [4] H. A. Videla and L. K. Herrera, "Understanding microbial inhibition of corrosion. A comprehensive overview," *International Biodeterioration and Biodegradation*, vol. 63, no. 7, pp. 896–900, 2009.
- [5] M. Heydari and M. Javidi, "Corrosion inhibition and adsorption behaviour of an amido-imidazoline derivative on API 5L X52 steel in CO₂-saturated solution and synergistic effect of iodide ions," *Corrosion Science*, vol. 61, pp. 148–155, 2012.
- [6] J. L. Mora-Mendoza and S. Turgoose, "Fe₃C influence on the corrosion rate of mild steel in aqueous CO₂ systems under turbulent flow conditions," *Corrosion Science*, vol. 44, no. 6, pp. 1223–1246, 2002.
- [7] D. S. Carvalho, C. J. B. Joia, and O. R. Mattos, "Corrosion rate of iron and iron-chromium alloys in CO₂ medium," *Corrosion Science*, vol. 47, no. 12, pp. 2974–2986, 2005.
- [8] A. Ostovari, S. M. Hoseinie, M. Peikari, S. R. Shadizadeh, and S. J. Hashemi, "Corrosion inhibition of mild steel in 1 M HCl solution by henna extract: a comparative study of the inhibition by henna and its constituents (Lawson, Gallic acid, α -d-Glucose and Tannic acid)," *Corrosion Science*, vol. 51, no. 9, pp. 1935–1949, 2009.
- [9] G. A. Zhang and Y. F. Cheng, "Corrosion of X65 steel in CO₂-saturated oilfield formation water in the absence and presence of acetic acid," *Corrosion Science*, vol. 51, no. 8, pp. 1589–1595, 2009.
- [10] M. Elayyachy, A. El Idrissi, and B. Hammouti, "New thio-compounds as corrosion inhibitor for steel in 1 M HCl," *Corrosion Science*, vol. 48, no. 9, pp. 2470–2479, 2006.
- [11] S. H. S. Dananjaya, M. Edussuriya, and A. S. Dissanayake, "Inhibition action of lawson on the corrosion of mild steel in acidic media," *The Online Journal of Science and Technology*, vol. 2, pp. 32–36, 2012.
- [12] A. Y. El-Etre, "Khillah extract as inhibitor for acid corrosion of SX 316 steel," *Applied Surface Science*, vol. 252, no. 24, pp. 8521–8525, 2006.
- [13] Y. Ren, Y. Luo, K. Zhang, G. Zhu, and X. Tan, "Lignin terpolymer for corrosion inhibition of mild steel in 10% hydrochloric acid medium," *Corrosion Science*, vol. 50, no. 11, pp. 3147–3153, 2008.
- [14] S. H. Khalid and P. Sisodia, "Paniala (*F. lacourtia Jangomas*) plant extract as eco friendly inhibitor on the corrosion of mild steel in acidic media," *Rasayan Journal of Chemistry*, vol. 4, no. 3, pp. 548–553, 2011.
- [15] M. R. Singh and G. Singh, "Hibiscus cannabinus extract as a potential green inhibitor for corrosion of mild steel in 0.5M H₂SO₄ solution," *Journal of Materials and Environmental Science*, vol. 3, no. 4, pp. 698–705, 2012.
- [16] A. Khadraoui, A. Khelifa, H. Hamitouche, and R. Mehdaoui, "Inhibitive effect by extract of *Mentha rotundifolia* leaves on the corrosion of steel in 1 M HCl solution," *Research on Chemical Intermediates*, vol. 40, pp. 961–972, 2014.
- [17] O. K. Abiola and A. O. James, "The effects of Aloe vera extract on corrosion and kinetics of corrosion process of zinc in HCl solution," *Corrosion Science*, vol. 52, no. 2, pp. 661–664, 2010.
- [18] J. C. da Rocha, J. A. da Cunha Ponciano Gomes, and E. D'Elia, "Corrosion inhibition of carbon steel in hydrochloric acid solution by fruit peel aqueous extracts," *Corrosion Science*, vol. 52, no. 7, pp. 2341–2348, 2010.
- [19] P. Kalaiselvi, S. Chellammal, S. Palanichamy, and G. Subramanian, "Artemisia pallens as corrosion inhibitor for mild steel in HCl medium," *Materials Chemistry and Physics*, vol. 120, no. 2-3, pp. 643–648, 2010.
- [20] D. Ben Hmamou, R. Salghi, L. Bazzi et al., "Prickly pear seed oil extract: a novel green inhibitor for mild steel corrosion in 1 M HCl Solution," *International Journal of Electrochemical Science*, vol. 7, no. 2, pp. 1303–1318, 2012.
- [21] M. D. Griffiths and J. H. Anthony, *The New Royal Horticultural Society Dictionary of Gardening*, Macmillan Press, London, UK, 1992.
- [22] C.-C. Chyau, S.-Y. Tsai, P.-T. Ko, and J.-L. Mau, "Antioxidant properties of solvent extracts from *Terminalia catappa* leaves," *Food Chemistry*, vol. 78, no. 4, pp. 483–488, 2002.
- [23] U. D. Akpabio, "Evaluation of proximate composition, mineral element and anti-nutrient in almond (*Terminalia catappa*) seeds," *Research Journal of Applied Sciences*, vol. 3, no. 4, pp. 2247–2252, 2012.
- [24] L. Matos, J. M. Nzikou, A. Kimbonguila et al., "Composition and nutritional properties of seeds and oil from *Terminalia catappa* L.," *Advance Journal of Food Science and Technology*, vol. 1, no. 1, pp. 72–77, 2009.
- [25] W. H. Morrison, R. J. Hamilton, and C. Kalu, "Sunflower seed oil," in *Developments in Oils and Fats*, R. J. Hamilton, Ed., pp. 132–152, Chapman and Hall, London, UK, 1995.
- [26] A. Domsch and B. Irrgang, "Sulfosuccinates," in *Anionic Surfactants: Organic Chemistry*, H. W. Stache, Ed., vol. 56 of *Surfactant Science Series*, pp. 501–547, Marcel Dekker, New York, NY, USA, 1996.
- [27] A. Adewuyi and R. A. Oderinde, "Analysis of the lipids and molecular speciation of the triacylglycerol of the oils of *Luffa cylindrical* and *Adenopus breviflorus*," *CYTA—Journal of Food*, vol. 10, no. 4, pp. 313–320, 2012.
- [28] A. Adewuyi, R. A. Oderinde, B. V. S. K. Rao, and R. B. N. Prasad, "Synthesis of alkanolamide: a nonionic surfactant from the oil

- of gliricidia sepium,” *Journal of Surfactants and Detergents*, vol. 15, no. 1, pp. 89–96, 2012.
- [29] D. Myers, *Surfactant Science and Technology*, John Wiley & Sons, New York, NY, USA, 3rd edition, 2006.
- [30] A. K. Maayta, M. B. Bitar, and M. M. Al-Abdallah, “Inhibition effect of some surface active agents on dissolution of copper in nitric acid,” *British Corrosion Journal*, vol. 36, no. 2, pp. 133–135, 2001.
- [31] L. Tang, G. Mu, and G. Liu, “The effect of neutral red on the corrosion inhibition of cold rolled steel in 1.0 M hydrochloric acid,” *Corrosion Science*, vol. 45, no. 10, pp. 2251–2262, 2003.
- [32] A. M. Abdel-Gaber, B. A. Abd-El-Nabey, I. M. Sidahmed, A. M. El-Zayady, and M. Saadawy, “Kinetics and thermodynamics of aluminium dissolution in 1.0 M sulphuric acid containing chloride ions,” *Materials Chemistry and Physics*, vol. 98, no. 2-3, pp. 291–297, 2006.
- [33] T. H. Ibrahim and M. A. Zour, “Corrosion inhibition of mild steel using fig leaves extract in hydrochloric acid solution,” *International Journal of Electrochemical Science*, vol. 6, no. 12, pp. 6442–6455, 2011.
- [34] A. Adewuyi, A. Göpfert, and T. Wolff, “Succinyl amide gemini surfactant from *Adenopus breviflorus* seed oil: a potential corrosion inhibitor of mild steel in acidic medium,” *Industrial Crops and Production*, vol. 52, pp. 439–449, 2014.
- [35] X. Wang, Y. Wan, Q. Wang, F. Shi, Z. Fan, and Y. Chen, “Synergistic inhibition between bisbenzimidazole derivative and chloride ion on mild steel in 0.25 M H₂SO₄ solution,” *International Journal of Electrochemical Science*, vol. 8, no. 2, pp. 2182–2195, 2013.
- [36] A. Zarrouk, I. Warad, B. Hammouti, A. Dafali, S. S. Al-Deyab, and N. Benchat, “The effect of temperature on the corrosion of Cu/HNO₃ in the presence of organic inhibitor: part-2,” *International Journal of Electrochemical Science*, vol. 5, no. 10, pp. 1516–1526, 2010.
- [37] F. El-Hajjaji, R. A. Belkhemima, B. Zerga et al., “Time and temperature elucidation on steel corrosion inhibition by 3-methyl-1-prop-2-ynylquinoxalin-2(1H)-one in molar hydrochloric acid: part 2,” *Journal of Material Environmental Science*, vol. 5, pp. 263–270, 2014.
- [38] H. Keleş, M. Keleş, and I. Dehri, “Adsorption and inhibitive properties of aminobiphenyl and its Schiff base on mild steel corrosion in 0.5 M HCl medium,” *Colloids and Surfaces A: Physicochemical and Engineering Aspects*, vol. 320, no. 1–3, pp. 138–145, 2008.
- [39] E. A. Noor and A. H. Al-Moubaraki, “Thermodynamic study of metal corrosion and inhibitor adsorption processes in mild steel/1-methyl-4[4/(-X)-styryl pyridinium iodides/hydrochloric acid systems,” *Materials Chemistry and Physics*, vol. 110, no. 1, pp. 145–154, 2008.
- [40] A. S. Patel, V. A. Panchal, G. V. Mudaliar, and N. K. Shah, “Impedance spectroscopic study of corrosion inhibition of Al-Pure by organic Schiff base in hydrochloric acid,” *Journal of Saudi Chemical Society*, vol. 17, no. 1, pp. 53–59, 2013.



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