Research Article

Cuminum cyminum Extracts as Eco-Friendly Corrosion Inhibitor for Mild Steel in Seawater

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The inhibitive effect of Jeera (*Cuminum cyminum*) plant extracts on the corrosion of mild steel in an aqueous solution of seawater was investigated using potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. The stability of the inhibition efficiency of Jeera extracts was examined by weight-loss method. Potentiodynamic polarization curves indicated that the Jeera extract behaves as an anodic type inhibitor. EIS measurements showed that the dissolution process occurs under activation control. The corrosion rates of steel and the inhibition efficiencies of the extract obtained from impedance and polarization measurements were in good agreement. Inhibition was found to increase with an increasing concentration of the plant extract. The results obtained show that the Jeera extract could serve as an effective inhibitor for the corrosion of mild steel in seawater.

1. Introduction

Recently, plant extracts have again become important as an environmentally acceptable, readily available, and renewable source for a wide range of needed inhibitors. Plant extracts are viewed as an incredibly rich source of naturally synthesized chemical compounds that can be extracted by simple procedures with low cost. However, synergistic (and antagonistic) effects are often expected with these mixtures of inhibitors that may affect their inhibition efficiency. Several investigations have been reported using such economic plant extracts. El Hosary et al. [1] studied the corrosion inhibition of aluminium and zinc in 2 N HCl using naturally occurring *Hibiscus sabdariffa* (Karkade) extract. The inhibition of corrosion of steel, aluminium, and copper in HCl, H₂SO₄, and citric acid by molasses was also studied [2], and 83% and 13% inhibition efficiencies were obtained for HCl and H₂SO₄ solutions, respectively, containing 0.75% molasses. Loto reported the inhibitive action of *Vernonia amygdalina* (bitter leaf) on the corrosion of mild steel in 0.5 M HCl at 28°C [3]. Avwiri and Igbo studied the inhibitive action of *V. amygdalina* on the corrosion of aluminium alloys in HCl and HNO₃ at concentrations of 0.2 and 0.4 g/L at 29°C [4]. They showed that the

solution extract of the leaves serves as an excellent inhibitor. The inhibition effect of *Zanthoxylum alatum* plant extract on the corrosion of mild steel in 20%, 50%, and 88% aqueous orthophosphoric acid has been investigated by weight loss and electrochemical impedance spectroscopy (EIS). Plant extract was found to reduce the corrosion of steel more effectively in 88% than in 20% phosphoric acid [5]. An inhibition efficiency of 75.11% was observed with the extract of the leaves of *Nypa fruticans* Wurmb [6] for the corrosion of mild steel in hydrochloric acid solutions. El-Etre et al. examined some naturally occurring substances as corrosion inhibitors for different metals in various environments [7–11].

The application of extracts of henna, thyme, bbugaine, and inriine was investigated for their anticorrosion activity [12–15]. The effect of addition of bbugaine on steel corrosion in HCl is patented [16]. Saleh and El-Hosaray studied the peel of pomegranate [17] and beetroot [18, 19] as corrosion inhibitor for mild steel in acid media. Sanghvi et al. have investigated the anticorrosion activity of *Embllica officinalis*, *Terminalia chebula*, *Terminalia bolivia* [20], *Sapindus trifoliatus*, and *Acacia concinna* [21]. Corrosion inhibition has also been studied for the extracts of *Swertia angustifolia* [22], *Eucalyptus leaves* [23], *Eugenia jambolana* [24], *Pongamia*

TABLE 1: Water analysis.

Parameters	Result
Total dissolved salts (mg/L)	8000 ppm
pH	8.1
Calcium as Ca (mg/L)	160 ppm
Total hardness (CaCO ₃ equivalent)	100 ppm
Magnesium as Mg (mg/L)	100 ppm
Sodium as Na (mg/L)	0
Chloride as Cl (mg/L)	17600 ppm
Sulphate as SO ₄ (mg/L)	3254 ppm

glabra, *Annona squamosa* [25], *Acacia arabica* [26], *Carica papaya* [27], *Azadirachta indica* [28], and *Vernonia amygdalina* [29] for steel in acid media. The anticorrosion effect of *Andrographis paniculata* [30] and tea wastes [31] has been reported from our laboratories. Kliskic et al. analyzed aqueous extract of *Rosmarinus officinalis* [32] as corrosion inhibitor for aluminium alloy corrosion in chloride solution. Guar gum was analyzed for its anticorrosion activity by Abdallah [33]. Martinez and Stern have studied the inhibitory mechanism of low carbon steel corrosion of mimosa tannin in H₂SO₄ media [34]. Oguzie investigated the efficiency of *Telfairia occidentalis* extract as corrosion inhibitor in both HCl and H₂SO₄ media [35]. The extracts of chamomile, halfabar, black cumin, and kidney bean were analyzed for their inhibitive action of corrosion of steel in acid media by Abdel-Gaber et al. [36]. El-Hosary et al. [37] studied the corrosion inhibition of aluminium and zinc in HCl using *Hibiscus sabdariffa* extract. Rajendran et al. [38, 39] studied the corrosion inhibition of aluminium in rain water containing garlic extract. Aqueous extracts of rhizome powder [40], beet root extract [41], and *Hibiscus rosa-sinensis* have been used as corrosion inhibitors.

The present work is to examine the aqueous Jeera extract as an inhibitor for corrosion of carbon steel in solution-containing seawater. Weight loss measurements, potentiodynamic polarization, fluorescence, and UV-spectroscopy are used to study surface film formed on the metal surface.

2. Experimental

2.1. Preparation of Plant Extract of Jeera Extract. An aqueous plant extract was prepared by grinding 10 g of (*Cuminum cyminum*) extract, filtering, and making up to 100 using double distilled water.

2.2. Preparation of Specimens. Carbon steel specimens (0.0267% S, 0.06% P, 0.4% Mn, 0.1% C, and the rest iron) of dimensions 1.0 cm × 4.0 cm × 0.2 cm were polished to a mirror finish and degreased with trichloroethylene.

2.3. Weight Loss Method. Relevant data of seawater used in the study are given in Table 1.

Carbon steel specimens in triplicate were immersed in 100 mL of the solutions containing various concentrations of the inhibitor for one day. The weight of the specimens before and after immersion was determined using Shimadzu balance, model AY 62. The corrosion products were cleansed

with Clarke's solution [42]. The inhibition efficiency (IE) was then calculated using

$$\text{I.E} = 100 \left[1 - \left(\frac{W_2}{W_1} \right) \right] \%, \quad (1)$$

where W_1 = corrosion rate in the absence of the inhibitor, and W_2 = corrosion rate in the presence of the inhibitor.

2.4. Surface Examination. The carbon steel specimens were immersed in various test solutions for a period of one day, taken out, and dried. The nature of the film formed on the surface of metal specimens was analyzed by FTIR spectroscopic study.

2.4.1. FTIR Spectra. FTIR spectra were recorded in a Perkin-Elmer 1600 spectrophotometer. The film was carefully removed and mixed thoroughly with KBr made in to pellets, and FTIR spectra were recorded.

The fluorescence spectra of the film formed on the CS samples recorded with a Hitachi F-4500 fluorescence spectrophotometer.

2.5. Potentiodynamic Polarization. A three-electrode cell consisting of mild steel as working electrode (WE), a platinum wire counter electrode (CE), and a saturated reference electrode was used for measurements. All the potential values reported here were VSSCE. The working electrode was mechanically polished on various grades of emery sheet, rinsed with double distilled water, and degreased with trichloroethylene. Potentiodynamic polarization curves were recorded using an H and CH electrochemical work station impedance analyzer model CHI 660A provided with iR compensation option. Polarization curve measurements were carried out at scan rate of 0.01 V s⁻¹. The exposed area (1 cm²) was mechanically polished with a series of emery sheets of variable grades. The samples were washed thoroughly with double distilled water before insertion in the cell. During the polarization study, the scan rate was 0.01 V s⁻¹, hold time at E_f was 0 s, and quiet time was 2 s.

2.6. Ac Impedance Measurements. The instrument used for polarization was used for AC impedance study also. The cell set-up was the same as that had been used for polarization measurements. The real part and imaginary part of the cell impedance were measured in ohms at various frequencies. The values of charge transfer resistance, R_{ct} , and the double layer capacitance, C_{dl} , were calculated. The equivalent electrical circuit diagram is shown in Figure 7.

3. Result and Discussion

3.1. Analysis of Results from Weight Loss Method. Table 2 shows the values of corrosion rates and inhibition efficiencies obtained from weight loss measurements of different concentrations of Jeera extract. 4 mL of the Jeera extract offered 93% corrosion inhibition efficiency to carbon steel immersed in 100 ml solution containing seawater. When the

TABLE 2: Corrosion rates (milligram per square decimeter per day) (Mdd) of carbon steel immersed in seawater in the presence and absence of inhibitors and the inhibition efficiencies (Ie) obtained by mass loss method. Inhibitor: Jeera extracts (*Cuminum cyminum*). Period of immersion: 1 day.

Jeera extract	CR/mdd	Inhibition efficiency IE%
0	21.52	—
2	18.49	45
4	2.35	93
6	4.37	87
8	14.46	51

FIGURE 1: Polarization curves of carbon steel immersed in various test solutions: (a) seawater, (b) seawater + Jeera extract 4 mL.

concentration of Jeera extract was increased, the inhibition efficiency decreased, and the corrosion rate increased, and this is due to the fact that when higher concentrations of Jeera extract are added, the protective film (Fe^{2+} -*Cuminum cyminum* complex) formed on the metal surface goes in to the solution and thus destroying the protective film. It may be considered that the protective film formed may go into transpassive state, where the film is broken [43].

3.2. Analysis of Polarization Curves. A polarization study has been used to detect the formation of protective film on the metal surface [44]. When a protective film formed on the metal surface, the linear polarization resistance (LPR) increases, and the corrosion current (I_{corr}) decreases. The potentiodynamic polarization curves of carbon steel immersed in various test solution are shown in Figure 1. The corrosion parameters, namely, corrosion potential (E_{corr}) tafel slopes (b_c = cathodic; b_a = anodic), linear polarization resistance (LPR), and the corrosion current (I_{corr}) are given in Table 3 when carbon steel is immersed in seawater. The corrosion potential of seawater is -926 mV VS SCE. The formulation consisting of 4 mL of Jeera extract in presence of seawater solution shifts the corrosion potential -883 mV VS SCE. This suggested that anodic reaction is controlled predominantly. The (LPR) value increases from 51.67×10^{-2} to 63.67×10^{-2} ohm cm^2 . This suggests that a protective film is formed

FIGURE 2: AC impedance spectra (Nyquist plots) of carbon steel immersed in various test solutions: (a) seawater, (b) seawater + *Phyllanthus amarus* 4 mL.

SCHEME 1: Cuminaldehyde.

on the metal surface. Further the corrosion current decreases from 7.963×10^{-6} to 6.295×10^{-6} Acm^2 [45, 46].

3.3. Analysis of Ac Impedance Spectra. AC impedance spectra have been used to detect the formation of the film formed on the metal surface. If the protective film is formed, the charges transfer resistance increases, and double layer capacitance value decreases [40]. The AC impedance spectra of carbon steel immersed in various solutions are shown in Figure 2 (Nyquist) and Figure 3 (impedance-Bode plots). The AC impedance parameter, namely, charge transfer resistance (R_{ct}) and double layer capacitance (C_{dl}) are given in Table 4.

When carbon steel is immersed in aqueous solution containing seawater, the R_{ct} value is 88 ohm cm^2 , and C_{dl} value is $1.027 \times 10^{-7} \text{ F/cm}^2$. When 4 ml of (*Cuminum cyminum*) extract is added, the R_{ct} value increases from 88 ohm cm^2 to 116 ohm cm^2 , and C_{dl} value decreases from $1.027 \times 10^{-7} \text{ F/cm}^2$ to 0.7817×10^{-8} . This suggest that a protective film is formed on the metal surface of the metal. Further there is increase in impedance log (Z/ohm), value from 2.02 to 2.12 (derived from Bode plot shown in Figure 3).

3.4. Fourier Transfer-Infrared Spectra. The main constituent of Jeera extract is cuminaldehyde [47]. The structure of cuminaldehyde is shown in Scheme 1. It contain carboxylic group, cumin structure.

The *Cuminum cyminum* extract was evaporated to dryness to a solid mass. Its FTIR spectrum is shown in Figure 4(a). $-\text{C}=\text{C}$ stretching frequency appeared at 2141 cm^{-1} .

TABLE 3: Corrosion parameters of carbon steel immersed in seawater in the absence and presence of inhibitors.

System	E_{corr} mV versus SCE	b_c mV/decade	b_a mV/decade	LPR Ωcm^2	I_{corr} A/cm^2
Seawater	-926	152	236	65.32×10^{-2}	6.164×10^{-6}
Seawater + (<i>Cuminum cyminum</i>) extract (4 mL)	-883	153	247	51.67×10^{-2}	0.7963×10^{-7}

TABLE 4: AC impedance parameters of carbon steel immersed in various solutions. Inhibitors: Jeera extract.

System	R_{ct} Ωcm^2	C_{dl} F/cm^2	Impedance value $\log(z/\Omega\text{cm})$
Seawater	88	1.027×10^{-7}	2.02
CC (4 mL) + Seawater	128	7.0703×10^{-8}	2.17

FIGURE 3: Bode plot of carbon steel immersed in various solutions (Bode plots). (a) Seawater, (b) Seawater + 4 ml Jeera extract.

FIGURE 4: FTIR spectra. (a) Aqueous solution of Jeera extract, (b) Aqueous solution of seawater + Jeera extract 4 mL.

FIGURE 5: UV-spectra. (a) Aqueous solution of Jeera extract, (b) Aqueous solution of Jeera extract + Fe^{2+} .

FIGURE 6: Fluorescence spectra. (a) Aqueous solution of Jeera extract, (b) film formed on the metal surface after immersion Jeera extract + 4 ml *Cuminum cyminum*.

The aromatic $-\text{CH}$ stretching frequency appeared at 2927 cm^{-1} . $-\text{C}=\text{O}$ stretching frequency appeared at 1607 cm^{-1} [48, 49].

The FTIR spectrum of the protective film formed on the surface of the metal after immersion in the aqueous solution containing seawater and Seawater containing 4 mL of Jeera extract is shown in Figure 4(b). $-\text{OH}$ stretching frequency appeared at 3402 cm^{-1} to 3435 cm^{-1} . $-\text{C}=\text{C}$ stretching frequency appeared at 2141 cm^{-1} to 2091 cm^{-1} . The aromatic $-\text{CH}$ stretching frequency appeared at 2927 cm^{-1} to 2923 cm^{-1} . $-\text{C}=\text{O}$ stretching frequency appeared at 1607 cm^{-1} to 1638 cm^{-1} .

3.5. Fluorescence Spectra. The UV-visible adsorption spectrum of aqueous solution of *Cuminum cyminum* and Fe^{2+} is shown in Figure 5. Peaks appear at 228 nm, 268 nm. When the

FIGURE 7: Equivalent electrical circuit diagram. R_s : solution resistance; R_{ct} : charge transfer resistance; C_{dl} : double layer capacitance.

Fe^{2+} is added to the aqueous solution of *Cuminum cyminum*, peak appears at 225 nm and 265 nm [46].

The fluorescence spectrum ($\lambda_{\text{ex}} = 225\text{ nm}$) of an aqueous solution of Fe^{2+} -*Cuminum cyminum* is shown in Figure 6(a). A peak appears at 252 nm. This due to that Fe^{2+} -active principle complex is formed in solution [40].

The fluorescence spectrum ($\lambda_{\text{ex}} = 225\text{ nm}$) of the film formed on the surface of the metal after immersion in the solution containing seawater and 4 ml of *Cuminum cyminum* extract is shown in Figure 6(b). The peaks appeared at 252 nm confirming the presence of Fe^{2+} -*Cuminum cyminum* extract complex formed on the metal surface.

4. Conclusion

The corrosion inhibition by aqueous solution of Jeera extract in the presence and absence of inhibitor was studied by weight-loss study and electrochemical measurements. The results show that inhibitor has the ability of reducing the corrosion rate of carbon steel in aqueous solution containing Jeera extract, and it acts as an anodic inhibitor. This effectiveness is confirmed by electrochemical impedance spectra and potential polarization analysis.

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References

- [1] A. A. El Hosary, R. M. Saleh, and A. M. Shams El Din, "Corrosion inhibition by naturally occurring substances-I. The effect of Hibiscus subdariffa (karkade) extract on the dissolution of Al and Zn," *Corrosion Science*, vol. 12, no. 12, pp. 897–904, 1972.
- [2] A. A. El Hosary and R. M. Saleh, *Progress in Understanding and Prevention of Corrosion*, vol. 2, The Institute of Materials, London, UK, 1993.
- [3] C. A. Loto, "The effect of Vernonia amygdalina (bitter leaf) solution extract on the corrosion inhibition of mild steel," *Nigerian Corrosion Journal*, vol. 19, pp. 20–28, 1998.
- [4] G. O. Awiri and F. O. Igho, "Inhibitive action of Vernonia amygdalina on the corrosion of aluminium alloys in acidic media," *Materials Letters*, vol. 57, no. 22-23, pp. 3705–3711, 2003.
- [5] G. Gunasekaran and L. R. Chauhan, "Eco friendly inhibitor for corrosion inhibition of mild steel in phosphoric acid medium," *Electrochimica Acta*, vol. 49, no. 25, pp. 4387–4395, 2004.
- [6] K. O. Orubite and N. C. Oforka, "Inhibition of the corrosion of mild steel in hydrochloric acid solutions by the extracts of leaves of Nypa fruticans Wurmb," *Materials Letters*, vol. 58, no. 11, pp. 1768–1772, 2004.
- [7] A. Y. El-Etre, "Natural honey as corrosion inhibitor for metals and alloys. I. Copper in neutral aqueous solution," *Corrosion Science*, vol. 40, no. 11, pp. 1845–1850, 1998.
- [8] A. Y. El-Etre and M. Abdallah, "Natural honey as corrosion inhibitor for metals and alloys. II. C-steel in high saline water," *Corrosion Science*, vol. 42, no. 4, pp. 738–738, 2000.
- [9] A. Y. El-Etre, "Inhibition of acid corrosion of aluminum using vanillin," *Corrosion Science*, vol. 43, no. 6, pp. 1031–1039, 2001.
- [10] A. Y. El-Etre, "Inhibition of aluminum corrosion using Opuntia extract," *Corrosion Science*, vol. 45, no. 11, pp. 2485–2495, 2003.
- [11] A. Y. El-Etre, M. Abdallah, and Z. E. El-Tantawy, "Corrosion inhibition of some metals using lawsonia extract," *Corrosion Science*, vol. 47, no. 2, pp. 385–395, 2005.
- [12] A. Chetouani and B. Hammouti, "Corrosion inhibition of iron in hydrochloric acid solutions by naturally henna," *Bulletin of Electrochemistry*, vol. 19, no. 1, pp. 23–25, 2003.
- [13] Chetouani, "Etude Numerique de problemes non linear at application aux problemes de dynamique de population," [Ph.D. thesis], University Oujda, Oujda, Morocco, 2003.
- [14] B. Hammouti, S. Kertit, and M. Mellhaoui, "Bgugaine: a natural pyrrolidine alkaloid product as corrosion inhibitor of iron in HCl medium," *Bulletin of Electrochemistry*, vol. 11, p. 553, 1995.
- [15] B. Hammouti, S. Kertit, and A. Melhaoui, "Electrochemical behaviour of bgugaine as a corrosion inhibitor of iron in 1 M HCl," *Bulletin of Electrochemistry*, vol. 13, no. 3, pp. 97–98, 1997.
- [16] S. Kertit, B. Hammouti, and M. Mellhaoui, "Bgugaine comme inhibiteur de corrosion du fer en milieu acide chlorhydrique," Moroccan Patent no. 23910, 1995.
- [17] R. M. Saleh and A. A. El-Hosary, "Corrosion inhibition by naturally occurring substance-I the effect of Hibiscus subdariffa (Karkade) extract on the dissolution of Al and Zn," in *Proceedings of the 13th Seminar on Electrochemistry*, CECRI, Karaikudi, India, 1972.
- [18] A. El-Hosary, M. M. Gowish, and R. M. Saleh, "Evaluation of quinolines as inhibitors by electrochemical techniques," in *Proceedings of the 2nd International Symposium and Oriented Basic Electrochemistry*, vol. 7, SAEST, IIT, Madras, Technical Session, 1980, paper 6.24.
- [19] J. Arockia Selvi, S. Rajendran, V. Ganga Sri, A. John Amalraj, and B. Narayanasamy, "Corrosion inhibition by beet root extract," *Portugaliae Electrochimica Acta*, vol. 27, no. 1, pp. 1–11, 2009.
- [20] M. J. Sanghvi, S. K. Shukla, A. N. Mishra, M. R. Padh, and G. N. Mehta, *5th National Congress on Corrosion Control*, New Delhi, India, 1995.
- [21] M. J. Sanghvi, S. K. Shukla, A. N. Mishra, M. R. Padh, and G. N. Mehta, "Formulation of 5% HCl corrosion inhibition for mild steel using weight loss and DC polarization technique," in *International Conference on Maintenance, Inspection, Corrosion, Materials Engineering and Plant Reliability Baroda (MICMEP '99)*, vol. 84–87, p. 87, Baroda, India, February 1999.
- [22] S. J. Zakvi and G. N. Mehta, "Acid corrosion of mild steel and its inhibition by swertia augustifolia-study by electrochemical techniques," *Transactions of the SAEST*, vol. 23, no. 4, pp. 407–410, 1988.
- [23] P. Kar, A. Hussein, G. Varkey, and G. Singh, "Corrosion inhibition of mild steel in hydrochloric acid by acid extracts of sapindus trifolius, acacia concina and Trifla, Trans," *MFAI*, vol. 51, pp. 143–147, 1996.
- [24] S. A. Verma and G. N. Mehta, "Effects of acid extracts of powered seeds of Eugenia Jambolans on corrosion of mild steel in HCl-study by DC polarisation techniques," *Transactions of the SAEST*, vol. 32, no. 4, pp. 89–93, 1997.
- [25] P. Sakthivel, P. V. Nirmala, S. Umamaheswari et al., "Corrosion inhibition of mild steel by extracts of Pongamia Glabra and Annona Squamosa in acidic media," *Bulletin of Electrochemistry*, vol. 15, no. 2, pp. 83–86, 1999.
- [26] S. Verma and G. N. Mehta, "Effect of acid extracts of acacia arabica on acid corrosion of mild steel," *Bulletin of Electrochemistry*, vol. 15, no. 2, pp. 67–70, 1999.
- [27] U. J. Ekpe, E. E. Ebenso, and U. J. Ibok, "Inhibitory action of Azadirachta indica leaves extract on the corrosion of mild steel in H₂SO₄," *West African Journal of Biological and Applied Chemistry*, vol. 37, pp. 13–30, 1994.
- [28] U. J. Ekpe, E. E. Ebenso, and U. J. I. Ibok, *Journal of the West African Science Association*, vol. 37, p. 13, 1994.
- [29] A. Loto, "The effect of bitterleaf extracts on corrosion of mild steel in 0.5M HCl and H₂SO₄ solutions," *Nigerian Corrosion Journal*, pp. 19–20, 1998.
- [30] S. P. Ramesh, K. P. Vinod Kumar, and M. G. Sethuraman, "Extract of andrographis paniculata as corrosion inhibitor of mild steel in acid medium," *Bulletin of Electrochemistry*, vol. 17, no. 3, pp. 141–144, 2001.
- [31] M. G. Sethuraman, P. Vadivel, and K. P. Vinod Kumar, "Tea wastes as corrosion inhibitor for mild steel in acid medium," *Journal of the Electrochemical Society of India*, vol. 50, p. 143, 2001.
- [32] M. Kliskic, J. Radosevic, S. Gudic, and V. Katalinic, "Aqueous extract of Rosmarinus officinalis L. as inhibitor of Al-Mg alloy corrosion in chloride solution," *Journal of Applied Electrochemistry*, vol. 30, no. 7, pp. 823–830, 2000.
- [33] M. Abdallah, "Guar gum as corrosion inhibitor for carbon steel in sulfuric acid solutions," *Portugaliae Electrochimica Acta*, vol. 22, pp. 161–175, 2004.
- [34] S. Martinez and I. Stern, "Inhibitory mechanism of low-carbon steel corrosion by mimosa tannin in sulphuric acid solutions," *Journal of Applied Electrochemistry*, vol. 31, no. 9, pp. 973–978, 2001.

- [35] E. Oguzie, "Inhibition of acid corrosion of mild steel by *Telfaria occidentalis*," *Pigment and Resin Technology*, vol. 34, no. 6, pp. 321–326, 2005.
- [36] M. Abdel-Gaber, B. A. Abd-El-Nabey, I. M. Sidahmed, A. M. El-Zayaday, and M. Saa dawy, "Inhibitive action of some plant extracts on the corrosion of steel in acidic media," *Corrosion Science*, vol. 48, no. 9, pp. 2765–2779, 2006.
- [37] A. El-Hosary, R. M. Saleh, and A. M. Sharns El Din, "Corrosion inhibition by naturally occurring substances-I. The effect of *Hibiscus subdariffa* (karkade) extract on the dissolution of Al and Zn," *Corrosion Science*, vol. 12, no. 12, pp. 897–904, 1972.
- [38] S. Rajendran, S. Muthulakshmi, R. Rajeswari, and A. Vijitha, "Emerging trends in corrosion science and engineering," *Journal of the Electrochemical Society of India*, vol. 54, no. 2, p. 61.
- [39] S. Rajendran and K. Anuradha, "Corrosion behaviour of aluminium in rain water containing garlic extract," *Surface Engineering*, vol. 21, no. 3, pp. 229–231, 2005.
- [40] S. Rajendran, S. Shanmugapriya, T. Rajalakshmi, and A. J. Amal Raj, "Corrosion inhibition by an aqueous extract of rhizome powder," *Corrosion*, vol. 61, no. 7, pp. 685–692, 2005.
- [41] S. Rajendran, J. Arokiaselvi, and V. Gangasree, "Corrosion inhibition by beet root extract," *Protugalia Electrochemica Acta*, vol. 27, no. 1, pp. 1–11, 2009.
- [42] G. Wranglen, *Introduction to Corrosion and Protection of Metals*, vol. 236, Chapman & Hall, London, UK, 1985.
- [43] J. Sathyabama, R. Susai, S. J. Arokia, and A. A. John, "Methyl orange as corrosion inhibitor for carbon steel in well water," *Indian Journal of Chemical Technology*, vol. 15, pp. 462–466, 2008.
- [44] S. Rajendran, S. P. Sridevi, N. Anthony, A. J. Amalraj, and M. Sundaravadivelu, "Corrosion behaviour of carbon steel in polyvinyl alcohol," *Anti-Corrosion Methods and Materials*, vol. 52, no. 2, pp. 102–107, 2005.
- [45] F. R. Selvarani, S. Santhamadarasi, J. W. Sahayaraj, A. J. Amalraj, and S. Rajendran, "Synergistic effect of succinic acid and Zn^{2+} in controlling corrosion of carbon steel," *Bulletin of Electrochemistry*, vol. 20, no. 12, pp. 561–565, 2004.
- [46] S. Rajendran, S. M. Reenkala, N. Anthony, and R. Ramaraj, "Synergistic corrosion inhibition by the sodium dodecylsulphate- Zn^{2+} system," *Corrosion Science*, vol. 44, no. 10, pp. 2243–2252, 2002.
- [47] N. S. Iacobellis, P. Lo Cantore, F. Capasso, and F. Senatore, "Antibacterial activity of *Cuminum cyminum* L. and *Carum carvi* L. essential oils," *Journal of Agricultural and Food Chemistry*, vol. 53, no. 1, pp. 57–61, 2005.
- [48] S. Agnesia Kanimozhi and S. Rajendran, "Inhibitive properties of sodium tungstate- Zn^{2+} system and its synergism with HEDP," *International Journal of Electrochemical Science*, vol. 4, pp. 353–368, 2009.
- [49] R. M. Silverstein, G. C. Bassler, and T. C. Morrill, *Spectroscopic Identification of Organic Compound*, vol. 95, John Wiley & Sons, New York, NY, USA, 1986.