Corrosion Inhibition of Cu-Zn-Fe Alloy in Hydrochloric Acid Medium by Crude Ethanol Extracts from Roots-Leaves Synergy of Solanum melongena

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Abstract

The corrosion inhibition of Cu-Zn-Fe alloy in hydrochloric acid medium by crude ethanol extracts from roots-leaves synergy of Solanum melongena have been studied with chemical methods (mass loss and gasometric methods). At 3.0 grams per litre concentration of the roots-leaves synergy of Solanum melongena, it was observed that a 98.8 % inhibition efficiency was recorded as corrosion rate of alloy was decreasing with inhibitor increase. Temperature evaluation on the inhibitor showed 99.2 > 88.4 > 85.6 % as trial was conducted from 303-323 respectively, and in respect to increasing concentration, corrosion rate was found to be 1.718 > 0.013, 0.0192 and 0.247 at 303, 313 and 323 respectively. All these present a good result for the synergistic inhibitor and a proof of its efficiency in controlling the corrosion of Cu-Zn-Fe alloy in hydrochloric acid medium. Inhibition mechanism was deduced from the activation and thermodynamic parameters that govern the process. Adsorption of extract on the Cu-Zn-Fe alloy was found to obey the Langmuir adsorption isotherm. The phenomenon of physical adsorption is proposed from the obtained thermodynamic parameters.

1. Introduction

Corrosion is a natural process since all natural processes tend toward the lowest possible energy states [1-3]. The most common kinds of corrosion result from electrochemical reactions. General corrosion occurs when most or all of the atoms on the same metal surface are oxidized, damaging the entire surface. Most metals are easily
oxidized: they tend to lose electrons to oxygen (and other substances) in the air or in water. The effects of corrosion in our daily lives are both direct, in that corrosion affects the useful service lives of our possessions, and indirect, in that producers and suppliers of goods and services incur corrosion costs, which they pass onto the consumers [2-5]. Some of the effects of corrosion include a significant deterioration of natural and historic monuments as well as increase the risk of catastrophic equipment failures. Corrosion also degrades important infrastructure such as steel-reinforced-highways, electrical towers, parking structures and bridges [4, 5-7]. Its effects can also be seen in plant shutdown, waste of valuable resources, loss or contamination of products, reduction in efficiency, and expensive overdesign. Corrosion damage can be prevented by using various methods such as upgrading materials, blending of production fluids, process control and chemical inhibition [2, 5-7]. The known effects of most synthetic corrosion inhibitors are the motivation for the use of some natural products. Natural products are nontoxic, biodegradable and readily available. Green and eco-friendly inhibitor research have become a wide spread area of corrosion control especially due to their environmental friendly, less expensive and easy availability and accessibility nature [1-3, 7-10]. Their effective and wide spread interest is also centered on the presence of hetero-atoms and dominance of aromatic characteristics, and alkyl groups that act to reduce corrosion through adsorption on metal and alloy surfaces the plant extracts are considered as an incredibly rich source of environmentally acceptable corrosion inhibitors [8-11]. This work is aimed at investigating Corrosion inhibition of Cu-Zn-Fe alloy in hydrochloric acid medium by crude ethanol extracts from roots-leaves synergy of Solanum melongena

2. Experimental

2.1 Preparation of ethanol extracts of Solanum melongena

The required roots and leaves of Solanum melongena were dried separately in a laboratory oven at a minimal temperature to avoid loss of major organic components of the plant and ground into powder form. Each powdered sample was extracted continually with absolute ethanol in a Soxhlet extractor for 48 hours. The extracts obtained separately were later evaporated of the excess ethanol through a water bath at 60°C. Ten grams each of the ethanol extracts of leaf and root were weighed and together diluted with 1000 ml 1 M HCl solution then kept for 24 hours to allow for complete dissolution. From the stock solution (10 g/L), inhibitor test solutions were prepared to obtain 1.0 g/L, 1.5 g/L, 2.0 g/L, 2.5 g/L and 3.0 g/L for mass loss and gasometric measurements respectively. The prepared solutions were then used to study the corrosion inhibition abilities of the extract.
2.2 Mass loss measurements

Prepared and weighed 5.0 cm x 0.08 cm Cu-Zn-Fe alloy dimension were considered for the mass loss experiment. These metals were immersed in various concentrations including the blank solution of the synergistic inhibitor using a 100 ml beaker and suspended with a polythene rope and a glass rod. Each of the test specimens were removed daily from the test solution, washed with distilled water, rinsed with ethanol, dried with acetone and re-weighed. Plots of weight loss against exposure time and concentration were generated and corrosion rates obtained from plots. Surface coverage and inhibition efficiency were estimated from equations (1) and (2) respectively:

\[ \theta = 1 - \frac{W_1}{W_2} \]  
\[ \text{IE}\% = \theta \times 100 \]  

where \( \theta \) is the surface coverage, \( W_1 \) is the corrosion rate of the blank, \( W_2 \) is the corrosion rate of the inhibitor, IE\% is the inhibition efficiency.

2.3 Hydrogen evolution measurements

100 mL of the 1 M HCl was introduced into the assembly and the initial volume of the indicator was noted. This was followed with the prepared and weighed 1.20 cm x 0.08 cm x 4.00 cm Cu-Zn-Fe alloy dimension dropped into the blank solution (1 M HCl) and the flask quickly closed. The volume of the hydrogen gas evolved from the corrosion reaction was monitored by volume changes in assembly after every minute for 30 minutes. In another experiment, a set of fresh alloy were immersed in the flask containing the inhibitor solutions (1.0 g/L, 1.5 g/L, 2.0 g/L, 2.5 g/L and 3.0 g/L) and the experiment repeated again. The study was conducted at 303K, 313 and 323 K using a thermostat water bath.

3. Results and Discussion

3.1 Effects of inhibitor concentration on mass loss of Cu-Zn-Fe alloy

Mass loss of metal or alloy is a consequence of the corrosion rate of the alloy due to oxidation at the anodic sites and cathodic hydrogen evolution [6, 9, 11]. The Cu-Zn-Fe alloy was found from Figures 1 and 2 to experience an increase in mass loss with increase in immersion time which could be as a result of increase retention of dissolved alloy particles which serves as bulk impurities [10-13]. The same mass loss was found decreasing with increase concentration implying that the corrosion sites in the alloy were
inhibited by the root-leaves synergy extracts [11-15]. This has been confirmed from Table 1 and Figure 3a-b were surface coverage ($\theta$) and inhibition efficiency (IE%) of Cu-Zn-Fe alloy increased with increase in inhibitor concentrations proving that the corrosion of the metal has been inhibited and a larger fraction of the surface is protected against alkaline attack [13, 16].

Figure 1. Variation of weight loss with immersion time for Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of *Solanum melongena* leaves.

Figure 2. Variation of weight loss with concentration for Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of *Solanum melongena* leaves.
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Table 1. Corrosion rates, surface coverage and inhibition efficiency for Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of Solanum melongena leaves.

| System       | CR (mg/cm²/hr) | θ   | IE%   |
|--------------|----------------|-----|-------|
| (Blank)      | 1.027          | -   | -     |
| 1.0 g/L      | 0.237          | 0.769| 76.9  |
| 1.5 g/L      | 0.189          | 0.816| 81.6  |
| 2.0 g/L      | 0.113          | 0.889| 88.9  |
| 2.5 g/L      | 0.096          | 0.907| 90.7  |
| 3.0 g/L      | 0.033          | 0.988| 98.8  |

CR= Corrosion rate  θ = Surface Coverage  IE% = Inhibition efficiency

Figure 3. Variation of (a) IE(%) and (b) CR with Conc. for Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of Solanum melongena leaves.

3.2 Effects of temperature on hydrogen gas evolution in Cu-Zn-Fe alloy inhibition

Table 2 revealed an inhibitor efficiency of 99.2 % > 88.4 % > 85.6 % as test was conducted between 303-323 K respectively, while in respect to increasing concentration, corrosion rate was found to be 1.718 (Blank) > 0.013 (303 K), 0.0192 (313K) and 0.247 (323K). The first scenario informed the gradual desorption of the weakly held inhibitor molecules on the Cu-Zn-Fe alloy surface due to strong increase temperature agitation from 303 to 323 K [12, 15, 16-20]. This decrease in inhibition efficiency with increase
temperature reveals a physical adsorption process [11-16]. The decrease in corrosion rate of Cu-Zn-Fe alloy as concentration increases explained the strong adsorption of the inhibitor molecules even at agitated temperatures [20-22] and all these present a good result for the synergistic inhibitor and a proof of its efficiency in controlling the corrosion of Cu-Zn-Fe alloy in hydrochloric acid medium. This has been summarized on the chart in Figures 4a-c.

**Figure 4.** Variation of weight loss with concentration for Cu-Zn-Fe Alloy in the presence and absence of root-leaves synergy extracts of *Solanum melongena* leaves.
Table 2. Corrosion rate, surface coverage and inhibition efficiency for Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of Solanum melongena leaves.

| Inhibitor Conc. (mg/cm²/min) | CR (mg/cm²/min) | θ (%) | IE (%) | CR (mg/cm²/min) | θ (%) | IE (%) | CR (mg/cm²/min) | θ (%) | IE (%) |
|-------------------------------|----------------|-------|--------|----------------|-------|--------|----------------|-------|--------|
| Blank                         | 1.718          | -     | -      | 1.718          | -     | -      | 1.718          | -     | -      |
| 1.0 g/L                       | 0.173          | 0.899 | 89.9   | 0.395          | 0.770 | 77.0   | 0.471          | 0.726 | 72.6   |
| 1.5 g/L                       | 0.099          | 0.942 | 94.2   | 0.375          | 0.782 | 78.2   | 0.471          | 0.770 | 77.0   |
| 2.0 g/L                       | 0.047          | 0.973 | 97.3   | 0.291          | 0.831 | 83.1   | 0.379          | 0.779 | 77.9   |
| 2.5 g/L                       | 0.022          | 0.987 | 98.7   | 0.276          | 0.839 | 83.9   | 0.348          | 0.797 | 79.7   |
| 3.0 g/L                       | 0.013          | 0.992 | 99.2   | 0.192          | 0.884 | 88.4   | 0.247          | 0.856 | 85.6   |

3.3 Thermodynamics

The temperature of the system was varied across the inhibitor concentrations from which the activation energy for the corrosion of Cu-Zn-Fe alloy in 1 M HCl was evaluated using the Arrhenius equation given by equation 3.

\[
\ln R_c = \ln A - \frac{E_a}{RT}
\]

where \( R_c \) is the corrosion rate, \( E_a \) is the apparent effective activation energy, \( R \) is the general gas constant, and \( A \) is the Arrhenius pre-exponential. Calculated values of Activation energy between 303 K and 323 K were obtained from the slope of Figure 5 and presented in Table 3. The values obtained in the inhibitor solution are greater than the value for the blank solution indicating that inhibitor retards the corrosion of Cu-Zn-Fe alloy in 1 M HCl solution [9, 13, 22-24]. Since the activation energy increased with inhibitor concentration, it implies that more energy has to be supplied to the system for the corrosion reaction to take place thus the observed decrease in corrosion rate [14, 22, 24-26]. The values are also consistent with the data expected for the mechanism of physical adsorption (<80 kJmol⁻¹) [17-21]. Enthalpy (\( \Delta H_{ads} \)), Entropy (\( \Delta S_{ads} \)) and Heat of adsorption (\( Q_{ads} \)) of Solanum melongena root-leaves extracts on Cu-Zn-Fe alloy were calculated using equations 4 (transition state equation) and 5 (for heat of adsorption equation),

\[
\frac{CR}{T} = \log \frac{R}{NR} + \frac{\Delta S}{2.303R} - \frac{\Delta H}{2.303RT} \log
\]

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\[ Q_{ads} = 2.303R \log \frac{\theta_2}{1-\theta_2} - \log \frac{\theta_1}{1-\theta_1} \times \frac{T_1 \times T_2}{T_2 - T_1} \text{ KJmol}^{-1} \]  

(5)

where \( Q_{ads} \) is the heat of adsorption, \( R \) is the universal gas constant, \( \theta_1 \) and \( \theta_2 \) are the degrees of surface coverage of the inhibitors at temperatures \( T_1 \) and \( T_2 \) respectively. From equation 4, values of \( \log(CR/T) \) were plotted against \( 1/T \) as shown in Figure 6 and from the slop and intercept of the plot, values of enthalpy and entropy of adsorption were calculated as shown in Table 3. From the calculated values of \( \Delta H^* \) (Table 3), it can be deduced that the adsorption of the inhibitor on Cu-Zn-Fe alloy surface is exothermic and the reaction becomes less exothermic with increase in inhibitor concentration [24-28]. The negative values of \( Q_{ads} \) indicated that the degree of surface coverage decrease with rise in temperature, supporting the earlier assumptions of physisorption mechanism for the inhibitor. The negative values for \( \Delta S^* \) shows the non-spontaneous dissolution of the Cu-Zn-Fe alloy and the increase in its values suggests decrease in disordering in the rate determining step [26-29].

| System   | Ea (kJ/mol) | \( \Delta H_{ads}^* \) (kJ/mol) | \( \Delta S_{ads}^* \) (kJ/mol) | \( Q_{ads} \) (kJ/mol) |
|----------|-------------|---------------------------------|---------------------------------|------------------------|
| Blank    | 6.9         | 66.9                            | -76.4                           | -                      |
| 1.0 g/L  | 10.0        | 74.5                            | -62.0                           | -36.10                 |
| 1.5 g/L  | 11.8        | 104.7                           | -35.9                           | -43.21                 |
| 2.0 g/L  | 11.8        | 104.7                           | -27.9                           | -44.14                 |
| 2.5 g/L  | 12.1        | 123.8                           | -24.1                           | -55.80                 |
| 3.0 g/L  | 14.1        | 131.3                           | -21.4                           | -72.65                 |

Table 3. Values of activation/thermodynamic parameters for carbon steel in 5 M Na₂CO₃ in the absence and presence of the plant extracts
Figure 5. Arrhenius plots for corrosion of Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of *Solanum melongena* leaves.

Figure 6. Transition state plots for corrosion of Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of *Solanum melongena* leaves.
3.4 Adsorption isotherm consideration

The surface coverage (θ) values for different concentrations of the inhibitors in 1 M HCl solutions was evaluated using gasometric data. The data were tested graphically to find a suitable adsorption isotherm to describe the adsorption characteristics of the extracts. A plot of Log(θ/C) against Log C (Figure 7) showed a straight line with regression coefficient of approximately unity (Table 4) indicating that adsorption followed the Langmuir adsorption isotherm [8, 15, 29-31]. The values for the equilibrium adsorption-desorption constant showed decrease with increasing temperature. This is an indication of good inhibition at lower temperatures hence a physical adsorption process just as indicated in Table 2 [22-23, 31-33]. The Gibbs free energy of adsorption values were negative and less than 20 kJ/mol indicating a physical adsorption, inhibitor stability and spontaneity at the forward reaction [31-34].

![Figure 7. Langmuir adsorption isotherm for corrosion of Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of Solanum melongena leaves.](http://www.earthlinepublishers.com)
Table 4. Adsorption parameters for corrosion of Cu-Zn-Fe alloy in the presence and absence of root-leaves synergy extracts of *Solanum melongena* leaves

| Temp. (K) | Equil. Const. $k$ (g/L) | Corr. Coef. $R^2$ | $\Delta G_{ads}^{\circ}$ (KJ/mol) |
|----------|-------------------------|-------------------|------------------|
| 303      | 0.8191                  | 0.9829            | -444.22          |
| 313      | 0.9773                  | 0.9737            | -318.40          |
| 323      | 1.4959                  | 0.9797            | -171.33          |

**Conclusion**

1. The percentage inhibition efficiency obtained from this experiment for corrosion inhibition of Cu-Zn-Fe alloy using synergy of root-leaves extracts of *Solanum melongena* leaves showed significant inhibition.

2. Inhibition was by adsorption of molecules of the combined extracts on the surface of the Cu-Zn-Fe alloy thereby retarding the anodic dissolution and cathodic hydrogen evolution.

3. Adsorption study reveals that the mechanism of adsorption follows Langmuir isotherm which implies a monolayer adsorption calculated from the correlation coefficient of 0.999 approximate.

4. Thermodynamic study reveals an inhibitor that was physical adsorbed, endothermic, stabled, spontaneous and with a very insignificant degree of disorderliness

**References**

[1] O. Benali, H. Benmehdi, O. Hasnaoui, C. Selles and R. Salghi, Green corrosion inhibitor: inhibitive action of tannin extract of *Chamaerops humilis* plant for the corrosion of mild steel in 0.5 M $\text{H}_2\text{SO}_4$, *J. Mater. Environ. Sci.* 4(1) (2013), 127-138.

[2] B.R. Fatemeh, M. Saeed and D. Athareh, Corrosion inhibition of mild steel in stimulated cooling water by blends of molybdate, nitrite and picrate as new anodic inhibitor, *Anti-corrosion Methods & Materials* 59(4) (2012), 182-189.

[3] K. Parameswari, S. Chitra, A. Selvaraj, S. Brindha and M. Menaga, Investigation of benzothiazole derivatives as corrosion inhibitors for mild steel, *Port. Electrochim. Acta* 30(2) (2012), 89-98. https://doi.org/10.4152/pea.201202089
[4] C.B. Pradeep Kumar and K.N. Mohana, Adsorption and thermodynamic characteristics of *Plumeria rubra* plant extracts on mild steel corrosion in industrial water medium, *International Research Journal of Pure & Applied Chemistry* 3(4) (2013), 330-346. https://doi.org/10.9734/IRJPAC/2013/5397

[5] R. Saratha and R. Meenakshi, Corrosion inhibitor: A plant extract, *Der Pharma. Chemica* 2(1) (2010), 287-294.

[6] T. He, W. Emori, R. Zhang, P.C. Okafor, M. Yang and C. Cheng, Detailed characterization of *Phellodendron chinense* Schneid and its application in the corrosion inhibition of carbon steel in acidic media, *Bioelectrochemistry* 130 (2019), 107332. https://doi.org/10.1016/j.bioelechem.2019.107332

[7] K. Boumhara, H. Harhar, M. Tabyaoui, A. Bellaouchou, A. Guenbour and A. Zarrouk, Corrosion inhibition of mild steel in 0.5 M H₂SO₄ solution by Artemisia herba-alba oil, *J. Bio. Tribo. Corros.* 5 (2019), Article No. 8. https://doi.org/10.1007/s40735-018-0202-8

[8] H.S. Gadow and M.M. Motawea, Investigation of the corrosion inhibition of carbon steel in hydrochloric acid solution by using ginger roots extract, *RSC Advances* 7(40) (2017), 24576-24588. https://doi.org/10.1039/C6RA28636D

[9] K.H. Hassan, A.A. Khadom and N.N. Kurshed, *Citrus aurantium* leaves extracts as sustainable corrosion inhibitor of mild steel in sulfuric acid, *South African J. Chemical Engineering* 22 (2016), 1-5. https://doi.org/10.1016/j.saajce.2016.07.002

[10] H. Louis, J. Japari, A. Sadia, M. Philip and A. Bamanga, Photochemical screening and corrosion inhibition of Poupartia birrea back extracts as a potential green inhibitor for mild steel in 0.5 M H₂SO₄ solution, *World News Nat. Sci.* 10 (2017), 100-112.

[11] V. Vorobyova and M. Skiba, A pricot pomace extract as a natural corrosion inhibitor of mild steel corrosion in 0.5 m NaCl solution: a combined experimental and theoretical approach, *Journal of Chemical Technology and Metallurgy* 55(1) (2015), 210-222.

[12] S.A. Umoren and M.M. Solomon Effect of halide ions on the corrosion inhibition efficiency of different organic species–a review, *J. Ind. Eng. Chem.* 21 (2015), 100-107. https://doi.org/10.1016/j.jiec.2014.09.033

[13] I.E. Uwah, B.U. Ugi, P.C. Okafor and A.I. Ikeuba, Comparative study of corrosion inhibition and adsorption characteristics of ethanol extracts of *Andrographis paniculata* (King bitters) and *Vernonia amygdalina* (Bitter leaf) on Mild Steel in HCl solution, *International Journal of Applied Chemistry* 9(1) (2013), 73-88.

[14] C. Sangeetha, Chinnakani and S. Selvaraj, *Jatropha gossypifolia* – A green inhibitor act as ant corrosive agent on carbon steel, *Journal of Advanced Scientific Research* 11 (2020), 1.
[15] K.A. Salima, B.A. Wassan and A.K. Anees, Synthesis and investigations of heterocyclic compounds as corrosion inhibitors for mild steel in hydrochloric acid, *International Journal of Industrial Chemistry* 10 (2019), 159-173. https://doi.org/10.1007/s40090-019-0181-8

[16] M. Abdallahal, S.O. Zaafarany, A.A. Al-Karanee, El-Fattaha, Antihypertensive drugs as an inhibitors for corrosion of aluminum and aluminum silicon alloys in aqueous solutions, *Arabian Journal of Chemistry* 5(2) (2012), 225-234. https://doi.org/10.1016/j.arabjc.2010.08.017

[17] M.T. Majd, M. Ramezanzadeh, B. Ramezanzadeh and G. Bahlakeh, Production of an environmentally stable anti-corrosion film based on *Esfand* seed extract molecules-metal cations: Integrated experimental and computer modeling approaches, *Journal of Hazardous Materials* 382 (2020), 1-16. https://doi.org/10.1016/j.jhazmat.2019.121029

[18] N.C. Ngobiri, E.E. Oguzie, Y. Li, L. Liu, N.C. Oforka and O. Akaranta, Eco-friendly corrosion inhibition of pipeline steel using *Brassica oleracea*, *International Journal of Corrosion* 2015 (2015), Art. ID 404139. https://doi.org/10.1155/2015/404139

[19] I.H. Ali and M. H.A. Suleiman, Effects of acid extract of leaves of Juniperus procera on corrosion inhibition of carbon steel in HCl solution, *Int. J. Electrochem. Sci.* 13 (2012), 3922.

[20] A.S. Fouda, M. Eissa and El-Hossiany, Ciprofloxacin as eco-friendly corrosion inhibitor for carbon steel in hydrochloric acid solution, *Int. J. Electrochem. Sci.* 13 (2018), 11096-11112. https://doi.org/10.20964/2018.11.86

[21] B.M. Prasanna, B.M. Praveen, H. Narayana, T.V. Venkatarangaiah and C.T. Harmesh, Ketosulfone drug as a green corrosion inhibitor for mild steel in acidic medium, *Ind. Eng. Chem. Res.* 53(20) (2014), 8436-8444. https://doi.org/10.1021/ie500232g

[22] D.A. Al-Shehri, Oil and gas wells: enhanced wellbore casing integrity management through corrosion rate prediction using an augmented intelligent approach, *Sustainability* 11(8) (2019), 1-18. https://doi.org/10.3390/su11030818

[23] Anees A. Khadom, Baker M. Abod, Hameed B. Mahood and Abdul Amir H. Kadhnum, Galvanic corrosion of steel-brass couple in petroleum waste water in presence of a green corrosion inhibitor: electrochemical, kinetics, and mathematical view, *Journal of Failure Analysis and Prevention* 18 (2018), 1300-1310. https://doi.org/10.1007/s11668-018-0525-2

[24] P.O. Ameh and N.O. Eddy, Theoretical and experimental studies on the corrosion inhibition potentials of 3-nitrobenzoic acid for mild steel in 0.1 M H$_2$SO$_4$, *Cogent Chemistry* 2 (2016), 1253904.
[25] A.S. Fouda, K. Shalabi and A. E-Hossiany, Moxifloxacin antibiotic as green corrosion inhibitor for carbon steel in 1 M HCl, *J. Bio. Tribo. Corros.* 2 (2016), Article 18. https://doi.org/10.1007/s40735-016-0048-x

[26] P.O. Ameh and N.O. Eddy, Experimental and computational chemistry studies on the inhibition efficiency of phthalic acid (PHA) for the corrosion of aluminum in hydrochloric and tetraoxosulphate (VI) acids, *Protection of Metals and Physical Chemistry of Surfaces* (2018), 1-13.

[27] P.R. Ammal, M. Prajila and A. Joseph, Effective inhibition of mild steel corrosion in hydrochloric acid using EBIMOT, a 1,3,4-oxadiazole derivative bearing a 2-ethbenzimidazole moiety: Electro analytical, computational and kinetic studies, *Egyptian Journal of Petroleum* 27 (2018), 823-833. https://doi.org/10.1016/j.ejpe.2017.12.004

[28] K.F. Khaled and N.A. Al-Mobarak, A predictive model for corrosion inhibition of mild steel by thiophene and its derivatives using artificial neural network, *Int. J. Electrochem. Sci.* 7 (2012), 1045-1059.

[29] G.A. Cookey, B.L. Tambari and D.S. Iboroma, Evaluation of corrosion inhibition potentials of green tip forest lily (*Clivia nobilis*) leaves extract on mild steel in acid media, *Journal of Applied Sci. Env. Mgt.* 22 (1) (2018), 90-94. https://doi.org/10.4314/jasem.v22i1.16

[30] O. Dagdag, A. El Harfi, O. Cherkaoui, Z. Safi et al., Rheological, electrochemical, surface, DFT and molecular dynamics simulation studies on the anticorrosive properties of new epoxy monomer compound for steel in 1 M HCl solution, *RSC Advances* 9 (2019), 4454-4462. https://doi.org/10.1039/C8RA09446B

[31] A. Singh, E.E. Ebenso and M.A. Quraishi, Theoretical and electrochemical studies of Metformin as corrosion inhibitor for mild steel in hydrochloric acid solution, *Int. J. Electrochem. Sci.* 7 (2012), 4766-4779.

[32] A. Singh, V.K. Singh and M.A. Quraishi, Inhibition effect of environmentally benign Kuchla (*Strychnos Nuxvomica*) seed extract on corrosion of mild steel in hydrochloric acid solution, *Rasayan J. Chem.* 3(4) (2010) 811-824.

[33] I.E. Uwah, A.I. Ikeuba, B.U. Ugi and V.M. Udowo, Comparative study of the inhibition effects of alkaloid and non-alkaloid fractions of the ethanolic extracts of *Costus afer* stem on the corrosion of mild steel in 5 M HCl solution, *Global Journal of Pure & Applied Sciences* 19(1) (2013), 23-31. https://doi.org/10.4314/gjpas.v19i1.4

[34] I.E. Uwah, B.U. Ugi, A.I. Ikeuba and K.E. Etuk, Evaluation of the inhibitive action of eco-friendly benign *Costus afer* stem extract of mild steel in 5 M HCl solutions, *International Journal of Development & Sustainability* 2(3) (2013), 1970-1981.