

# EFFECT OF BASICITY ON ELECTROCHEMICAL CORROSION BEHAVIOUR OF *ENANTIA CHLORANTHA* ON THE CORROSION OF MILD STEEL IN ACID ENVIRONMENTS.

## ABSTRACT

The effects of *Enantiachlorantha* (ET) stem bark ethanoic extract on the corrosion of Mild steel in acids environment and acid basicity to concentration ratio on the electrochemical corrosion behavior of *Enantiachlorantha* on mild steel in acid environments was studied using electrochemical techniques. The results showed that ET is a good inhibitor of Mild steel corrosion acids media. The Potentiodynamic polarization results showed *Enantiachlorantha* (ET) stem bark ethanoic extract to act as a mixed type corrosion inhibitor while the Electrochemical Impedance results showed the extract increased the charge transfer resistance and increased the double layer capacitance, attributing the corrosion inhibition process of *Enantiachlorantha* (ET) stem bark ethanoic extract to adsorption of its molecules on the Mild steel/acid interface. However, it was concluded that the basicity of the acid is an important factor on the inhibition performance. Hence need to balance it in order to achieve desired corrosion inhibition targets.

**KEYWORDS:** Acids, Adsorption. Corrosion Inhibition. Electrochemical, *Enantiachlorantha*, Mild steel.

## 1.0 INTRODUCTION

Environmental degradation occasioned by chemical pollution has become the bane of many climes. An estimate of about 18.3 % of global GDP is lost to air pollution alone [1-3]. A major consequence of chemical-aided environmental degradation is electrochemical corrosion. The consequences of electrochemical corrosion include deterioration of environmental aesthetics with great negative economic impact. Also, the industry suffers a huge economic loss due to chemical-aided corrosion. A typical example is the material loss due to acid pickling of petroleum pipelines. Though corrosion is thermodynamically inevitable, they have been appreciable progress in mitigation measures [4-7]. The application of corrosion inhibitors is a good example of a corrosion mitigation technique. Most synthetic inhibitors are toxic to humans and the environment [6-7].

However, a major undesirable impact of some synthetic corrosion inhibitors is the negative environmental consequences when they finally end up in the environment and are expensive and non-renewability. These have led to the search into the application of natural resources such as Phyto-substances as corrosion inhibitors [4-5]. Plant extracts are majorly green, cheap, and renewable. These extracts have varying degrees of corrosion inhibition performance depending on the physical and chemical environmental characteristics of the corrosive environment.

Most municipal and industrial environments are acidic in nature because their effluents are acidic in nature ranging from acidic gaseous products of combustion - carbon dioxide, carbon monoxide, and sulfur dioxide, and also discharges such from pipeline acid pickling.

The choice of acid when the need for its application arises must be based on scientific insight into the efficacy of the corrosion inhibitor to chosen acid as well as acid efficacy. The two common types of acids are sulphuric acid and hydrochloric acid. A major difference between acids is their basicity, which is a determinant of their acidic strength. Hence the need to investigate basicity's impact on green corrosion inhibitors' corrosion inhibition potentials. This will equally contribute to the baseline guiding the application of acids in industrial operations such as acid pickling.

Interestingly, Phyto green corrosion inhibitor's corrosion inhibition potentials have been attributed to the adsorption of natural product chemicals to the metallic substrate [3-7]. These classes of the chemical have been severally reported to also have medicinal properties. *Enantiachlorantha* is one medicinal plant with potential corrosion-inhibiting chemicals. Some of the phytochemicals in *Enantiachlorantha* are Phenolics, Flavonoids, Alkaloids, Glycosides, Sponins, Phlobatannins, Steroids. These compounds have adsorption active functionalities with potential corrosion inhibition characteristics.

Hence, this paper reports the studies on electrochemical corrosion characteristics of *Enantiachlorantha* on the corrosion of mild steel in a mono basic hydrochloric acid and a dibasic tetraoxosulphate vi acid.

## **2.0 MATERIALS AND METHOD**

### **2.1 Material preparation**

#### **Extract**

The bark of *Enantiachlorantha* was obtained from traditional medicine dealers and characterized by the Plant science department, University of Port Harcourt, Nigeria. They were cut into the smallest possible pieces and allowed to dry under the sun for three days. The dry stems were further broken down with a sterile sharp knife before being pulverized in a blender. About 500 g blended *Enantiachlorantha* stem bark was packed in a 1000 ml volumetric flask and 95 % ethanol was added to sufficiently cover the substrate surface. The set-up was allowed to stabilize, soak and extract for 60 hours. After which, it was decanted and filtered. The ethanol solvent was separated from the extract using a rotary evaporator. The extract was further dried using a thermo-stated water bath at 30 °C to a thick paste. The extracts were then used to prepare serial diluents of extract in 0.5 M H<sub>2</sub>SO<sub>4</sub> and 1.0 M HCl solutions.

#### **Metal coupons**

The metal coupons were obtained from the Engineering workshop, at the University of Port Harcourt. They were mechanically cut into 1 × 1 cm<sup>2</sup> shapes, and polished with 200 – 2000 grade SiC paper, under distilled water. They were thereafter rinsed with absolute ethanol,

acetone and dried in warm air. The ready coupons were stored in an active desiccator till, it was used as working electrode in the electrochemical set-up. The preparation was according to Ngobiriet *al.*, 2021 [9]

### Solution Preparation

The corrosive medium was prepared as serial diluents of 0.0 to 2.0 g/L BL extract in 0.5 and 1.0 M, H<sub>2</sub>SO<sub>4</sub> and HCl respectively.

## 2.2 Electrochemical experiments

The electrochemical studies were conducted with a VersaSTAT 400 complete DC voltameter and corrosion system with V3 studio software from Princeton applied research. The set up comprised a three-electrode system. The prepared mild steel coupon was the Working electrode facing the rectangular 2 X 2 cm<sup>2</sup> platinum foil that served as the Counter electrode, while a Saturated calomel electrode was used as the Reference electrode. The working electrode was encapsulated with epoxy resin to expose only 1 cm<sup>2</sup>. The experiments were conducted in an open, aerated, and unperturbed cell. The experiments were carried at open circuit potential (OCP) after 30 minutes at a temperature of 303 ± 1<sup>0</sup> K. The determinations were repeated to triplicate reproducible results and the mean value was recorded for further analysis.

### 2.2.1 Potentiodynamic polarization (PDP) determination

The potentiodynamic polarization (PDP) experiments were done at a cathodic potential of -250 mV to an anodic potential of +250 mV vs OCP at a scan rate of 0.333 mV s<sup>-1</sup>. The PDP parameters were extrapolated to obtain the corrosion current density (I<sub>corr</sub>), equilibrium corrosion potential (E<sub>corr</sub>), and other Tafel parameters. The Corrosion Inhibition efficiency (ηE) was evaluated using I<sub>corr</sub> values by applying the equation 1: -

$$\eta E (\%) = \frac{I_{corr}^0 - I_{corr}^i}{I_{corr}^0} \times 100 \dots\dots\dots \text{equation 1}$$

I<sub>corr</sub><sup>0</sup> and I<sub>corr</sub><sup>i</sup> are corrosion current densities in the uninhibited and inhibited cells respectively.

### 2.2.2 Electrochemical impedance spectroscopy (EIS) determinations

The electrochemical impedance spectroscopy (EIS) experiments were conducted at open circuit potential over a frequency range of 100 kHz to 10 mHz using a signal of 5 mV amplitude. The corrosion inhibition efficiency was determined using the charge transfer resistance (R<sub>ct</sub>) with the equation:

$$\eta E (\%) = \frac{R_{cti} - R_{ct}}{R_{cti}} \times 100 \dots\dots\dots \text{equation 2}$$

$R_{cti}$  and  $R_{ct}$  are the charge transfer resistance with and without BL extract respectively.

### 3.0 RESULTS AND DISCUSSION

#### 3.1 Potentiodynamic polarization (PDP) determination of the Effects of *Enantiachlorantha* (ET) stem ethanoic extract (ET) on the corrosion of mild steel in 0.5 M $H_2SO_4$ and 1.0 M HCl environments

The electrochemical potentiodynamic polarization experiments of the effects of *Enantiachlorantha* (ET) stem ethanoic extract (ET) on the corrosion of mild steel in 1.0 M HCl and 0.5 M  $H_2SO_4$  environments are presented in Figures 1, i and ii respectively. While Table 1 presents the electrochemical corrosion parameters in both environments. In order to compare the effects of acid strength on the corrosion inhibition process, 0.5 and 1.0 molar solutions of sulfuric and hydrochloric acids were used. This is to balance their basicity and theoretically balance their strength for a good comparison. ET exhibited significant and comparable inhibition of the corrosion of mild steel in both acids by decreasing the corrosion current density. This observation was more manifest at the lower concentration of 0.5 g/L ET. The inhibitor affected both the anodic and cathodic arms at the same acid strength. Consequently, *Enantiachlorantha* can be described as a mixed-type corrosion inhibitor [10] irrespective of the basicity or strength of the acid.

The values of the calculated corrosion inhibition efficiency were 37.7 % and 89.5 % in 1.0 M HCl, 41.9 % and 89.1 % in 0.5 M  $H_2SO_4$  when 0.5 g/L and 2.0 g/L ET were introduced into both systems respectively. There was an increase in corrosion inhibition efficiency with an increase in the concentration of the inhibitor in both acids. This trend has been severally reported [9-12]. Interestingly, both acids showed comparable efficiencies with no clear difference at varying concentrations of the additive and the same acid basicity. This is attributable to the balancing of the acid strength of a monobasic and a dibasic acid by doubling the concentration of the monobasic HCl. The blank cells showed active dissolution and consequent evolution of hydrogen gas, there was no indication of a passive region within the studied region in Figures 1 and 2.



From the above results, it can be assumed that that basicity rather than the type of acid affects corrosion. In other words, the cation in the acid affects corrosion and its inhibition than the anionic component of an acid.

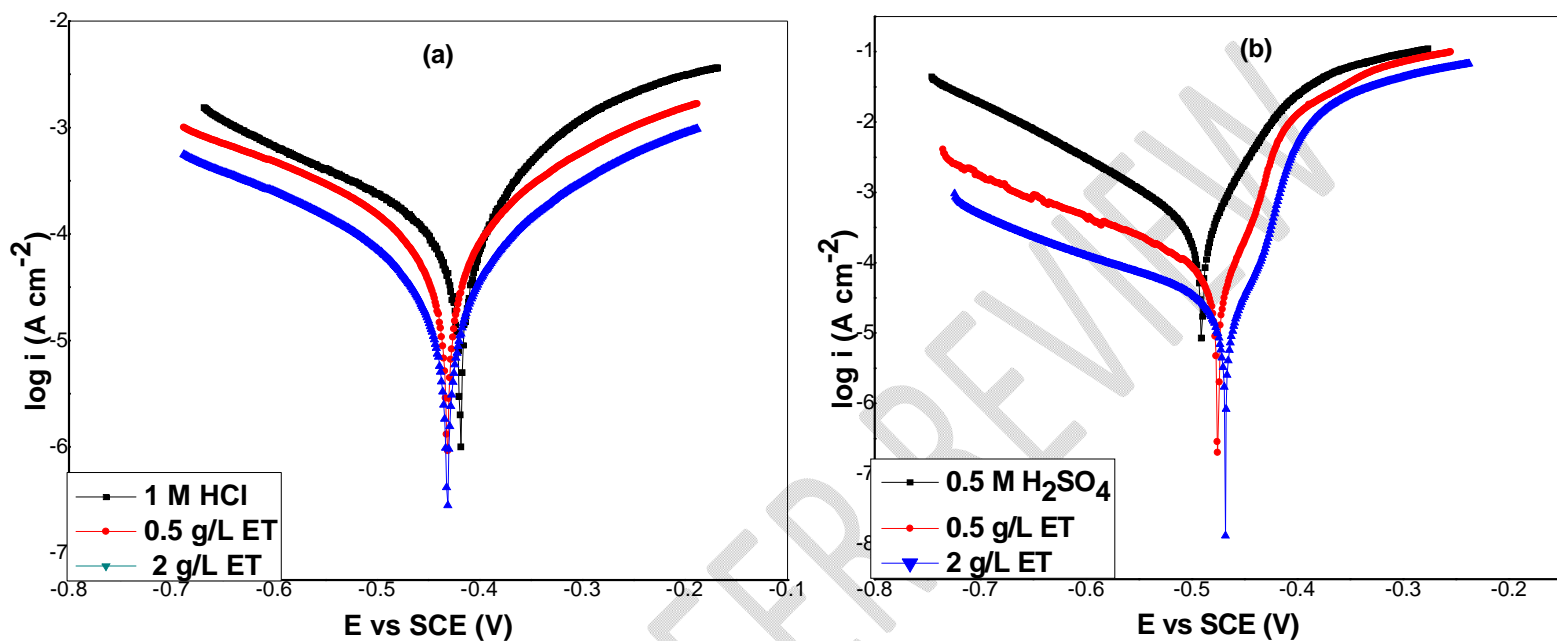


Figure 1. Potentiodynamic polarization curves of mild steel in: (i) 1 M HCl and (ii) 0.5 M H<sub>2</sub>SO<sub>4</sub> solutions without and with ET extract.

Table 1: Potentiodynamic Polarization Parameters for Mild Steel in 1 M HCl and 0.5 M H<sub>2</sub>SO<sub>4</sub> in the Absence and Presence of BL extract.

System	E <sub>corr</sub>	I <sub>corr</sub>	IE (%)
1 M HCl	<b>-566.4</b>	<b>183</b>	
0.5 g/L ET	-454.9	125.1	31.7
2 g/L ET	-456.9	19.3	89.5
0.5 M H <sub>2</sub> SO <sub>4</sub>	<b>-496.4</b>	<b>1340</b>	
0.5 g/L ET	-478.6	778.9	41.9
2 g/L ET	-489.2	115.4	89.1

### 3.2 Electrochemical Impedance Spectroscopy (EIS) determination of the Effects of *Enantiachlorantha* (ET) stem ethanoic extract (ET) on the corrosion of mild steel in 0.5 M H<sub>2</sub>SO<sub>4</sub> and 1.0 M HCl environments

Researchers have applied the electrochemical impedance of corrosion inhibitors to detect the formation of surface films on a metallic surface. This is evident when the solution resistance increases and the double-layer capacitance decreases [9,12,14]. The electrochemical corrosion characteristics of *Enantiachlorantha* (ET) stem bark ethanoic extract (ET) on the corrosion of mild steel in 1.0 M HCl and 0.5 M H<sub>2</sub>SO<sub>4</sub> environments are presented in Figure 2 (i) and (ii) respectively, on the acid-mild steel interface for the corrosion of mild steel in mono and dibasic acid environments. Figure 2 is Nyquist plots, with depressed capacitive semicircles in the high-frequency region corresponding to a single time constant. The depression at the center of the real axis is characteristic of solid electrodes that exhibit frequency depression. This observation has been severally reported by Researchers [5, 15-16]. It is noteworthy that, the shape of capacitive loops is similar both in the cell with ET and without ET, suggesting that the presence of ET does not alter the corrosion mechanism. The cell has two resistances, solution resistance ( $R_s$ ) and charge transfer resistance ( $R_{ct}$ ). Since the semicircles are similar in shape with different solution resistance. It could be inferred that the corrosion inhibition process is controlled by the solution resistance. If the transfer function is represented by the solution resistance shorted by a capacitor C which is parallel to charge transfer resistance, equation 5. This applies primarily to homogenous systems with one time constant and the center of the semicircle lying on the abscissa, unable to explain the depression of the semicircular capacitive loop. If a non-ideal frequency response occurs, the capacitor is exchanged with a constant phase element (CPE) with impedance  $Z_{CPE}$ , equation 6 [5, 17 - 18].

$$Z(\omega) = R_s + \left( \frac{1}{R_{ct}} + j\omega C \right)^{-1} \dots\dots\dots \text{equation 5}$$

$$Z_{CPE} = Q^{-1}(j\omega)^{-n} \dots\dots\dots \text{equation 6.}$$

Where Q and n represents constant phase element and exponent respectively while  $j = (-1)^{1/2}$  is an imaginary number,  $\omega$  is the angular frequency in rad s<sup>-1</sup> ( $\omega = 2\pi f$ , where f is frequency in Hertz).

It is noteworthy that, *Enantiachlorantha* (ET) stem bark ethanoic extract (ET) raised the charge transfer resistance from the uninhibited to the inhibited cell and consequent decrease in  $C_{dl}$  values. As earlier stated, this observation has been previously reported [9]. A physical observation reveals an increase in the diameter of the Nyquist semicircles translating to higher impedance in the inhibited cell by ET. This reveals the obvious corrosion inhibition character of *Enantiachlorantha* (ET) stem bark ethanoic extract (ET). While the decrease in the  $C_{dl}$  value indicates decrease in dielectric constant or increase double layer thickness caused by adsorption of inhibitor molecules at the metal/acid interface [14].

The corrosion electrochemical impedance spectroscopic parameters of ET ethanoic extract on Mild steel in multi-basic solutions are presented in Table 2. The values of the corrosion inhibition efficiency were calculated from equation 2, and presented in Table 2. The values obtained showed an increase as the concentration of ET was increased. The trend has been severally reported [19 – 20].

### ELECTROCHEMICAL IMPEDANCE SPECTROSCOPY

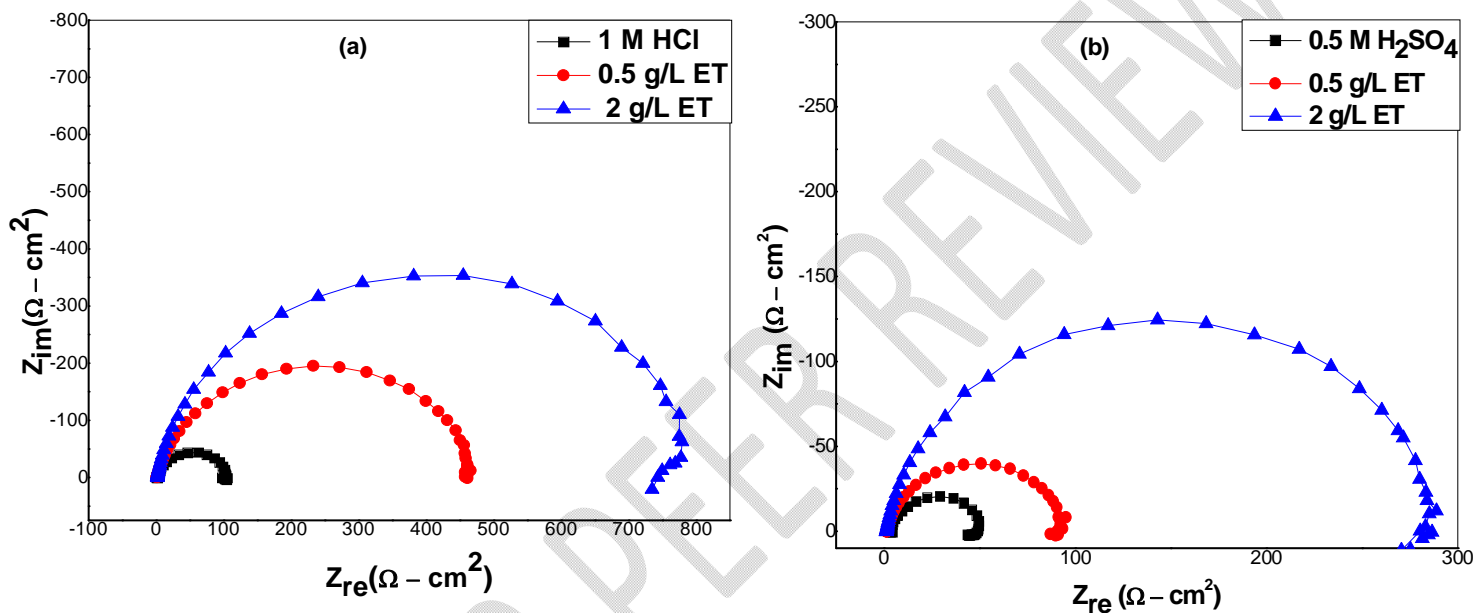


Figure 2: Electrochemical impedance spectroscopy for Mild steel in (i) 1 M HCl and (ii) 0.5 M H<sub>2</sub>SO<sub>4</sub> in the absence and presence of ET extract.

Table 2: Electrochemical Impedance Spectroscopy EIS, results for mild steel corrosion in 1 M HCl and 0.5 M H<sub>2</sub>SO<sub>4</sub> in the Absence and Presence of ET extract.

System	R <sub>s</sub> (Ω cm <sup>2</sup> )	R <sub>ct</sub> (Ω cm <sup>2</sup> )	N	C <sub>dl</sub> (F cm <sup>-2</sup> )	IE (%)
1 M HCl	<b>1.659</b>	<b>100.2</b>	<b>0.89</b>	<b>6.918E-5</b>	
0.5 g/L ET	2.001	451.3	0.88	7.094E-5	77.7
2 g/L ET	1.823	762.2	0.88	7.075E-5	87.0
0.5 M H <sub>2</sub> SO <sub>4</sub>	<b>2.173</b>	<b>50</b>	<b>0.89</b>	<b>3.649E-5</b>	
0.5 g/L ET	3.439	96.2	0.89	2.556E-5	48.3
2 g/L ET	4.16	278.4	0.88	2.178E-5	82.2

The Corrosion inhibition efficiency increased from 77.7 % to 87.0 % when the concentration of ET increased from 0.5 to 2.0 g/L in 1 M HCl while 0.5 M H<sub>2</sub>SO<sub>4</sub> the inhibition efficiency increased from 48.3 % to 82.2 %. This trend was similar to that of the PDP experiments and that of HCl in EIS experiments, except for the H<sub>2</sub>SO<sub>4</sub> experiment. This could be attributed to the greater adsorption of molecules of ET on the Mild steel surface.

Importantly, the basicity of acids determines their corrosion ferocity independent of the acid type. So, whether HCl or H<sub>2</sub>SO<sub>4</sub> is used for an industrial operation like Oil pipeline pickling. A similar result is expected, in as much the basicity to concentration ratio is balanced.

## CONCLUSION

This study examined the corrosion inhibition efficacy as well as the effect of basicity to acid concentration ratio, to corrosion and corrosion inhibition efficiency of ET ethanoic extract on the corrosion of Mild steel in a multi-basic acids environment. The results showed that ET exhibited a good corrosion inhibition of steel corrosion acids media. However, the basicity of the acid is an important factor on the corrosion inhibition performance. Therefore, they is need to balance the basicity to acid concentration ratio, in order to achieve desired inhibition targets. The ET extract exhibited mixed inhibition characteristics, while the mechanism of corrosion inhibition was attributed to adsorption of the molecules of *Enantiachlorantha* (ET) stem bark ethanoic extract on the metal/acid interface.

## REFERENCES

1. “World Bank. 2022. The Global Health Cost of PM2.5 Air Pollution: A Case for Action Beyond 2021. International Development in Focus; Washington, DC: World Bank. © World Bank. <https://openknowledge.worldbank.org/handle/10986/36501> License: CC BY 3.0 IGO.” URI <http://hdl.handle.net/10986/36501> , 43
2. Adesuyi, AA, Nnodu, VC, Akinola, MO, Njoku, KL, and Jolaoso, AO. (2015). Groundwater Quality Assessment in Elioizu Community, Port Harcourt, Niger Delta, Nigeria. International Journal of Scientific and Technology Research Vol. 4 (12).
3. Andreas K, Kay H, and Thomas P. (2019). Cadmium Background Levels in Groundwater in an Area Dominated by Agriculture. Integrated Environmental Assessment and Management, vol. 16(1): 103 – 113.
4. Anuchi, SO and Ngobiri, NC, Corrosion Inhibition of Mild Steel in a H<sub>2</sub>SO<sub>4</sub> solution by Piper Guineense squeezed extract. PortugaliaeElectrochimica Acta 2018, 36(4), 285-291.
5. Oguzie, EE, Chidiebere, MA, Oguzie, KL, Adindu, CB. Momoh-Yahaya, H. Biomass extract for material protection: Corrosion inhibition of mild steel in acidic media by Terminalia chebula extracts, Chem Eng. Comm. 2014, 790 – 803.
6. Sanni, O, Loto, CA, Popoola, API. Effect of ferrous gluconate inhibition on the electrochemical behaviour of mild steel in 3.5% NaCl. Int. J. Electrochem. Sci., 2013, 8, 5506–5514.
7. Njoku, DI; Okafor, PC; Gaz, H; Uwakwe, KJ.; Oguzie, EE; Li, Y. Outstanding anti-corrosion and adsorption properties of 2-amino-6-methoxybenzothiazole on Q235 and X70 carbon steels: Effect of time, XPS, electrochemical and theoretical considerations. Journal of Molecular Liquids, 2021, 324, 114663.
8. Adesokan AA, Yakubu MT, Owoyele BV, Akanji MA, Soladoye AO, Lawal, OK, African Journal of Biochemistry Research Vol 2 (7) 165-169, 2008. **Phytochemical and acute toxicity of ethanolic extract of Enantiachlorantha (oliv) stem bark in albino rats** Olamide E Adebisi<sup>1</sup>, Mathew O Abatan Interdiscip Toxicol 2013 6 (3), 145-151.
9. Ngobiri, NC., Li, Y, Liu, L. Corrosion Inhibition and Electrochemical behavior of Commercial Rutin in Acidic environment. PortugaliaeElectrochimica Acta 2021, 39. 323-334.
10. Agiriga EC, Oguzie EE, Chidiebere A, Okorochoa JN, Chikwe RN. Corrosion Inhibition action of *Landolphia heudelotii* on Mild steel in Acidic media. Pigment and Resin Technology 2020,
11. Abd El-Aziz Fouda, S.; A. Samir Abd El-Maksoud, A.; Elsherbiny El-Sayed, H.; Hazem Elbaz, A.; Ashraf Abousalem, S. Experimental and surface morphological studies of corrosion inhibition on carbon steel in HCl solution using some new hydrazide derivatives RSC Adv., 2021, 11, 13497.
12. Ji, G; Shukla, SK; Ebenso, EE, Prakash, R. Argemone mexicana leaf extract for inhibition of mild steel corrosion in sulphuric acid solutions. International Journal of Electrochemical Science, 2013, 8, 10878-10889, 2013.
13. Hong, SY, Kiew, PL. The Inhibitive and Adsorptive Characteristics of Orange Peel Extract on Metal in Acidic Media. Progress in Energy and Environment, 2019, 11, 1-14.
14. Johnsirani V, Sathiyabama J, Rajendran S, Suriya Inhibitory mechanism of Carbon steel corrosion in seawater by an aqueous extract of Heena leaves. ISRN Corrosion 2012, 9.

15. Khaled, K. F. Monte carlo simulations of corrosion of mild steel in 0.5 M sulphuric acid by some green corrosion inhibitors, *J. of solid state electrochem*, 2009, 13, 1743-1756.
16. Popova, A.; Sokolova, E.; Riacheva, S.; Christove, M. AC and DC study of the temperature effect on mild steel corrosion in acid media in the presence benzimidazole derivatives, *Corros. Sci.* 2003, 45, 35 – 58.
17. Moretti, G.; Guidi, F.; Gron. G. Tryptamine as a green corrosion inhibitor in 0.5 M deaerated sulphuric acid, *Corros.* 2004, 46, 378 – 403.
18. Opusunju UE, Ngobiri NC. Electrochemical Corrosion Behavior of Vernonia Amygdalina on Mild in Acid Environments. *Chemical Science and Engineering Research, Ariviyal* 2022, 4 (10) 54 – 57.
19. Okafor, PC.; Zheng, Y. Synergistic inhibition behavior of methyl quaternary imidazoline derivative and iodide ions on mild steel in H<sub>2</sub>SO<sub>4</sub> solutions. *Corrosion Science*, 2009, 51, 850-(852)859.
20. Singh, AK; Quraishi, MA. Study of some Bidentate Schiff bases of Isatin as corrosion inhibitors for mild steel in hydrochloric acid solution. *Int. J. Electrochem. Sci.* 2012, 7, 3222 (3226) 3241.