



Studies on the Corrosion Inhibition of Ethanol Extract of *Newbouldia Laevis* Stem Bark and Leaf on Mild Steel in Acidic Medium

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Abstract Numerous failures and eventual losses in the chemical industry have been traced to corrosion processes. Failures resulting from the inability of metals to support designed load requirements because of losses imposed by corrosion effects can be combated economically through the use of chemical inhibitors. Despite the fact that inhibitors are effective, they are associated with problems of toxicity, disposal, litigation and enormous costs. In order to protect the environment and reduce cost, the use of green inhibitors as substitutes and partial replacement of chemical inhibitors have become a method of choice. In this study, ethanol extracts of stem bark and leaf of *Newbouldia laevis* were employed on mild steel samples corroded in 0.5M hydrochloric acid solution in the absence and presence of varying concentrations of the extracts (inhibitors). Weight loss data was recorded after six hours out of which the highest inhibition efficiency was 85 % at 309K for stem bark extract and 76.70% at 309 K for the leaf extract. The trend depicted chemisorption process and fits into Langmuir, Temkin and Adejo-Ekwenchi adsorption isotherms.

Keywords weight loss method, green corrosion inhibitors, *Newbouldia laevis*

Introduction

Hydrochloric acid solution is commonly used for the removal of undesirable scale and rust in metalworking processes, cleaning of boilers, and heat exchangers [1, 2]. To prevent the metal dissolution and acid consumption during these processes, inhibitors are often used.

Metal depletion due to corrosion has become an essential engineering problem. Perhaps, no other source of waste except that disturbing human life is of greater concern to all. It has well been said that only through the elimination of waste caused by corrosion and the increase in our national efficiency we can hope to lower the cost of living on one hand, and raise our standard of living on the other. The elimination of waste is a total asset; it has no liabilities [3-5].

Corrosion studies might give insight into its kinetics so as to enable the prediction of the service life of equipment thereby indicating the environmental control for which a particular metal may be satisfactorily used [6, 7]. The present work was designed as a contribution to the growing interest on environmentally benign corrosion inhibitors to study (i) corrosion inhibition of mild steel in acid media using weight loss technique at a temperature range of 301 K to 317 K, (ii) to evaluate the activation energy, heat of adsorption process as well as determining the best adsorption isotherm for the adsorption of the extracts of *Newbouldia laevis* stem bark and leaf on mild steel surface.

Materials and Methods

Materials

Mild steel rods were procured and taken to the Department of Mechanical Engineering, University of Agriculture, Makurdi-Nigeria, where they were mechanically press-cut to form different coupons, each of dimensions $2.0 \times 2.0 \times 0.35$ cm with a tiny hole drilled at the edge of each for the purpose of suspension in the corrodant. The surfaces of the coupons were thoroughly polished to mirror finish using sand paper, degreased by washing with ethanol, dried with acetone, and preserved in a desiccator. Subsequently, the coupons were weighed and made ready for analysis. All reagents used were of analytical grade and the water used for preparation was distilled.

Methods

Newbouldia laevis stem bark and leaf were harvested, shed-dried for four weeks, pounded with mortar and pestle and soaked in absolute ethanol for 48 hours, with occasional shaking and filtered, thereafter, using a cotton wool. The ethanol was evaporated from the filtrate in a thermostated water bath at about 321 K and the residue preserved in a desiccator. A 0.5 M HCl was prepared and used as blank. The extract so obtained was then used to prepare solutions of 0.1, 0.2, 0.3, 0.4, and 0.5 gdm⁻³ in the 2 M HCl, respectively [8-15].

Weight Loss Measurement

The method adopted was that reported by scholars in [5,16].

Weight loss was evaluated using,

$$W = W_i - W_f \quad (1)$$

where W is the weight loss of the coupon, W_i the initial weight and W_f the weight after retrieval. Each reading reported is an average of three experimental readings recorded to the nearest 0.001 g. The inhibition efficiency was calculated using the formula,

$$\% \text{ I.E} = \left[1 - \frac{W_1}{W_2} \right] \times 100 \quad (2)$$

Where W_1 and W_2 are the weight losses in grams of mild steel coupon in the presence and absence of the inhibitor in the acid solution at the same temperature respectively. The degree of surface coverage, θ , was evaluated by the equation (3) [5, 17]

$$\theta = 1 - \frac{W_1}{W_2} \quad (3)$$

The corrosion rate of the mild steel coupons was determined for the immersion period from weight loss using equation (4)

$$\text{Corrosion rate (mg/cm}^2\text{/h)} = \frac{W_L}{At} \quad (4)$$

where W_L is the weight loss in milligrams (mg), A , the coupon surface area in cm² and t the immersion time in hours [6]

Using the Arrhenius equation (equation 5), values of E_a were obtained [3, 18].

$$\ln CR = \ln A + \frac{E_a}{RT} \quad (5)$$

An alternative formula of Arrhenius equation is:

$$\ln \left(\frac{CR}{T} \right) = \ln \left(\frac{R}{Nh} \right) + \frac{\Delta S^*}{R} - \frac{\Delta H^*}{RT} \quad (6)$$

Where h is plank's constant, N the Avogadro's number, ΔH^* is the enthalpy of activation and ΔS^* the entropy of activation. A plot of $\ln \left(\frac{CR}{T} \right)$ versus $\frac{1}{T}$ gave a straight line with a slope of $-\frac{\Delta H^*}{RT}$ and an intercept of $\ln \left(\frac{R}{Nh} \right) + \frac{\Delta S^*}{R}$ from where the values of ΔH^* and ΔS^* were calculated.

The values of heat of adsorption Q_{ads} were evaluated using equation 7 below;

$$\log \left(\frac{\theta}{1-\theta} \right) = \log A + \log K - \frac{Q_{ads}}{2.303 R} \left(\frac{1}{T} \right) \quad (7)$$



where θ is the degree of surface coverage, R is the molar gas constant, T is the absolute kelvin temperature, and A is a temperature independent factor. Values of heat of adsorption were obtained from the slope ($\frac{-Q_{ads}}{2.303R}$) of a plot of $\log\left(\frac{\theta}{1-\theta}\right)$ against $\frac{1}{T}$.

Values of ΔG_{ads} were evaluated using equation 3.8, where $K = \frac{\theta}{(1-\theta)C}$

$$\Delta G = -RT \ln(55.5K) \quad (8)$$

Results and Discussion

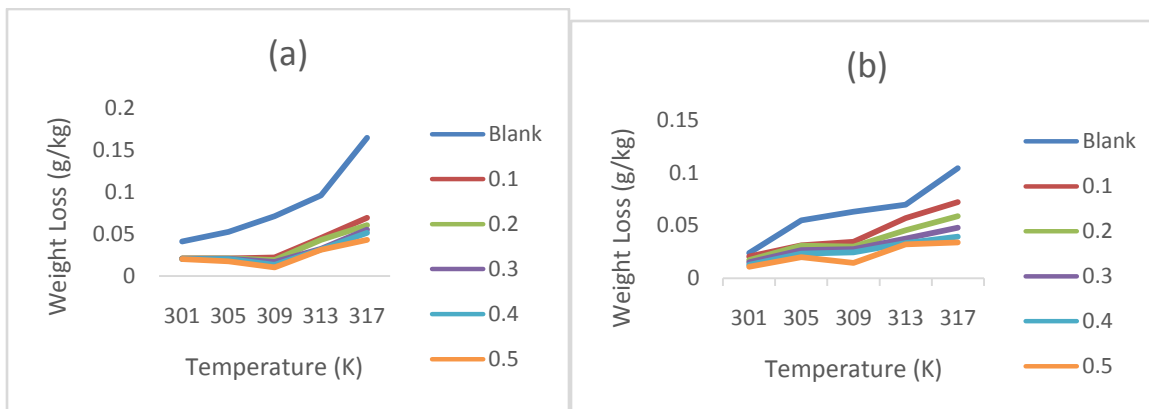


Figure 1: Weight loss (g) in the presence and absence of (a) *New bouldia laevis* stem extract (b) *New bouldia laevis* leaf extract

Figure 1 (a) and (b) depicts the results of weight loss for the corrosion of mild steel in acid medium in the absence and presence of different concentrations of *Newbouldia laevis* stem bark and leaf extracts (inhibitor) with time at different temperatures respectively. The results show that both stem bark and leaf extracts of the plant inhibited the corrosion of mild steel in acidic medium since there was a general decrease in weight loss in comparison with the blank. It was observed that the inhibitors minimized the loss in weight of mild steel coupons and the reduction was proportional to both inhibitor concentration and temperature. At each studied temperature, the weight loss of the metal without the inhibitor was highest.

Tables 1 and 2 show that inhibition efficiency for both extracts increased with increase in the concentration of the inhibitor and temperature; the highest inhibition efficiency was 96.30 % for stem bark and 94.67 % for leaf extracts obtained at concentration of 0.5 g/dm³ and at 317 K each, while the least value of 8.66 % was found for leaf and 48.91 % for stem bark at 0.1 g/dm³ and at 317 K. From the Tables, it can be seen that there is a significant difference between values of inhibition efficiency of the extract of stem bark and leaf at 301 K and 317 K. This increase in inhibition efficiency with rise in temperature suggest the inhibitor molecules were chemically adsorbed onto the coupon surface [19].

The rate of corrosion that was observed to be high in the blank came down significantly with the introduction of the inhibitors into the corrodent as seen in tables 5 and 6. Generally, it is clear that the rate of corrosion of mild steel was affected by temperature and concentration of these inhibitors [20].

The evaluated values of enthalpy of activation for both stem bark and leaf are positive and are lower than that of the blank as shown in Table 7 and 8, respectively, signifying that inhibition effectiveness increased with increase in temperature [21]. The positive values of enthalpy imply that the inhibition process was endothermic. The average difference in value of the, $E_a - \Delta H^*$ which equates to RT as shown in equation 9 for both extracts was found to be 2.560 kJ/mol almost same as the value of RT (2.570 kJ/mol). This proposes that the corrosion process of this metal in the acid medium is a unimolecular reaction [22].

$$E_a - \Delta H^* = RT \quad (9)$$



Table 1: Values of inhibition efficiency (IE%) of stem bark extract

Conc. g/dm ³	Percentage inhibition efficiency (IE%)				
	Blank	301 K	305 K	309 K	313 K
0.1	48.91	59.88	68.73	68.00	69.86
0.2	49.15	60.27	73.09	75.62	73.21
0.3	49.87	60.83	77.04	78.95	80.48
0.4	50.60	61.22	80.98	85.25	91.22
0.5	51.09	66.73	85.77	87.04	96.30

Table 2: Values of inhibition efficiency (IE%) of leaf extract

Conc. g/dm ³	Percentage inhibition efficiency (IE%)				
	Blank	301 K	305 K	309 K	313 K
0.1	8.669	3.593	5.907	45.89	46.99
0.2	16.00	10.78	12.24	57.17	62.59
0.3	18.67	19.76	22.79	66.99	74.14
0.4	27.33	23.95	29.54	73.43	88.35
0.5	32.67	28.74	28.27	78.10	94.67

Tables 3 and 4 showed that corrosion rate decreased with concentration of the inhibitor but was high at higher temperatures while surface coverage increased progressively with rise in both inhibitor concentration and temperature.

Table 3: Values of corrosion rate and surface coverage of stem bark extract

Conc. g/dm ³	Corrosion Rate (mgcm ⁻² h ⁻¹)					Surface coverage (θ)				
	301 K	305 K	309 K	313 K	317 K	301 K	305 K	309 K	313 K	317 K
	×10 ⁻⁴	×10 ⁻⁴	×10 ⁻⁴	×10 ⁻⁴	×10 ⁻⁴					
Blank	8.56	10.96	14.79	39.4	18.04	-	-	-	-	-
0.1	4.37	4.40	4.630	12.6	5.440	0.4890	0.5989	0.6873	0.6800	0.6986
0.2	4.35	4.35	3.980	9.60	4.830	0.4915	0.6027	0.7310	0.7562	0.7321
0.3	4.29	4.29	3.400	8.29	3.520	0.4987	0.6084	0.7704	0.7895	0.8049
0.4	4.23	4.25	2.810	5.81	1.580	0.5061	0.6122	0.8099	0.8524	0.9122
0.5	4.19	3.65	2.100	5.10	0.670	0.5109	0.6673	0.8577	0.8704	0.9630

Table 4: Values of corrosion rate and surface coverage of leaf extract

Conc. g/dm ³	Corrosion Rate (mgcm ⁻² h ⁻¹)					Surface coverage (θ)				
	301 K	305 K	309 K	313 K	317 K	301 K	305 K	309 K	313 K	317 K
	×10 ⁻⁴	×10 ⁻⁴	×10 ⁻⁴	×10 ⁻⁴	×10 ⁻⁴					
Blank	5.00	11.46	13.15	14.44	21.70	-	-	-	-	-
0.1	4.25	6.48	7.15	11.90	15.04	0.150	0.4345	0.4564	0.1819	0.4699
0.2	3.56	6.40	6.21	9.45	12.27	0.2875	0.4418	0.5277	0.3496	0.6259
0.3	5.15	5.54	5.71	7.83	9.95	0.3708	0.5164	0.5658	0.4613	0.7413
0.4	2.67	4.83	5.10	6.92	8.19	0.4667	0.5781	0.6117	0.5244	0.8835
0.5	2.29	4.17	3.06	6.67	7.04	0.5417	0.6364	0.7670	0.5415	0.9467

The negative values of entropy of activation, ΔS_{ads}^* , as shown in Tables 7 and 8 indicated that the activated complex in the rate-determining step represented an association, rather than dissociation, that is a decrease in disorderliness in going from reactants to the activated complex [22]. Heats of adsorption for both inhibitors were observed to be all positive indicating that the processes were endothermic.



ΔG_{ads} values also presented in Table 5 and 6 are all negative and increased with rise in temperature indicating that spontaneity of the adsorption process and stability of absorbed layer increased with rise in temperature for both extracts. However, the values are in the physical adsorption mechanism range as they are all below -20.0

Table 5: Evaluated Parameters of Kinetic energy and thermodynamics of *Stem bark* extract

Conc g/dm ⁻³	Ea (kJ/mol)	- ΔS^*_{ads} (kJ/mol)	- ΔH^*_{ads} (J/mol)	ΔG_{ads} (kJ/mol)				
				301 K	305 K	309 K	313 K	317 K
Blank	66.70	303.81	64.14	-	-	-	-	-
0.1	62.05	281.52	59.49	-15.70	-17.03	-18.25	-16.73	-17.49
0.2	56.00	261.80	53.58	-13.99	-15.32	-17.02	-15.16	-16.25
0.3	47.79	232.93	44.95	-13.05	-14.35	-16.52	-15.33	-15.56
0.4	44.99	224.23	42.41	-12.40	-13.67	-16.39	-14.66	-15.08
0.5	40.74	209.41	38.18	-11.90	-13.71	-16.71	-14.15	-15.16

Table 6: Evaluated Parameters of Kinetic energy and thermodynamics of *leaf*

Conc g/dm ⁻³	Ea (kJ/mol)	- ΔS^*_{ads} (kJ/mol)	- ΔH^*_{ads} (J/mol)	ΔG_{ads} (kJ/mol)				
				301 K	305 K	309 K	313 K	317 K
Blank	63.19	290.13	60.61	-	-	-	-	-
0.1	62.16	283.64	59.59	-11.47	-15.36	-15.78	-12.53	-14.50
0.2	56.63	264.91	54.06	-11.80	-13.67	-14.73	-13.02	-14.13
0.3	52.61	250.20	50.04	-11.74	-13.40	-14.09	-13.18	-14.19
0.4	51.75	246.20	49.18	-12.01	-13.30	-13.84	-13.09	-14.32
0.5	53.84	251.30	51.27	-12.20	-13.36	-15.16	-12.69	-14.35

Table 7: Evaluated Parameters of some linearized adsorption isotherms for stem bark extracts

Isotherm	Temperature (K)	R ²	Slope	Intercept	- ΔG	
Freundlich			<i>n</i>			
	301	0.8875	0.0277	-0.2856	8.405	
	305	0.5117	0.0498	-0.1803	9.132	
	309	0.9567	0.1328	-0.0365	10.10	
	313	0.8693	0.1740	-0.1108	9.787	
	317	0.9695	0.1424	-0.0984	9.988	
Langmuir	301	0.9998	1.932	0.0169	20.26	
	305	0.9919	1.486	0.0331	18.82	
	309	0.9952	1.095	0.0485	18.09	
	313	0.9932	1.339	0.0674	17.47	
	317	0.9948	1.272	0.0582	18.08	
Temkin					<i>-α</i>	
	301	0.8851	0.0318	0.5178	36.21	103.8
	305	0.5029	0.0722	0.6601	15.94	63.57
	309	0.8087	0.3787	0.8069	3.040	22.92
	313	0.8655	0.2399	0.7566	4.799	29.34
	317	0.9553	0.2132	0.7850	5.401	32.93
Adejo- Ekwenchi			<i>b</i>			
	301	0.8826	0.0276	0.3166	11.87	
	305	0.4889	0.0850	0.4684	12.92	
	309	0.7017	0.4278	0.6492	14.16	
	313	0.8615	0.2642	0.5764	13.91	
	317	0.9174	0.2713	0.6332	14.43	



Table 8: Evaluated Parameters of some linearized adsorption isotherms for leaf extracts

Isotherm	Temperature (K)	R ²	Slope	Intercept	-ΔG	
Freundlich		<i>n</i>				
	301	0.9938	0.7920	-0.0160	9.959	
	305	0.8663	0.2304	-0.1555	9.277	
	309	0.8708	0.2822	-0.0740	9.880	
	313	0.9254	0.6394	-0.0569	10.11	
	317	0.9940	0.4863	-0.0200	10.45	
Langmuir						
	301	0.9739	0.6743	0.5880	11.38	
	305	0.9761	1.3965	0.1339	15.28	
	309	0.9267	1.1404	0.1447	15.28	
	313	0.9171	1.1654	0.3716	13.03	
	317	0.9945	1.0565	0.2320	14.43	
Temkin					<i>-α</i>	
	301	0.9830	0.5501	0.6847	2.093	17.77
	305	0.8538	0.2721	0.6768	4.232	24.71
	309	0.8087	0.3787	0.8069	3.041	22.92
	313	0.9620	0.4702	0.6693	2.448	18.98
	317	0.9921	0.5157	0.8135	2.358	18.45
Adejo-Ekwenchi			<i>b</i>			
	301	0.9511	0.3704	0.4225	12.48	
	305	0.8372	0.2478	0.4667	12.91	
	309	0.7016	0.4278	0.6492	14.16	
	313	0.9731	0.3175	0.4110	12.91	
	317	0.9739	0.4461	0.5870	14.15	

Table 7 shows the results of fitness of the leaf extract of the plant to three isotherms tested, using R² as the basis. These are the Freundlich, Langmuir, Temkin, and Adejo-Ekwenchi adsorption isotherms.

Freundlich isotherm, a plot of $\log \theta$ versus $\log C$ gave a straight line with slope equal to *n* and intercept $\log K$. The positive adsorption equilibrium constant, *K*, values are indication of favourable adsorption. The parameter, *n*, in the Freundlich isotherm is related to intensity of adsorption and it varies with heterogeneity of the material [24]. Values of ΔG_{ads} obtained through this isotherm were all below 20 kJ/mol adhering to physisorption.

From the Adejo-Ekwenchi adsorption isotherm in Table 7 and 8 for both extracts, it was observed that the values of K_{AE} were fairly rising. The increase in K_{AE} value with temperature implies a favourable adsorption process. The values of *b* did not follow an ordered trend. This could be categorized as physisorption feature. In general, it can be said that the adsorption processes of the extracts can best be modeled by the Freundlich, Langmuir, Temkin and Adejo-Ekwenchi isotherms [25-29].

Conclusion

Newbouldia laevis stem bark and leaf extract can be used as a replacement for synthetic, toxic, and scarce inhibitors due to environmental friendliness [1-6, 12]. The focus on green corrosion inhibitors is mainly due to economic reasons, strict environmental regulations and renewability.

References

- [1]. Adejo, S. O., Ekwenchi, M. M. and Adams, G. I. (2010). Thermodynamic, kinetic and adsorptive parameters of methanol leaves extract of *Cochlospermum tinctorium* as eco-friendly inhibitor for corrosion of mild steel in H₂SO₄ medium. *International Journal of Chemistry* (In print).
- [2]. Graeme, W. *Corrosion protection*. Chemistry Department, University of Auckland (2011). 401, 187- 190.



- [3]. Ating, E. I., Umoren, S. A., Udousoro, I. I., Ebenso E. E. and Udoh, A. P. (2010). Leaves extract of *Ananas sativum* as green corrosion inhibitor for aluminium in hydrochloric acid solutions. *Green Chemistry Letters and Reviews*, 3(2): 61-68.
- [4]. Adejo, S. O., Ekwenchi, M. M., Odiniya, E. O., Acholo, J. P. and Banke, S. P. (2010). Ethanol extract of leaves of *Portulaca oleracea* as green inhibitor for corrosion of mild steel in H₂SO₄ medium. *Proceedings of International Conference on Research and Development, Accra, Ghana*, 3(10): 113-119.
- [5]. Adejo, S. O., Ekwenchi, M. M. and Banke, S. P. (2010). Ethanol extract of leaves of *Manihot esculentum* as eco-friendly inhibitor for corrosion of mild steel in H₂SO₄ medium. *Proceeding of the 33rd Annual International Conference of Chemical Society of Nigeria, Osun*, 240 – 244.
- [6]. Oguzie, E. E., Okolue, B. N., Ebenso, E. E., Onuoha, G. N. and Onuchukwu, A. I. (1994). Evaluation of the inhibitory effect of methylene blue dye on the corrosion of aluminium in HCl solutions. *Material Chemistry and Physics*, 401, 187- 190.
- [7]. Obot, I. B. and Obi-Egbedi, N. O. (2008). Inhibitory effect and adsorption characteristics of 2,3-diaminonaphthalene at aluminium/hydrochloric acid interface: Experimental and theoretical study. *Surface Review and Letters*, 15, 903-911.
- [8]. Quariachi, E. E., Paolini, J., Bouklah, M., Elichiss, A. J., Boucyanzer, A., Hammauti, B., Desjobert, J. M. and Costa, J. (2010). Adsorption properties of Rosmarinus of ficinalis nil as green corrosion inhibitors on C38 steel in 0.5 M H₂SO₄. *Acta Metallurgica Sinica*. www.amse.org.an 23/02/2009.
- [9]. Eddy, N. O. and Ebenso, E. E. (2008). Adorption and inhibitive properties of ethanol extracts of *Musa sapientum* peels as green corrosion inhibitor for mild steel in H₂SO₄. *African Journal of Pure and Applied Chemistry*, 2(6): 046-054.
- [10]. Sivaraju, M., Kannan, K. (2010). Eco-friendly inhibitor (Tributes terrestris L) for mild steel corrosion in 1N Phosphoric acid. *Asian Journal of Chemistry*, 22(1): 233-244.
- [11]. Kasthuri, P. K., Arulanantham, A. (2010). Eco-friendly extract of Euphorbia hirta as corrosion inhibitor on mild steel in sulphuric acid medium. *Asian Journal of Chemistry*, 22(1): 430-434.
- [12]. Sivaraju, P. K., Arulanantham, A. (2010). Inhibitive properties of plant extract (Acalypha indica L.) on mild steel corrosion in 1N phosphoric acid. *International Journal of Chemical and Technological Research*, 2(2): 256- 265.
- [13]. Obot, I. B. and Obi-Egbedi, N. O. (2009). *Ipomoea involucrata* as an eco-friendly inhibitor for aluminium in alkaline medium. *Portugaliae electrochemical Acta*, 27, 517-521.
- [14]. Dahmani, M., Touhami, A., Al-Deyab, S. S., Jammouti, B. and Bouyanzer, A. (2010). Corrosion Inhibition of C38 steel in 1 M HCl: A comparative study of Black pepper extract and its isolated piperine. *International Journal of Electrochemistry Science*, 51, 060-1069.
- [15]. Rani, D. P. and Selvara, J. S. (2010). *Embllica officinalis* leaves extract as corrosion inhibition for copper and its alloy (cu-272N) in Natural Sea water. *Scholars Research library: Archives of Applied Science Research*, 2(6): 140-150. www.scholarreseachlibrary.com
- [16]. Al-Turkustani, A.M., Arab, S. T. and Al-Qarni, L. S. S. (2010). The use of *Ruta chalepensi* as corrosion inhibitor for steel corrosion in 2 M sulphuric acid solution. *Oriental Journal of Chemistry*, 26(2): 437-454.
- [17]. Oguzie, E. E., Enenebeaku, C. K., Akalezi, C. O., Okoro, S. C., Ayuk, A. A. and Ejike, E. N. (2010). Adsorption and corrosion inhibiting effect of *Dacryodis edulis* extract on low-carbon-steel corrosion in acidic media. *Journal of Colloid and interface Science* 349(1): 238-292.
- [18]. Aboia, O. K. and James, A. O. (2010). The effects of Aloe vera extract on Corrosion and Kinetics of Corrosion process of zinc in HCl Solution, *Corrosion Science* 52(2): 661-664.
- [19]. Ating, E. I., Umoren, S. A., Udousoro, I. I., Ebenso, E. E. and Udoh, A. P. (2010). Leaves extract of *Ananas sativum* as green corrosion inhibitor for aluminium in hydrochloric acid solutions. *Green Chemistry Letters and Reviews*, 3(2): 61-68.



- [20]. Raja, P. B., Rahim, A. A., Osman, H. and Awang, K. (2010). Inhibitory effect of *Kopsia singaporensis* extract on the corrosion behavior of mild steel in acid media. *Wuli Huaxue Xuebao/Acta Physico-Chimica Sinic*, 26(8): 2171-2176.
- [21]. Umeron, S. A., Obet, I. B., Akpabio, L. E. and Etuk, S. E. (2008). Adsorption and corrosive inhibitive properties of *Vigna unguiculata* in alkaline and acidic media. *Pigment and Resin technology*, 37(2): 98-105.
- [22]. Okafor, P. C., Ebenso, E. E. and Ekpe, E. U. (2010). *Azadirachta indica* Extracts as Corrosion inhibitor for mild steel in Acid Medium. *International Journal of Electrochemical Science*, 5, 978-993.
- [23]. Oguzie, E. E. (2006). Studies on the inhibitive effect of *Ocimum viridis* extract on the acid corrosion of mild steel. *Materials Chemistry and Physics*, 93, 441-445.
- [24]. Oguzie, E. E. (2008). Corrosion inhibitive effect and adsorption behaviour of *Hibiscus sabdariffa* extract on mild steel in acidic media. *Portugaliae Electrochimica Acta*, 26, 303-307.
- [25]. El-Etre, A. Y. (2007). Inhibition of acid corrosion of carbon steel using aqueous extract of olive leaves. *Journal of Colloid & Interface Science*, 314, 578-580.
- [26]. Obot, I. B., Umoren, S. A. and Obi-Egbedi, N. O. (2011). Corrosion inhibition and adsorption behaviour for aluminium by extract of *Aningeria robusta* in HCl solution: Synergistic effect of iodide ions. *Journal of Material and Environmental Science*. 2(1): 60-71.
- [27]. Umoren, S. A. and Ekanem, U. F. (2010). Inhibition of mild steel corrosion in H₂SO₄ using exudate gum from *Pachylobus edulis* and synergistic potassium halide additives. *Chemical Engineering Communication*, 197, 1339-1341.
- [28]. Umoren, S. A., Obot, I. B., Ebenso, E. E., Okafor, P. C., Ogbobe, O. and Oguzie, E. E. (2006). Gum Arabic as a potential corrosion inhibitor for aluminium in alkaline medium and its adsorption characteristics. *Anti-Corrosion Methods and Materials*, 53, 277-279.
- [29]. Umoren, S. A., Obot, I. B. and Obi-Egbedi, N. O. (2009). *Raphia hookeri* gum as a potential eco-friendly inhibitor for mild steel in sulphuric acid. *Journal of Materials Science*, 44, 274-279.

