DOI: 10.2478/auoc-2021-0006

Ovidius University Annals of Chemistry Volume 32, Number 1, pp. 40 - 45, 2021

Comparative studies of inhibitive properties of *Ficus polita* and *Ficus platyphylla* on corrosion inhibition of mild steel in acidic medium

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Abstract. The menace of corrosion of steel in industries has been widely acknowledged. Analysis of oil pipeline failures in oil and gas industries in the Niger Delta area of Nigeria showed corrosion as one of the major causes of failure. Eco-friendly, cheap and renewable materials such as plant extracts have been investigated as alternative to the use of expensive synthetic chemicals which are often hazardous. In this study inhibitive properties of ethanol extracts of *Ficus polita* and *Ficus platyphylla* leaves as eco-friendly inhibitors of mild steel in 2 M sulfuric acid solution were investigated by weight loss method at temperatures of 301, 305, 309 and 313 K. The study has shown that both plant extracts inhibited the corrosion of mild steel in the acid medium. The inhibition efficiency (*IE*) and surface coverage (θ) for both extracts increased with increase in concentration and temperature. This trend is suggestive of chemical adsorption. However, the leaf extract of *Ficus polita* showed higher *IE* compared to *F. platyphylla*. Thermodynamic parameters and apparent activation energy obtained from the studies revealed the inhibition by both plant extracts to be spontaneous, exothermic and chemisorptive, while the adsorption mechanism of both plant extracts on the steel surface aligned with the Freundlich isotherm model, *F. polita* fits well to Temkin and Adejo-Ekwenchi isotherm models in addition.

Keywords: steel corrosion; weight loss; thermodynamics; *Ficus polita*; *Ficus platyphylla*; adsorption model.

1. Introduction

Corrosion is the main cause of wear in machineries, pipelines and mild steel products in general. One or more forms of corrosion such as pitting, crevices, cracking, fatigue or intergranular are involved during corrosion of mild steel corrosion resulting in the failure of components [1]. Corrosion swigs a major part of production cost in industries. The cost of corrosion to the economy of any nation is nefarious [2]. In addition to the cost corrosion adds to environmental pollution which remains a major challenge nations have to deal with [3].

The use of corrosion inhibitors has been considered an easy and cost-effective approach to combating corrosion. Synthetic inhibitors exist and are effective but add to environmental contamination hence alternative and eco-friendly inhibitors are essential [4]. Natural products of plant origin and substances from other renewable sources have gained heightened interest by researchers as green corrosion inhibitors [5-7], because they are biodegradable [8, 9], less toxic [10] and do not contain heavy metals. In the light of these, several plants extracts have been investigated and their corrosion inhibition properties are often attributed to phytochemicals present [11-14]. The active phytochemicals in plants that are effective for corrosion inhibition are those that have heteroatom in their aromatic or long carbon chain [15, 16]. The presence of π-electrons or suitable functional groups from the inhibitor's molecule enables the transfer of charge from it to the charged metal surface (physical adsorption) or the transfer of electron from the inhibitor's molecule to vacant *d*-orbital of the metal (chemical adsorption) [17-19]. Heterocyclic and phenolic compounds which contains oxygen, sulfur, nitrogen atoms, and multiple bonds in the molecules have active sites for adsorption onto metal surfaces [20, 21] with decrease in efficiency following the order P > S > N > O [3].

F. polita and *F. platyphylla* belong to the family Moraceae, and genus *Ficus*. Several species of *Ficus* have shown excellent percentage inhibition efficiency [22, 23] on mild steel. Usman and coworkers [24] reported tannins, flavonoids, phlobatannins, terpenoids as present in *Ficus polita*. Kubmarawa *et al.* [25] and Akesa and team [26] reported tannins, saponins, flavonoids, glycosides, volatile oils and steroids as present in *Ficus platyphylla*. These tropical plants grow naturally in virgin lands in Benue State and serve mainly for shade in areas where they are planted. This work is aimed at investigation and comparison of the corrosion inhibition efficiency *F. polita* and *F. platyphylla* on mild steel in acidic medium using the weight loss method.

2. Experimental

2.1. Materials and reagents

F. polita and *F. platyphylla* leaves were obtained from the Main Campus of Benue State University, and identified by the Botanist, in Department of Biological Science, Benue State Makurdi-Nigeria.

Mild steel coupons (3x4 flat bar low carbon mild steel China) were obtained from the Engineering

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The reagents were purchased from Guangdong Guanghua Sci Tech China (absolute ethanol, C_2H_5OH 99.7%; sulfuric acid, H_2SO_4 98%) and BDH Chemicals Ltd., England (acetone, C_3H_6O 99.5%).

2.2. Methods

The fresh samples of *F. polita* and *F. platyphylla* leaves were washed to remove dirt and sand particles, shade dried and reduced to powder. 20 g of the sample were extracted by cold maceration in 200 mL of C_2H_5OH for 48 hours. The filtrate was separated from the residues over cotton wool and concentrated at 321 K in a thermostat water bath (Clifton, Nickel-Electro Ltd., England) to remove the solvent. The extract was then kept in a desiccator to avoid contamination. Stock solutions of 0.1, 0.2, 0.3, 0.4 and 0.5 g·dm^{-3} in 2 M H_2SO_4 were prepared preceding the analysis. Coupons of dimensions 1.8 cm x 2.0 cm x 0.03 cm were prepared from a sample of mild steel of composition by weight (%) Fe (98.84), Mn (0.70), P (0.04), C (0.18), Si (0.40) and S (0.40). Each coupon was weighed and degreased in acetone, dried and preserved in a desiccator prior to the experiment.

Previously prepared mild steel coupons were suspended without plant extracts (blank) and with plant extracts in varying concentrations of the extracts at varying temperatures (301 to 313 K) in the water bath for 6 hours as reported by Wang *et al.* [18] and Adejo *et al.* [27], with slight modifications. The reaction of each coupon was quenched in a saturated solution of CH_3COONa, washed in distilled water and dried in acetone and then re-weighed after cooling. The difference in weight was used to calculate the inhibition efficiency and surface coverage (θ) through Equations 1 and 2, respectively [23, 28]:

$$IE\ (\%) = 1 - \frac{W1}{W2}\ X\ 100 \tag{1}$$

$$\theta = 1 - \frac{W1}{W2} \tag{2}$$

where W_1 is weight of the coupon in the absence and W_2 weight of the coupon in the presence of plant extracts, respectively.

3. Results and discussion

3.1. Inhibition efficiency and surface coverage

The inhibition efficiency and surface coverage were calculated using Equations 1 and 2 respectively by substituting the weight loss data in the absence and presence of the plant extracts. Table 1 and Table 2 show inhibition efficiency and surface coverage of the green corrosion inhibitors on mild steel in 2 M H_2SO_4 at varying temperatures and concentrations. Inhibition efficiency and surface coverage increased with increase in inhibitor concentration and rise in temperature (K). The increase in IE with rise in temperature is suggestive of chemisorption and consistent with the work reported by [29-31]. As temperature rises, more adsorbate forms chemical bond with the metal surface thereby inhibiting corrosion. *Ficus polita* leaf extract showed higher surface coverage and *IE* compared to *F. platyphylla* leaf extract. This may be due to the large quantity of phytol (23.3%); 6, 10, 14-trimethyl-2-pentadecanone (15.0%); (*E*)-6, 10-dimethyl-5, 9-undecadien-2-one (7.3%) and drimenol (5.8%), sesquiterpenes (α-yiangene, α-copaene), γ-cadienee, (*E, E)*-α-farnesene in *F. polita* [32]. Although *F. platyphylla* contains volatile oils, terpenoids are absent. Terpenoids are highly conjugated and electron rich compounds which may provide more adsorption sites. This difference in their chemical composition may account for the higher inhibition efficiency observed with *F. polita.* However, reasoning is still open to speculations.

Table 1. Variation of *IE* and θ of *Ficus polita* leaf extract with concentration and temperature

Conc. g·dm^{-3}	Inhibition efficiency (*IE* %)				Surface coverage (θ)			
T [K]	*301*	*305*	*309*	*313*	*301*	*305*	*309*	*313*
0.1	17.77	19.13	22.30	27.80	0.1777	0.1913	0.2230	0.2780
0.2	23.42	25.83	27.70	30.04	0.2342	0.2583	0.2770	0.3004
0.3	26.96	28.66	30.95	33.50	0.2696	0.2866	0.3095	0.3350
0.4	36.96	39.21	43.24	46.14	0.3696	0.3921	0.4324	0.4614
0.5	45.82	48.98	53.85	55.96	0.4582	0.4898	0.5385	0.5596

Table 2. Variation of IE and θ of *F. platyphylla* leaf extract with concentration and temperature

Conc. g·dm^{-3}	Inhibition efficiency (*IE* %)				Surface coverage (θ)			
T [K]	*301*	*305*	*309*	*313*	*301*	*305*	*309*	*313*
0.1	1.65	3.13	6.22	8.41	0.0165	0.0313	0.0622	0.0841
0.2	3.31	5.00	10.52	13.38	0.0331	0.0500	0.1052	0.1338
0.3	6.43	10.83	12.59	18.03	0.0643	0.1083	0.1259	0.1803
0.4	13.60	18.96	19.26	23.57	0.1360	0.1896	0.1926	0.2357
0.5	23.71	25.00	30.74	35.10	0.2371	0.2500	0.3074	0.3510

3.2. Calculated values of activation energy and heat of adsorption

The apparent activation energy (E_a) was calculated from the Arrhenius equation given as [22, 33]:

$$log\ C_R = log\ A - \left(\frac{E_a}{2.303RT}\right) \tag{3}$$

E_a was obtained from the slope of the plot of log C_R against 1/*T*, where C_R is corrosion rate (mg/cm^2·h), *A* is the constant frequency factor, E_a is the apparent activation energy, *R* is molar gas constant and *T* is absolute temperature. The values of heat of adsorption (Q_{ads}) were obtained from the slope Q_{ads}/ 2.303R of the plot of log θ/1-θ against 1/T.

Tables 3 and 4 show the data for activation energy (E_a) and thermodynamic properties (Q_{ads}, ΔH, ΔS and ΔG) for the process of corrosion inhibition of extracts of *Ficus polita* and *Ficus platyphylla* respectively. The apparent activation energy (E_a) of the inhibition process decreased with increasing inhibitor concentration. Values of activation energy in physisorption process are lower than 40 kJ/mol, while higher than this limit is chemisorption [33]. This implies that the green inhibitors are adsorbed to the surface of the metal by chemical bonding.

3.3. Thermodynamic properties

The enthalpies (ΔH) of adsorption of both plant extracts decreased with increase in inhibitor concentration, the strength of the adsorption increased with increase in the concentration of the inhibitor indicative of interaction between the metal surface and the inhibitors [27]. The values of heat of adsorption for both *F. polita* and *F. platyphylla* extracts were positive implying that both processes are endothermic and did take up energy from the surrounding. The Gibb's free energy is negative implying spontaneity of the adsorption reactions. It is also important to note that values of Gibb's free energy of adsorption, greater than –40 kJ/mol are consistent with the transfer of electron from the inhibitor to the metal surface which represents a chemical adsorption whereas, values of Gibb's free energy less than -40 kJ/mol signifies the mechanism of physical adsorption [34]. This confirms further the mechanism of adsorption of both green inhibitors is chemisorption as the values of the Gibb's free energy are greater than -40 kJ/mol.

Table 3. Activation energy (E_a) and thermodynamic parameters (ΔH, ΔS and ΔG_{ads}) of *F. polita* leaf extract inhibition process

Conc. g·dm^{-3}	E_a (kJ/mol)	ΔH (kJ/mol)	ΔS (J/ K)	-Q_{ads} (kJ/mol)	ΔG_{ads} (kJ/mol)			
Blank	75.54	73.04	209.38	-	301	305	309	313
0.1	70.30	67.79	366.24	25.24	21.72	24.14	29.61	40.24
0.2	70.45	67.94	366.08	18.80	15.56	17.73	19.77	22.44
0.3	70.06	67.55	364.41	18.04	12.37	13.64	15.42	17.55
0.4	65.75	63.24	348.87	42.14	14.73	16.42	19.65	22.38
0.5	62.35	59.84	336.31	25.74	17.00	19.55	24.08	26.56

Table 4. Activation energy and thermodynamic parameters (Q_{ads}, ΔH, ΔS and ΔG_{ads}) of *F. platyphylla* leaf extract inhibition process

Conc. g·dm^{-3}	E_a (kJ/mol)	ΔH (kJ/mol)	ΔS (J/ K)	-Q_{ads} (kJ/mol)	ΔG_{ads} (kJ/mol)			
Blank	67.19	66.60	362.00	-	301	305	309	313
0.1	62.18	61.79	346.39	117.19	1.686	3.290	6.843	9.597
0.2	59.40	56.91	329.33	106.28	1.720	2.680	6.065	8.072
0.3	58.83	56.32	327.00	73.06	2.302	4.123	4.953	7.663
0.4	60.14	57.63	330.66	39.33	3.955	5.956	6.153	8.057
0.5	55.98	54.40	323.70	38.77	6.247	6.789	9.159	11.305

3.4. Adsorption isotherms

The linearized forms of the isotherms studied are given in the equations below [35, 36]:

Langmuir: $$\frac{C}{\theta} = \frac{1}{K} + C \quad (4)$$

Freundlich: $$log\ \theta = log\ K_F + n_F\ log\ C \quad (5)$$

Temkin: $$\frac{-2\alpha\theta}{2.303} = \log k + \log C \quad (6)$$

El-Awady: $$log \frac{\theta}{(1-\theta)} = log\ K + y\ log[C] \quad (7)$$

Adejo- Ekenchi: $$log \frac{1}{1-\theta} = log\ K_{AE} + b\ log\ C \quad (8)$$

where θ is surface coverage, K is corrosion rate constant, n_F is Freunlich constant, the parameter α indicates the type of interaction at adsorbent surface, y is number of water molecules replaced by corrosion inhibitor in El-Awady isotherm, b is slope, and K_{AE} is the Adejo-Ekwenchi adsorption constant.

The data for adsorption isotherms shown in Table 5 for Langmuir, Freundlich, El-Awady, Temkin and Adejo-Ekwenchi isotherms were employed to study the adsorption mechanism of *F. polita*. The values of the equilibrium constants (K_{ads}) were all positive, indicative of favorable adsorption. The R^2 values of Langmuir isotherm is a bit far less than unity thus the adsorption cannot be modeled by this isotherm. The R^2 values in Freundlich isotherm are close to unity and also the values of n parameter are close to the typical value of 0.6 [27] and thus these data can be modeled by this isotherm. The fitting of the adsorption into Temkin isotherm model confirms further the chemical adsorption mechanism of the inhibitor onto the metal surface. The negative values of the α parameter is indicative of repulsive interaction of the molecules within the layer of adsorption. Temkin isotherm model fitting is a feature of chemisorption [37]. For El-Awady isotherm, values of y >1 implies a multilayer formation and values of y < 1 implies monolayer, that is an inhibitor occupies more than one active site. The values of y from this study were less than one indicative of mono layer formation and confirming further chemisorption adsorption mechanism [27, 38]. The b parameter in the Adejo-Ekwenchi isotherm is useful in resolving the mechanism of adsorption. Values of parameter b decreasing with rise in temperature shows physical adsorption and increase or fairly constant b value with increase in temperature indicates chemisorption. The value of b in this study increases with increase in temperature which signifies chemical adsorption mechanism [39].

Table 5. Adsorption isotherm parameters for adsorption of *F. polita* leaf extract onto the mild steel surface

Isotherm	T [K]	R^2	Slope	Intercept	K_{ads}		-ΔG_{ads}
Langmuir	301	0.7741	1.2666	0.5410	1.8484		11.5889
	305	0.7486	1.2420	0.5043	1.9829		11.9206
	309	0.7103	1.1633	0.4497	2.2237		12.3713
	313	0.7710	1.1513	0.4023	2.4857		12.8213
						n	
Freundlich	301	0.9484	0.5749	-0.1999	0.6311	0.5749	8.8992
	305	0.9314	0.5561	-0.1883	0.6482	0.5561	9.0855
	309	0.8934	0.5247	-0.1638	0.6858	0.5247	9.3495
	313	0.9114	0.5102	-0.1431	0.7193	0.5102	9.5944
						- α	
Temkin	301	0.8739	0.3830	0.5319	1.7022	0.0833	11.3830
	305	0.8531	0.3900	0.5538	1.7399	0.0856	11.5893
	309	0.8169	0.4180	0.6004	1.8228	0.0908	11.8607
	313	0.8407	0.4300	0.6305	1.8785	0.0934	12.0926
			y				
El-Awady	301	0.9201	0.8192	0.1076	1.3532		10.8082
	305	0.8979	0.8146	0.1382	1.4780		11.1754
	309	0.8529	0.8167	0.2050	1.2859		10.9644
	313	0.8708	0.8207	0.2530	2.0365		12.3026
			b				
Adejo-Ekwenchi	301	0.8343	0.2443	0.3074	2.0296		11.8227
	305	0.8096	0.2585	0.3265	2.1208		12.0911
	309	0.7701	0.2921	0.3692	2.3399		12.5021
	313	0.7926	0.3106	0.3967	2.4929		12.8288

Table 6 shows the fitting of data into various adsorption isotherms for the *F. platypylla* leaf extract onto the mild steel surface. The R^2 values show that the adsorption data fit into Freundlich isotherm. The equilibrium constants (K_{ads}) were positive implying favorable adsorption. Although the R^2 values of Freundlich isotherm are close to unity, the n parameter is greater than 0.6 [40]. The y values for El-Awady isotherm are greater than 1 which implies the reaction forms multilayer suggesting physical adsorption mechanism, hence the data does not fit into this isotherm.

Table 6. Adsorption isotherm parameters for adsorption of *F. platypylla* leaf extract onto the mild steel surface

Isotherm	T [K]	R^2	Slope	Intercept	K_{ads}		$-G_{ads}$
						n	
Freundlich	301	0.9544	1.6407	0.2305	1.7002	1.6407	11.38
	305	0.9552	1.3484	0.2313	1.7033	1.3484	11.54
	309	0.9309	0.9195	0.3251	2.1140	0.9195	12.24
	313	0.9598	0.8107	0.2731	1.8754	0.8107	12.09
						$-\alpha$	
Temkin	301	0.7362	0.1223	0.2619	1.2994	0.0612	10.71
	305	0.8408	0.1339	0.3060	1.3580	0.0670	10.96
	309	0.7718	0.1320	0.3363	1.3998	0.0660	11.18
	313	0.8323	0.1461	0.3960	1.4859	0.0731	11.48
			y				
El-Awady	301	0.9419	1.7793	0.1032	1.1429		10.39
	305	0.9474	1.5031	0.0805	1.1312		10.50
	309	0.9077	1.0799	0.1540	1.3887		11.16
	313	0.9358	0.9963	0.0650	1.1620		10.84

4. Conclusions

Ethanol leaf extracts of *F. polita* and *F. platyphylla* were investigated for their corrosion inhibition properties onto the surface of mild steel in acidic medium, with *F. polita* showing higher inhibition efficiency than *F. platyphylla*. The chemisorption adsorption mechanism of *F. polita* best fit Freundlich, Temkin and Adejo-Ekwenchi isotherm models, while chemisorption mechanism of *F. platyphylla* fits well Freundlich adsorption isotherm model.

Acknowledgements

We appreciate the Botanist, Mr. Waya for helping with identification of the plants.

Conflict of interest

Authors declare no conflict of interest.

References

[1]. L.T. Popoola, A.S. Grema, G.K. Latinwo, B. Gutti, A.S. Balogun, Corrosion problems during oil and gas production and its mitigation, International Journal of Industrial Chemistry 4 (2013) e35.

[2]. D. Kesavan, M. Gopiraman, N. Sulochana Green inhibitors for corrosion of metals: A review, Chemical Science Review and Letters 1 (2012) 1-8.

[3]. S.O. Adejo, S.G. Yiase, L. Leke, M. Onuche, M.V. Atondo, T.T. Uzah, Corrosion studies of mild steel in sulphuric acid medium by acidimetric method, International Journal of Corrosion Scale Inhibition 8 (2019) 50–61.

[4]. H. Wei, B. Heidarshenas, L. Zhou, G. Hussain, Q. Li, K.K. Ostrikov, Green inhibitors for steel corrosion in acidic environment: State-of-art, Materials Today Sustainability 10 (2020) 100044. https://doi.org/10.1016/j.mtsust.2020.100044

[5]. M. Bendahou, M. Benabdellah, B. Hammouti, A study of rosemary oil as a green corrosion inhibitor for steel in 2 M H_3PO_4, Pigment and Resin Technology 35 (2006) 95–100. http://dx.doi.org/10.1108/03699420610652386.

[6]. C. Verma, E.E. Ebenso, I. Bahadur, M.A. Quraishi, Sulfur and phosphorus heteroatom-containing compounds as corrosion inhibitors: An overview, Heteroatom Chemistry 29 (2018) e21437. https://doi.org/10.1002/hc.21437

[7]. C. Verma, E.E. Ebenso, I. Bahadur, M.A. Quraishi, An overview on plant extracts as environmental sustainable and green corrosion inhibitors for metals and alloys in aggressive corrosive media, Journal of Molecular Liquids. 266 (2018) 577-590. https://doi.org/10.1016/j.molliq.2018.06.110

[8]. S. Marzorati, L. Verotta, S.P. Trasatti, Green corrosion inhibitors from natural sources and biomass wastes, Molecules 24 (2019) 48. https://doi.org/10.3390/molecules24010048

[9]. P.C. Okafor, M.E. Ikpi, I.E. Uwah, E.E. Ebenso, U.J. Ekpe, S.A Umoren, Inhibitory action of *Phyllanthus amarus* extracts on the corrosion of mild steel in acidic media, Corrosion Science 50 (2008) 2310–2317.

[10]. U.J. Ahile, S.O. Adejo, J.A. Gbertyo, F.F. Idachaba, R.L. Tyohemba, S.O. Ama, Ethanol stem extract of *Mucuna Pruriens* as green corrosion inhibitor for corrosion of aluminium in H_2SO_4, Journal of Applied Chemistry 3 (2014) 2039-2046.

[11]. X. Li, S. Deng, H. Fu, Inhibitive effects and mechanism of phosphates on the stress corrosion cracking of brass in ammonia solutions, Corrosion Science 62 (2012) 163-175. http://dx.doi.org/10.1016/j.corsci.2012.05.008.

[12]. P.B. Raja, M.G. Sethuraman, Natural products as corrosion inhibitor for metals in corrosive media — A review, Materials Letters 62 (2007) 113–116.

[13]. N. Karthiga, S. Rajendran, P. Shanthy, A. Krishnaveni, J. Jeyasundari, R.M. Joany, A.C.C. Mary, T. Umasankareswari, Corrosion inhibition of mild steel by an aqueous extract of allium sativum, International Journal of Nano Corrosion Science and Engineering 2 (2015) 255-269.

[14]. P.R. Sivakumar and A. P. Srikanth, Green corrosion inhibitor: A comparative study, Sådhanå 45 (2020) 56. https://doi.org/10.1007/s12046-020-1283-x

[15]. L.A. Nnanna, O.C. Nwadiuko, N.D. Ekekwe, C.F. Ukpabi, S.C. Udensi, K.B. Okeoma, B.N. Onwuagba, I.M. Mejeha, Adsorption and inhibitive properties of leaf extract of *Newbouldia leavis* as a green inhibitor for aluminium alloy in H_2SO_4, American Journal of Material Science 1 (2011) 143-148.

[16]. S.K. Sharma, A. Peter, I.B. Obot, Potential of *Azadirachta indica* as a green corrosion inhibitor against mild steel, aluminum, and tin: a review, Journal of Analytical Science and Technology 6 (2015) 26. https://doi.org/10.1186/s40543-015-0067-0

[17]. L. H. Madkour, U.A. Zinhome, Inhibition, kinetic

and thermodynamic effects of new azo derivatives on iron corrosion in acidic and alkaline solutions, Standard Scientific Research and Essays 2 (2014) 705-724.

[18]. Q. Wang, B. Tan, H. Bao, Y. Xie, Y. Mou, P. Li, D. Chen, Y. Shi, X. Li, W. Yang, Evaluation of *Ficus tikoua* leaves extract as an eco-friendly corrosion inhibitor for carbon steel in HCl media, Biochemistry 128 (2019) 49-45.

[19]. A. Rodríguez-Torres, M.G. Valladares-Cisneros, C. Cuevas-Arteaga, M.A. Veloz-Rodríguez, Study of green corrosion inhibition on AISI 1018 carbon steel in sulfuric acid using *Crataegus mexicana* as eco-friendly inhibitor, Journal of Materials and Environmental Sciences 10 (2019) 101-112.

[20]. A. Singh, E.E. Ebenso, M.A. Quraishi, Theoretical and electrochemical studies of *Cuminum cyminum* (Jeera) extract as green corrosion inhibitor for mild steel in hydrochloric acid solution, International Journal of Electrochemical Science 7 (2012) 8543-8559.

[21]. H. Lgaz, R. Salghi, I.H. Ali, Corrosion inhibition behavior of 9-hydroxyrisperidone as a green corrosion inhibitor for mild steel in hydrochloric acid: Electrochemical, DFT and MD simulations studies, International Journal of Electrochemical Science 13 (2018) 250 – 264. DOI: 10.2964/2018.01.26.

[22]. R.A. Anaee, M.H. Alzuhairi, H.A. Abdullah, Corrosion inhibition of steel in petroleum medium by *Ficus carica* leaves extract, Asian Journal of Engineering and Technology 2 (2014) 235-243.

[23]. M. K. Bagga, R. Gadi, O.S. Yadav, R. Kumar, R. Chopra, G. Singh, Investigation of phytochemical components and corrosion inhibition property of *Ficus racemose* stem extract on mild steel in H_2SO_4 medium, Journal of Environmental Chemical Engineering 4 (2016) 4699-4707.

[24]. A.U. Usman, O. O. Kaigama, A.M. Ibisagba, I. A. Fulata, J. Ahmed, Phytoconstituents evaluation and antimicrobial efficacy of the crude flavonoids and saponins rootbark extracts of *Terminalia avicennioides* and *Ficus polita*, Journal of Herbmed Pharmacology 7 (2018) 106-111. DOI: 10.15171/jhp.2018.18

[25]. D. Kubmarawa, M.E Khan, A.M. Punah, M. Hassan, Phytochemical and antimicrobial screening of *Ficus platyphylla* against human/animal pathogens, The Pacific Journal of Science and Technology 10 (2009) 382-386.

[26]. T.M. Akesa, D.K. Adedzwa, R.W. Anyam, S.T. Apeelu, J.I. Waya, P.T. Dughdugh, Taxonomic studies of members of the family Moraceae in selected areas of Benue State, Nigeria, Global Scientific Journal 5 (2017) 68-84.

[27]. S.O. Adejo, M.M. Ekwenchi, J.U. Ahile, J.A. Gbertyo, A. Kaior, Resolution of adsorption characterization ambuiguity through the Adejo-Ekwenchi adsorption isotherm: A case study of leaf extract of *Hyptis suaveolen* poit as green corrosion inhibitor of corrosion of mild steel in 2M HCl, Journal of Emerging Trends in Engineering and Applied Sciences 5 (2014) 201-205.

[28]. M.A. Velázquez-González, J.G. Gonzalez-Rodriguez, M.G. Valladares-Cisneros, M.G., I.A. Hermoso-Diaz, Use of *Rosmarinus officinalis* as green corrosion inhibitor for carbon steel in acid medium, American Journal of Analytical Chemistry 5 (2014) 55-64.

[29]. E.E. Oguzie, C.B. Adindu, C.K. Enenebeaku, C.E. Ogukwe, M.A. Chidiebere, K.L. Oguzie, Natural products for materials protection: mechanism of corrosion inhibition of mild steel by acid extracts of *Piper guineense*, Journal of Physical Chemistry 116 (2012) 13603-13615.

[30]. S.O. Adejo, M.M. Ekwenchi, P.O. Olatunde, E.F. Agbajeola, Adsorption characteristics of ethanol root extract of *Portulaca oleracea* as eco-friendly inhibitor of corrosion of mild steel in H_2SO_4 medium, IOSR Journal of Applied Chemistry 7 (2014) 55-60.

[31]. C.A. Adah, J.A. Gbertyo, G.A. Otokpa, Studies on the corrosion inhibition of ethanol extract of *Newbouldia laevis* stem bark and leaf on mild steel in acidic medium, Chemistry Research Journal 5 (2020) 96-103.

[32]. I.A. Ogunwande, M.A. Sonibare, T.D. Thang, N.X. Dung, M.O. Soladoye, O.O. Morohunfolu, Comparative analysis of the oils of three *Ficus* species from Nigeria, Journal of Essential Oil Research 20 (2011) 386-389.

[33]. V.J. Inglezakis, A.A. Zorpas, Heat of adsorption, adsorption energy and activation energy in adsorption and ion exchange systems, Desalination and Water Treatment 39 (2012) 149–157. DOI: 10/5004/dwt.2012.3000

[34]. E.O. Nnabuk, F. Awe, E.E. Ebenso, Adsorption and inhibitive properties of ethanol extracts of leaves of *Solanum melongena* for the corrosion of mild steel in 0.1 M HCl, International Journal of Electrochemical Science 5 (2010) 1996 – 2011.

[35]. A.I. Onen, J.T. Barminas, J. Jacob, Inhibitory action of *Ficus carica* extracts on aluminium corrosion in acidic medium, Chemical Science Transactions 2 (2013) 1326-1333. DOI:10.7598/cst2013.558.

[36]. V.G. Vasudha, P.K. Shanmuga, *Polyalthia longifolia* as a corrosion inhibitor for mild steel in HCl solution, Research Journal of Chemical Science 3 (2013) 21-26.

[37]. N. Ayawei, A.N. Ebelegi, D. Wankasi, Modelling and interpretation of adsorption isotherms, Journal of Chemistry 2017 (2017) 3039817. https://doi.org/10.1155/2017/3039817.

[38]. E. Ituen, O. Akaranta, A. James, Evaluation of performance of corrosion inhibitors using adsorption isotherm models: An overview, Chemical Science International Journal 18 (2017) 1-34.

[39]. S.O. Adejo, S.G.Yiase, J.A. Gbertyo, E. Ojah, Aspartic acid as corrosion inhibitor of mild steel corrosion using weight loss, acidimetry and EIS measurement, Journal of Advances in Chemistry 15 (2018) 6262-6274.

[40]. S.O. Adejo, M.M. Ekwenchi, J.A. Gbertyo, T. Menenge, J.O. Ogbodo, Determination of

adsorption isotherm model best fit for methanol leaf extract of *Securinega virosa* as corrosion inhibitor for corrosion of mild steel in HCl, Journal of Advances in Chemistry 10 (2014) 2737-2742.

Received: 01.09.2020
Received in revised form: 16.03.2021
Accepted: 17.03.2021