Available online at www.worldscientificnews.com

World Scientific News

An International Scientific Journal

WSN 109 (2018) 195-210 EISSN 2392-2192

Plant extract as biodegradable inhibitor for zinc in dilute solution of sulphuric acid

O. D. Onukwuli[1], **J. O. Ezeugo**[2,*]

[1]Department of Chemical Engineering, Nnamdi Azikwe University, Awka, Nigeria

[2]Department of Chemical Engineering, Chukwumeka Odumegwu Ojukwu University, Anambra State, Nigeira

*E-mail address: jn.ezeugo@coou.edu.ng

Phone: +2348063873600

ABSTRACT

The inhibitive action of the ethanol extract of oil from *Picralima nitida* leaf, towards acid corrosion of zinc, is tested using weight loss, and thermometry methods. It was found that the extract acted as a good corrosion inhibitor for zinc corrosion in 0.5 M H_2SO_4 solution. The inhibitive action of the extract was discussed in view of Langmuir adsorption isotherm. It was revealed that the adsorption of the extract on zinc surface is governed by spontaneous process. The inhibition efficiency (IE) increases in line with corresponding increase in extract concentration. The temperature effect of the corrosion inhibition on the IE was studied. Revelation from the studies indicates that the presence of extract increases the activation energy of the corrosion reaction. Furthermore, from the calculated thermodynamic parameters, it was observed that Picralima nitida extract provides a good protection to zinc against pitting corrosion in chloride ion containing solutions.

***Keywords*:** Zinc, corrosion, inhibition, *Picralima nitida* leaf, inhibitor

1. INTRODUCTION

Corrosion is an electrochemical process that gradually returns metals such as zinc to its natural state in the environment. In other words, corrosion can be said to be destruction of

(Received 24 August 2018; Accepted 07 September 2018; Date of Publication 08 September 2018)

material resulting from exposure and interaction with the environment. It is a major problem that requires immediate confrontation for safety, environment, and economic reasons [1]. Zinc consists of wide variety of alloys used since ancient times. Building industry frequently uses zinc alloys in roofing of house and other construction work because of its ductility and malleability. Therefore, zinc alloys are widely used in the production of many components and die-casting fittings in automobile and manufacturing and the mechanical industry, thanks to its super or super plasticity.

Zinc, in spite of the so called super plasticity is not spared by corrosion, especially after prolonged period of exposure in corrosive environment, such as H_2SO_4. For this reasons a lot of efforts have been made using corrosion preventive practices and the use of green corrosion inhibitors is one of them [2]. The use of green inhibitors for the control of corrosion of zinc and alloys which are in contact with aggressive environment is an accepted and growing practice [3-5]. Large numbers of organic compounds are being studied to investigate their corrosion inhibition potential. Revelation of these studies shows that organic compounds are not only expensive, but also toxic to living beings [6].

Plant extracts and organic species have therefore become important as an environmentally acceptable, readily available, and renewable source for a wide range of inhibitors [7]. They are the rich sources of ingredients which have very high inhibition efficiency and are hence termed “Green Inhibitors” [8]. Green corrosion inhibitors [9] are biodegradable and do not contain heavy metals or other toxic compounds. The successful use of naturally occurring substances to inhibit the corrosion of the metals in acidic and alkaline environment have been reported by some research groups [10] to mention but a few. Research efforts to find naturally organic substances or biodegradable organic materials to be used as effective corrosion inhibitors of a wide number of metals has been one of the key areas in this research work.

The aim of this study is to investigate the inhibitive properties of *Picralima nitida* leaves extract onto zinc in sulphuric acid media. Several studies have already been carried out and have remained focused on the *Picralima nitida* leaf extract for their various pharmacological activities. Firstly, *Picralima nitida* plant is a tree that can reach a height of 35 meters, but is usually less. It is a commonly used herbal remedy in West Africa. All parts of the plant are bitter throughout its distribution area.

The seeds, barks, roots and leaves have a reputation as a febrifuge and remedy for malaria as well as also being extensively used for pain relief and treatment of chest and stomach problems, pneumonia and intestinal worms [11]. A decoction of the leave is taken as a treatment for measles. The *Picralima nitida* leaf contains many organic compounds, such as phenolics, terpenoids, and tannins as their major phytocompounds and also saponins, flavonoids and alkaloids in moderate amount to scavenge free radicals induce detoxification.

Presently, to the best of our knowledge no reported work in area of environment has been carried out on the corrosion inhibitive properties of the *Picralima nitida* leaves extract. Therefore, the aim of this research is to undertake a thorough investigation towards that, in 0.5 M H_2SO_4 using the leaf extract of picralima nitida. The study was done using thermometric method, weight loss (Gravimetric) method and FTIR analysis. The effect of temperature and concentration on the rate of corrosion were also studied, and some thermodynamic and kinetic parameters were calculated, too.

2. EXPERIMENTAL METHODS

2. 1. Materials

Gravimetric and thermometric tests were performed on 99.988% Zn, other components (we%) were: Pb 0.003, Cd 0.003, Fe 0.002, Sn 0.001, Cu 0.00, Al 0.001. The sheet of zinc was cut into coupons (2.6 cm × 2.6 cm × 0.015 cm), cleaned and polished with emery paper to expose shining polished surface. The coupons were degreased with acetone in order to remove any trace of oil and impurities and finally washed with double distilled water, dried in air and then stored in desiccators prior to use. The aggressive solution of 0.5 M H_2SO_4 was made from analytical grade, sulphuric acid and distilled water. *Picralima nitida* leave collected from Uke in Anambra, Nigeria, was sun-dried for three days. The dried leave were ground to increase the surface area and stored in a closed container. For every of the extraction process, 30 grams of each of the ground *Picralima nitida* leave were measured and soaked in 100 ml of ethanol for 48 hours. At the end of the 48hrs, each plant mixture was filtered. The filtrate is the mixture of the plant extract and the ethanol. The extract of *Picralima nitida* leave obtained in ethanol solvent was concentrated, distilled off the solvent and evaporated to dryness. The plant extract was weighed and stored for the corrosion inhibition study.

2. 2. Fourier transform infrared (FTIR) analysis of *Picralima nitida* extract and corrosion product

The zinc was immersed in the H_2SO_4 medium in the presence of the *Picralima nitida* leave extract. At the end of the corrosion study, the corrosion products in the beakers were collected with aid of sample bottles Oguzie et al (2013). SHIMADZU FT-IR spectrophotometer, model: IR affinity – 1, 5/NA 2137470136 SI) was used for the determination of the functional groups of the PNL extract (pure) and corrosion product in the presence of the PNL extract. Comparative analysis of various FTIR produced peaks were carried out in order to determine the exact functional groups for the corrosion inhibition process.

2. 3. Thermometric Method of the Corrosion Inhibition Study

The measurements were carried out using a thermostat set at 30 °C for the zinc in free and inhibited H_2SO_4. The temperatures of the system containing the zinc and the test solution were recorded regularly until a steady temperature value was evaluated using eqn. (1) [12-14].

$$RN = \frac{T_m - T_i}{t} \tag{1}$$

where T_m and T_i are the maximum and initial temperatures (°C) respectively and t is the time in minutes elapsed to reach T_m.

The inhibitor efficiency was determined using eqn. (2)

$$IE\% = 1 - \frac{RN\ add}{RN\ free} \times 100 \tag{2}$$

where RN_{free} and RN_{add} are the reaction numbers for the zinc dissolution in free and inhibited corrosive media respectively.

2. 4. Weight loss (gravimetric) Method using one factor at a time

The weight loss methods were carried out applying one factor at a time. Considering the said method, the weight loss method was carried out at different temperatures and with various concentrations of the *Picralima nitida* extract. Weighed zinc coupons were separately immersed in 250 ml open beakers containing 200 ml of 0.5 M H_2SO_4. More so, zinc coupons were separately immersed in 150 ml open beakers containing 200 ml of 0.5 M H_2SO_4 with various concentrations of the extract.

The variation of weight loss was monitored periodically at various temperatures in the absence and presence of various concentrations of the extracts. At the appropriate time, the coupons were taken out, immersed in acetone, scrubbed with a bristle brush under running water, dried and reweighed. The weight loss was calculated as the difference between the initial weight and the weight after the removal of the corrosion product. The experimental readings were recorded. The weight loss (Δw), corrosion rate (CR) and inhibition efficiency (IE) were determined using the eq (3-5), respectively. The surface coverage was obtained using equation 5 [15].

$$\Delta w = wi - wf \tag{3}$$

$$CR = \frac{we - fe}{At} \tag{4}$$

$$(IE\%) = 1 - \frac{w_0 - w_1}{w_0} \times 100 \tag{5}$$

$$\theta = \frac{w_0 - w_1}{w_0} \tag{6}$$

where w_i and w_f are the initial and final weight of zinc samples respectively, W_1 and W_0 are the weight loss values in presence and absence of inhibitor, respectively. A is the total area of the zinc sample and t is the immersion time.

2. 4. 1. Effect of temperature on the corrosion rate

Effect of temperature on the corrosion rate was described using Arrhenius equation

$$CR = A\, e^{-Ea/RT} \tag{7}$$

where CR is the corrosion rate of the zinc, A is the pre-exponential factor, Ea is the activation energy, and R is the universal gas constant. Eq. (7) can be linearized to form eq. (8).

$$In\,(CR) = In\,A - \left({}^{Ea}/_{R}\right)\left(\frac{1}{T}\right) \tag{8}$$

Considering the corrosion rate of the zinc at T_1 and T_2 as Cr_1 and CR_2, then eq. (8) can be expressed by eq. (9).

$$In\left(\frac{CR_2}{CR_1}\right) = \left(\frac{Ea}{2.303R}\right)\left(\frac{1}{T_1} - \frac{1}{T_2}\right) \quad (9)$$

Thermodynamic parameter for the adsorption process. The heat of adsorption Q_{ads} ($kjmol^{-1}$) was calculated using eq. (10) [16]

$$Qads = 2.303R\left[\log\left(\frac{\theta_2}{1-\theta_2}\right) - log\left(\frac{\theta_1}{1-\theta_1}\right) \times \frac{T_2\,T_1}{T_2 - T_1}\right] \quad (10)$$

where R is the gas constant, θ_1 and θ_2 are the degree of surface coverage at temperature T_1 and T_2 respectively.

2. 4. 2. Consideration of the Adsorption isotherm

The data obtained for the degree of surface coverage were used to test for the applicability of different adsorption isotherms (Langmuir, Frumkin, Temkin and Flory-Huggins isotherms).

Langmuir Isotherm

Langmuir isotherm can be expressed by eq (11) (22, 23)

$$\frac{C}{\theta} = \frac{1}{K} + C \quad (11)$$

where C is the concentration of the inhibitor, K is the adsorption equilibrium constant and θ is the degree of surface coverage. In logarithmic form, eq. (11) can be expressed in eq. (12)

$$\log\frac{C}{\theta} = \log C - \log K \quad (12)$$

Frumkin isotherm

Frumkin adsorption isotherm can be expressed according to eq. (13)

$$\log\left((Cc) * \left(\frac{\theta}{1-\theta}\right)\right) = 2.303logK + 2\,\alpha\theta \quad (13)$$

where K is the adsorption –desorption constant and α is the lateral interaction term describing the interaction in adsorbed layer.

Temkin isotherm

Temkin isotherm can be expressed by eq. (14) (Zhang & Hua ,2009).

$$\theta = \frac{2.303 \log K}{2a} - \frac{2.303 \log C}{2a} \quad (14)$$

where k is the adsorption equilibrium constant, a is the attractive parameter, θ is the degree of surface coverage, C is the concentration of the inhibitor

Florry-Huggins Isotherm

The Flory-Huggins isotherm can be expressed by eq (15)

$$\log\left(\frac{\theta}{C}\right) = \log k + x \log(1 - \theta) \quad (15)$$

where x is the size parameter and is a measure of the number of adsorbed water molecules.

The free energy of adsorption (ΔG_{ads}) was calculated according to eq. (16) [18, 19]

$$\Delta G_{ads} = -2.303RT \log (55.5K) \quad (16)$$

where R is the gas constant, T is the temperature, K values obtain from the isotherms (Langmuir, Frumkin, Temkin and Flory-Huggins isotherm) were used to obtain the values of ΔGads according to eq. (16).

3. RESULTS AND DISCUSSION

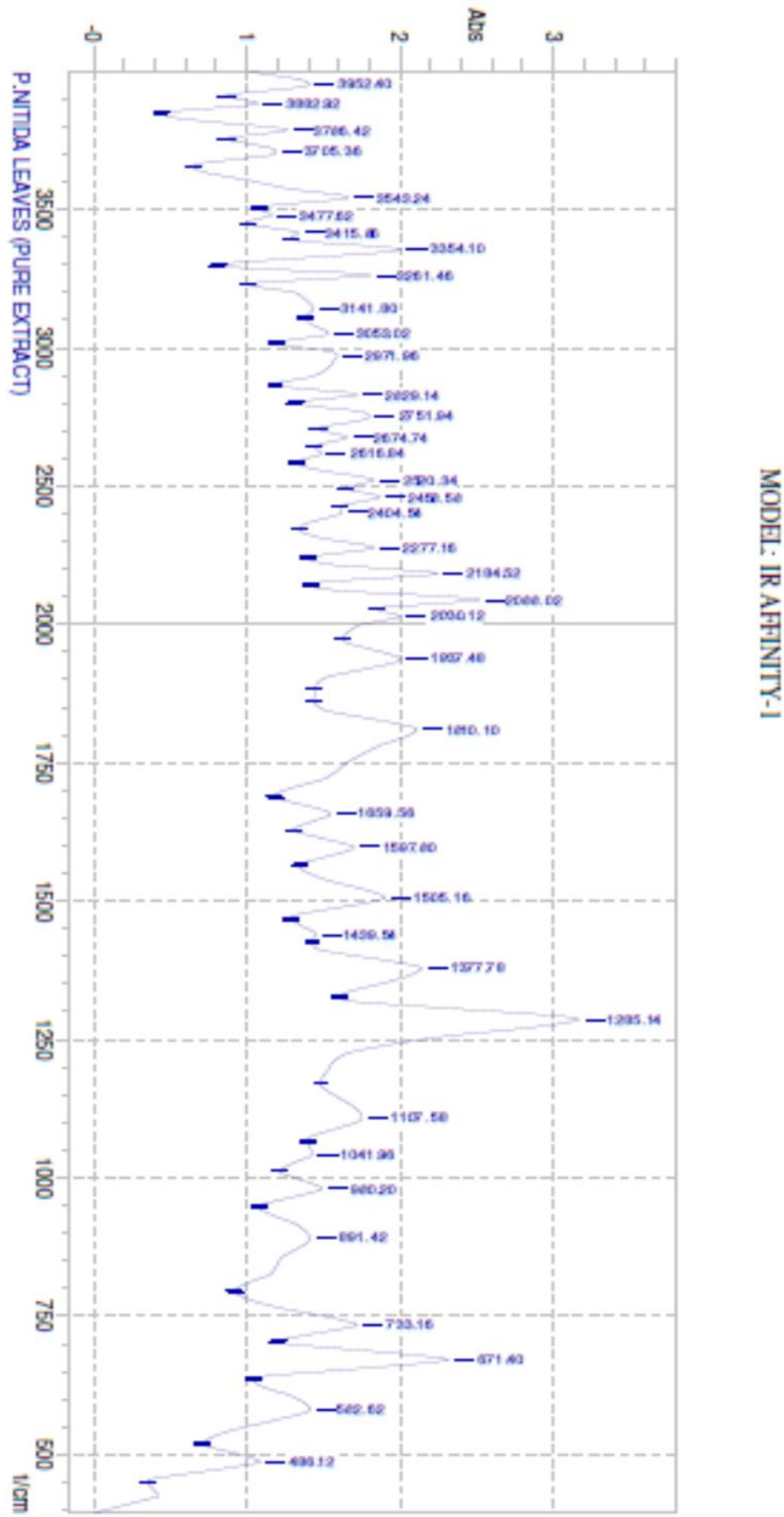
FTIR Spectrophotometer is a strong instrument that can be used to identify the type of bonding, especially functional group (s) present in organic compounds. Fig. 1. shows the FTIR spectrum of the ethanol extract of *Picralima nitida* leaf extract. Initial absorption at 3952.4 to 3543.24 cm^{-1} (associated hydroxyl) was overlapped by the strong stretching bond of O-H. The peak at 3477.62 to 3261.46 cm^{-1} is attributed to medium and often broad stretch band of amines and amides, N-H.

Wave band 3141.8 cm^{-1} and 3053.02 cm^{-1} are variable stretch of alkyl and aldehyde bond group, C-H. The absorption band at 2971.96 cm^{-1} stands for strong and very broad stretch of carboxylic acid (free bond of alcohol). Wave band of 2751.94 cm^{-1}, 2829.14 cm^{-1} are two-peaked medium stretch bond of aldehyde, $C \equiv C$.

The peak at 2404.54 cm^{-1} to 2030.12 cm^{-1} represent variable and sharp stretch bond of alkyne and nitrite, C=N. Wave band 1837.48 cm^{-1}, 1658.65 cm^{-1} are strong representative of stretch bond of acids, esters anhydrides and aldehydes, C=O.

The absorption bands 1597.8 cm^{-1}, 1439.54 cm^{-1} are multiple sharp, medium peaks stretch of aromatic bond, C=C. This shows that *Picralima nitida* leaves extract contains mixtures of compounds, that is, alkaloids, flavonoids, phenolics, phytates, terpenoids, tannins and steroids [20, 25-31].

(a)



(b)

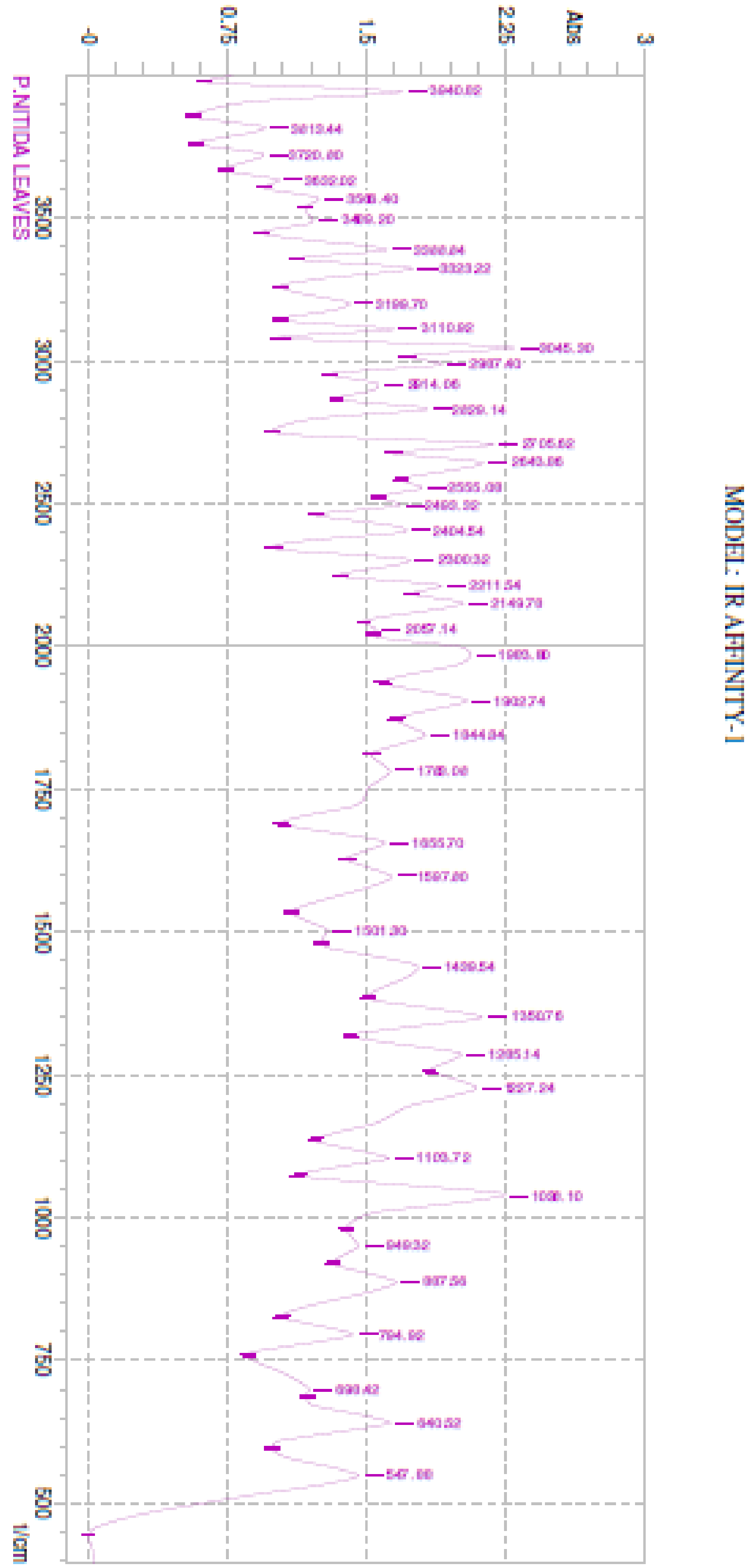


Figure 1. FTIR spectrum of **(a)** *Picralima nitida (pure)* leaf extract and **(b)** corrosion product.

3. 1. Results of the corrosion inhibition as determined by thermometric studies

The effect of concentration of *Picralima nitida* leaves (inhibitor) extract on the reaction number (RN) and the inhibition efficiency (IE) of zinc in the 0.5 M H_2SO_4 medium is presented in table 1. It was revealed that increase in concentration of the inhibitor lowers the reaction number. This is in agreement with previous observation [21]. More so, the inhibition efficiency increases with increasing concentration of the inhibitor.

Table 1. Effect of the *Picralima nitida* leaf extracts on the IE (%) of zinc in 0.5 M H_2SO_4 medium

Inhibitor concentration (gL^{-1})	RN	IE (%)
0	0.1868	
0.2	0.0995	46.74
0.45	0.0801	57.13
0.7	0.0524	71.95
0.95	0.0364	80.5
1.2	0.0342	81.72

3. 2. Weight loss measurement

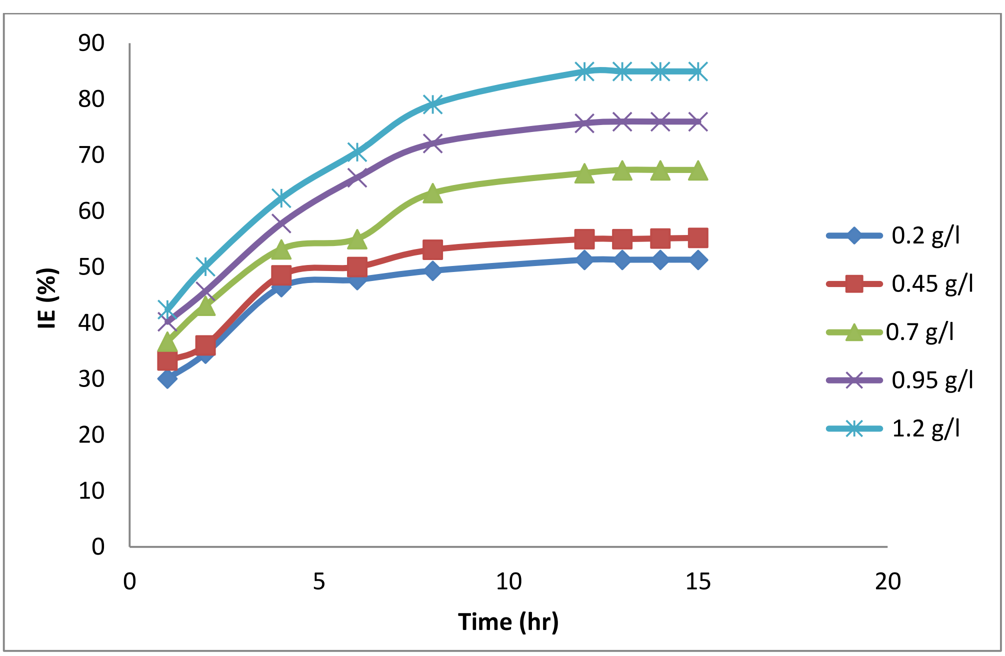


Figure 2. Represents the relation between time and inhibition efficiency of zinc in 0.5 M H_2SO_4 at various concentration of *Picralima nitida* leaves extract.

Fig. 2 represents the relation between time and inhibition efficiency of zinc in 0.5 M H_2SO_4 at various concentration of *Picralima nitida* leaves extract while Table 2 represent experimental results of weight loss and corrosion rate using one factor at a time. Inspection of Fig. 2 reveals that the loss of weight increases linearly with increasing time in all tested solutions. However, the slopes of the obtained lines which represent the rate of weight loss, are affected by addition of *Picralima nitida* extract. The presence of the extract causes a sharp decrease in the rate of weight loss. IEs at different concentrations of the extract were calculated using the equation (17).

$$IE(\%) = \frac{w_0 - w_1}{w_0} \times 100 \tag{17}$$

where W_1 and W_0 are the weight loss value in presence and absence of inhibitor, respectively.

3. 2. 1. Adsorption studies and inhibition mechanism.

The values of IEs and θs of different *Picralima nitida* extract concentrations are given in Table 2. The tabulated data revealed that, the *Picralima nitida* leaf extract acts as a good corrosion inhibitor for the acid corrosion of zinc. The corrosion inhibition increases with increasing extract concentration. The analysis of the *Picralima nitida* extract revealed that the ethanolic extract contains toluene, formular C_7H_8, molecular weight 92, cyclohexane having formula C_8H_{16}, molecular weight 112, hexane, 1,3-cyclopenta deine, molecular weight 156. It also contains at least ten non-volatile acids including eicosane and citric acids. The adsorption of the compounds on the electrode surface make a barrier for mass and charge transfers [22]. The outcome of this situation leads to a protection of the metal surface from the attack of the aggressive anions of the acid. The extent of protection increases with increasing of the surface fraction occupied by the adsorbed molecules. As the extract concentration is increased, the number of the adsorbed molecules on the surface increases. Table 2 represents also the values of adsorption isotherm parameter. From the table, a parameter (θ), which was estimated from the IE values, could be used to represent the fraction of the surface occupied by the adsorbed molecules. In-depth examination of Table 2 revealed that the values of θ increases with increasing inhibitor concentration. The dependence of the fraction of the surface occupied by the adsorbed molecules on the inhibitor.

Table 2. Corrosion inhibition of zinc in 0.5 M H_2SO_4 with *picralima nitida* leave extract.

Time (hr)	Temperature (K)	Inhibitor conc. (gL^{-1})	Weight loss (g)	Corrosion rate (Mg/cm^2 hr)	Inhibition efficiency (%)	Degree of surf.cov.
12	303	0	0.671	6.213	-	-
		0.2	0.327	30.28	51.27	0.5127
		0.45	0.302	2.796	54.99	0.5499
		0.7	0.223	2.065	66.77	0.6677
		0.95	0.163	1.509	75.71	0.7571
		1.2	0.101	0.935	84.95	0.8495

12	313	0 0.2 0.45 0.7 0.95 1.2	0.68 0.34 0.277 0.199 0.142 0.141	6.296 3.148 2.565 1.843 1.615 1.306	- 49.7 59.02 70.56 78.99 79.14	- 0.497 0.5902 0.7056 0.7899 0.7914
12	323	0 0.2 0.45 0.7 0.95 1.2	0.645 0.411 0.319 0.233 0.183 0.175	5.972 3.806 2.954 2.157 1.694 1.62	- 39.56 53.09 65.74 73.09 74.26	- 0.3956 0.5309 0.6574 0.7309 0.7426

Concentration (C) is shown in Fig. 3. A plot of C/θ versus C gives a straight line with unit slope. The results indicated that the adsorption of inhibitor molecules on the zinc surface follow Langmuir isotherm. In order words, the result suggests that there are no interactions or repulsion forces between the adsorbed molecules. It is of interest to note here that, the θ values obtained from the other used techniques also obey the Langmuir adsorption isotherm. The standard adsorption free energy (ΔG_{ads}) was calculated using the following equation (18).

$$K = \frac{1}{999}\exp\left(-\frac{\Delta G_{ads}}{RT}\right) \tag{18}$$

where 999 is the concentration of water in solution expressed in gL^{-1}. R is gas constant, and T absolute temperature. The mean value of standard adsorption free energy (ΔG_{ads}) was 46.402 $kjmol^{-1}$. The negative values of ΔG_{ads} guarantee the spontaneity of the adsorption process and stability of the adsorbed layer on the metal surface. It is generally known that, values of ΔG_{ads} up to -20 $KJmol^{-1}$ is consistent with electrostatic interaction between the charged molecules and the charged metal (physisorption). While those around – 40 $kjmol^{-1}$ or higher are associated with chemisorptions as a result of sharing or transfer of electrons from the molecules to the metal surface to form a coordinate type of bon [23].

Other researchers however suggested that the range of ΔG_{ads} of chemical adsorption processes for inhibitor in aqueous media lies between -21 and -42 $KJmol^{-1}$ (28). From table 3 the values of ΔG_{ads} as recorded in the present work has been considered within the range of physical adsorption. Limited increase in the absolute value of ΔG_{ads} at 303 K temperature, then, heat of adsorption decreases again at 313 k initiating that the adsorption was somewhat favourable at the experimental temperature and *Picralima nitida* leave extract adsorbed according to physical mechanisms, i.e. desorption of inhibitor molecules when temperature increased. Moreover, the major characteristic of Langmuir isotherm can be expressed in terms of linear regression coefficient. The value of the linear regression coefficient is close to unity, hence adsorption of the *Picralima nitida* leaf extract follows Langmuir isotherm and R^2 value is 0.994 ≥ 0.982. It is very important to note that the smaller values of R^2 indicate a highly favourable adsorption. $R^2 > 1$ unfavorable, $R^2 = 1$ linear, $0 < R^2 < 1$ favourable and if $R^2 = 0$ irreversible. The table 3 shows that various values of R^2 for the entire tested isotherms model. The values of k_{ads} are relatively small indicating that the interaction between the adsorbed extract molecules and metal surface is physically adsorbed.

Table 3. Adsorption parameters for the corrosion inhibition of Zinc in H_2SO_4 by PNL extract

Adsorption isotherm	Temperature (k)	R^2	Log K	K	ΔGads (KJ/mol)	Isotherm property	
Langmuir isotherm	303 323	0.994 0.982	-0.14 -0.118	0.7244 0.7621	-9.307 -10.057		
Frumkin isotherm	303 323	0.973 0.995	-1.1624 -1.0499	0.0688 0.0891	-3.375 -4.293	α	2.083 1.962
Temkin isotherm	303 323	0.871 0.983	-1.7958 -1.5190	0.0160 0.0303	0.299 -1.396	A	-2.703 -2.429
Flory-Huggins isotherm	303 323	0.675 0.95	0.494 0.519	3.1189 3.3037	-12.985 -13.997	X	0.871 1.188

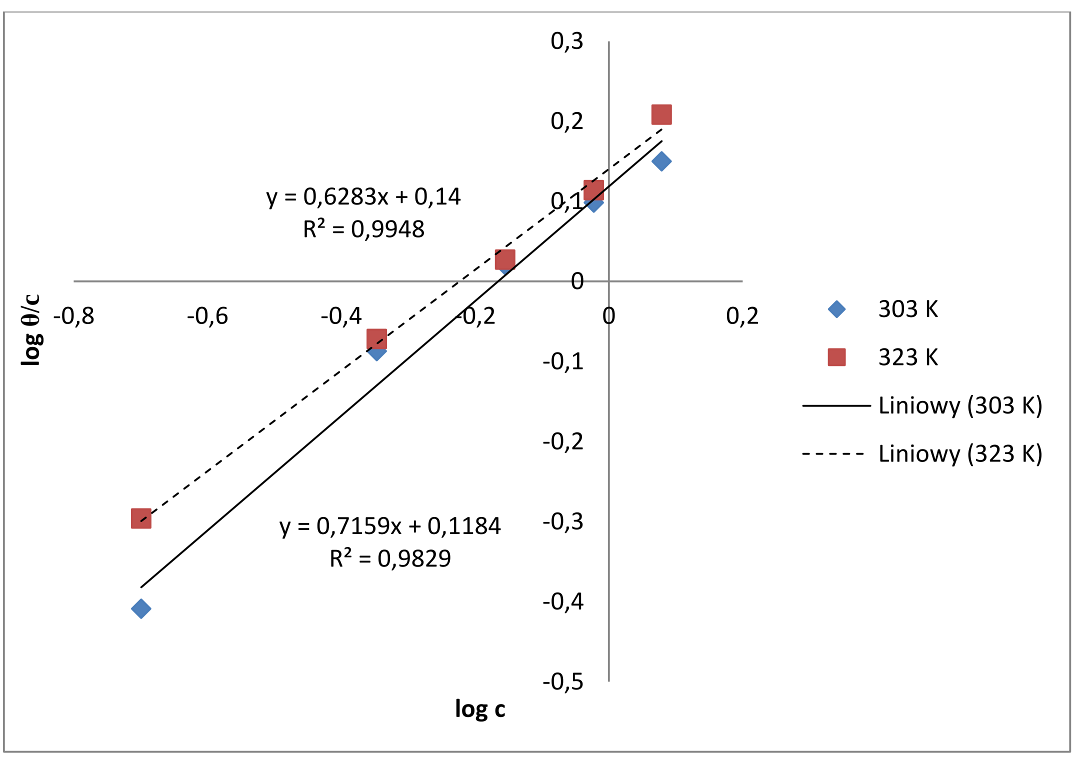


Figure 3. Plot of Langmuir isotherm for zinc in H_2SO4 with PNL extracts

A close look at Table 4 shows various inhibition concentrations (gL^{-1}) and their respective activation energy (kj mol^{-1}). From the table, calculated Ea value for the inhibited solution with *Picralima nitida* extract is 52.404 and 82.985 $kjmol^{-1}$ in the presence of the inhibitor of 0.95 and 1.2 gL^{-1} extract concentrations, while with 0.45 and 0.70 gL^{-1} concentrations, activation energies are 33.418 and 19.434 $kjmol^{-1}$. The higher values of Ea suggest that dissolution of zinc in the presence of inhibitors is slow, indicating a strong inhibitive action of phytocompounds of alkaloids, flavonoids and tannins presence in *Picralima nitida* leave extracts, which leads to increasing the energy barrier for the corrosion process [24]. Actually, toluene molecules (the main compound of *Picralima nitida* leaf extracts are easily protonated and exist in 0.5 M H_2SO_4 medium in cationic form. Indeed, it is logical to assume that in this study, the electrostatic cat ion adsorption is responsible for the good protective properties of this compound.

Table 4. Activation Energy and Heat of Adsorption for the Corrosion Inhibitor of Zinc in 0.5 M H_2SO_4 at various Inhibition Concentrations

Inhibitor concentration (gL^{-1})	Ea (kj mol^{-1})	ΔG_{ads} (kj mol^{-1})
0.2	21.425	-19.313
0.45	5.150	-3.113
0.70	4.084	-1.874
0.95	10.835	-5.601
1.20	51.498	-27.310

4. CONCLUSIONS

The *Picralima nitida* leaf extract acted as a good inhibitor for corrosion of zinc in 0.5 M H_2SO_4 solution and the IE increases with increasing extract concentration. The adsorption process is physical as various studies techniquse point towards physisorption. More so, the increase in temperature decreases the IE of the extract while the presence of *Picralima nitida* extract increases the activation energy of the corrosion reaction. The *PNL* extract further provides strong protection against corrosion of zinc in presence of sulphate ions. The extent of protection increases with increasing extract concentration.

References

[1] Abdel Rehim, S.S., Omar, A.H., Amin A.M., & Khaled, F.K. (2008). The corrosion inhibition of low carbon steel in concentrated sulphuric acid solutions. Part1: Chemical and electrochemical (AC & DC) studies. *Corrosion Science*, 50, 2258-2271

[2] Abdel-Rehim, S.S., Khaled, K.F. & Al-Mobarak N.A. (2011). Corrosion Inhibition of Iron in Hydrochloric acid using pyrazole. *Arabian Journal of Chemistry* 4, 333-337.

[3] Akalezi, C.O., Oguzie, E.E., Ogukwe, C.E. & Ejele, A.E. (2015). Rothmannia Longiflora extract as corrosion inhibitor for mild steel in acidic media. *Int. J. Ind. Chem.* 6, 273-284.

[4] Al-Otaibi, M.S., Al-Mayouf, A.M., Khan, M. & Mousa, A.A. (2014). Corrosion Inhibitory action of some plant extracts on the corrosion of mild steel in acidic media. *Arabian Journal of Chemistry* 7, 340-346.

[5] Ameer, M.A., & Fekry A.M., (2011). Corrosion Inhibition of mild steel by natural product compound. *Progress in Organic Coating*, 71, 343-349,

[6] Aprael, S.Y., Anees A.K. & Rafal K.W (2013). Apricot juice as green corrosion inhibitor of mild steel in phosphoric acid. *Alexandria Engineering Journal* 52, 129-135.

[7] Ating, E.I., Umoren S.A., Udousoro, I.I., Ebenso, E.E. & Udoh, A.P. (2010). Leaves extract of Ananas Sativum as green corrosion inhibitor for aluminium in hydrochloric acid solutions. *Green Chemistry Letters & Reviews* 3, 61-68.

[8] Ayati, N.S., Khandandel, S., Momeni M., Moayed, M.H., Davoodi, A. & Rahimizadeh M. (2011). Inhibitive effect of synthesized 2-(3-pyridyl)-3,4-dihydro-4-quinazolinone as a corrosion inhibitor for mild steel in hydrochloric acid. *Material Science & Physics 126*, 873-879.

[9] El-Etre, A.Y. (2003). Inhibition of Aluminium corrosion using Opuntia extract. *Corrosion Science* 45, 2485-2495.

[10] Fouda, A.S., Shalabi, K. & Idress., A.A (2015). Ceratonia siliqua extract as a green corrosion inhibitor for copper and brass in nitric acid solutions. *Green Chemistry Letters & Reviews*, 8, 3-4, 17-29.

[11] Gerengi, H., Katarzyna, S & Sahin, H.I. Corrosion-inhibiting effects of Mimosa extract on brass-MM55 corrosion in 0.5 M H_2SO_4 acidic media. *Journal of Industrial and Engineering Chemistry* Volume 18, Issue 6, 25 November 2012, Pages 2204-2210

[12] Ihebrodike, M.M., Nwandu, M.C., Okeoma, K.B., Nnanna, L.A., Chidiebere, M.A., Eze, F.C & Emeka. (2012). Experimental & theoretical assessment of the inhibiting action of Aspilia Africana extract on corrosion of aluminium alloy AA3003 in hydrochloric acid. *J. Materials Science* 47, 2559-2572.

[13] Khaled, K.F. (2008). Adsorption and inhibitive properties of a new synthesized guanidine derivative on corrosion of copper in 0.5M H_2SO_4 . *Applied Surface Science*, 255, 1811-1818,

[14] Khaled, K.F. (2010). Corosion control of copper in nitric acid solutions using some amino acids – A combined experimental and theoretical study. *Corrosion Science*, 52, 3225-3234,

[15] Khaled, K.F. (2010). Studies of Iron corrosion Inhibition using Chemical, electrochemical & computer simulation techniques. *Electrochimica Acta,* 55, 6523-6532,

[16] Matjaz, F. & Jennifer J. (2014). Application of Corrosion Inhibitors for steels in acidic media for the oil and gas industry: A review. *Corrosion Science* 86, 17-41.

[17] Migahed, M.A., Abdul-Raheim, Atta, A.M. & Brostow W. (2010). Synthesis & evaluation of a new water soluble corrosion inhibitor from recycled poly(ethylene terphethalate). *Material Chemistry and Physics,* 121, 208-214.

[18] Murthy, Z.V.P. & Vijayaragavan, K. (2014). Mild steel corrosion inhibition by acid extract of leaves of Hibiscus Sabdariffa as a green corrosion inhibitor and sorption behavior. *Green Chemistry Letters & Reviews* 7, 209-219,

[19] Narayana, H., Praveen, B.M., Prasanna, B.M., Venkatesha T.V., & Abd Hamid, S.B. (2014). Anthranilic Acid as corrosion Inhibitor for mild steel in Hydrochloric Acid. Media. *Procedia Material Science,* 5, 712-718.

[20] Nnabuko, O.E., Momoh-Yaya, H.& Oguzie, E.E (2015). Theoretical & experimental studies on the corrosion inhibition potentials of some Purines for aluminium in 0.1 M HCl. *Journal of Advance Research* 6, 203-217.

[21] Oguzie, E.E. (2008) Evaluation of the Inhibitive effect of some plant extracts on the acid corrosion of mild steel. *Corrosion Science* 50, 2993-2998,

[22] Oguzie, E.E., Iheabunike, Z.O., Oguzie, K.L., Ogukwe, C.E., Chidiebere, M.A., Enenebeaku, C.K. & Akalezi C.O. (2013). Corrosion Inhibiting effect of Aframomum melegueta Extracts & Adsorption Characteristics of the active Constituents on Mild Steel in Acidic Media. *Journal of Dispersion Science & Technology* 34, 516-527.

[23] Patchaiah, K., Subbiah C., Seeni P. & Gopalan S. (2010). Artemisia pallens as corrosion inhibitor for mild steel in HCL medium. *Materials Chemistry & Physics* 120, 643-648.

[24] Quartarone, G., Ronchin, L., Vavasori A., Tortato, C. & Bonaldo L. (2012). Inhibitive action of gramine towards corrosion of mild steel in deaerated 1.0M hydrochloric acid solutions. *Corrosion Science* 64, 82-89.

[25] T. O. Magu, V. M. Bassey, B. E. Nyong, O. E. Obono, N. A. Nzeata-Ibe, O. U. Akakuru. Inhibition studies of Spondias mombin L. in 0.1 HCl solution on mild steel and verification of a new temperature coefficient of inhibition efficiency equation for adsorption mechanism elucidation. *World News of Natural Sciences* 8 (2017) 15-26

[26] M. E. Ikpi, F. E. Abeng, O. E. Obono. Adsorption and Thermodynamic Studies for Corrosion Inhibition of API 5L X-52 Steel in 2 M HCl Solution by Moxifloxacin. *World News of Natural Sciences* 9 (2017) 52-61

[27] M. E. Ikpi, F. E. Abeng, B. O. Okonkwo. Experimental and computational study of levofloxacin as corrosion inhibitor for carbon steel in acidic media. *World News of Natural Sciences* 9 (2017) 79-90

[28] F. E. Abeng, V. D. Idim, P. J. Nna. Kinetics and Thermodynamic Studies of Corrosion Inhibition of Mild Steel Using Methanolic Extract of Erigeron floribundus (Kunth) in 2 M HCl Solution. *World News of Natural Sciences* 10 (2017) 26-38

[29] H. Louis, J. Japari, A. Sadia, M. Philip, A. Bamanga. Photochemical screening and corrosion inhibition of Poupartia birrea back extracts as a potential green inhibitor for mild steel in 0.5 M H_2SO_4 medium. *World News of Natural Sciences* 10 (2017) 95-100

[30] B. Adindu Chinonso, E. Oguzie Emeka. Investigating the extract constituents and corrosion inhibiting ability of *Sida acuta* leaves. *World News of Natural Sciences* 13 (2017) 63-81

[31] Maduabuchi A. Chidiebere, Simeon Nwanonenyi, Demian Njoku, Nkem B. Iroha, Emeka E. Oguzie, Ying Li, Experimental study on the inhibitive effect of phytic acid as a corrosion inhibitor for Q235 mild steel in 1 M HCl environment**.** *World News of Natural Sciences* 15 (2017) 1-19

[32] J. N. O. Ezeugo, O. D. Onukwuli, M. Omotioma, Optimization of corrosion inhibition of Picralima nitida leaves extract as green corrosion inhibitor for zinc in 1.0 M HCl**.** *World News of Natural Sciences* 15 (2017) 139-161