CORROSION INHIBITION AND ADSORPTION CHARACTERISTICS OF ETHANOLIC EXTRACT OF *Brachystegia eurycoma* SEED ON THE CORROSION OF MILD STEEL IN 1M H_2SO_4 ACID SOLUTION

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Abstract: Extract of *Brachystegia eurycoma* Seed (*BE*S) was investigated as corrosion inhibitor of mild steel in 1M H_2SO_4 using phytochemical screening, weight loss, scanning electron microscopy (SEM), and fourier transform infrared spectroscopy (FTIR). The analysis of the weight loss results showed that the Inhibition efficiency of the *Brachystegia eurycoma* seed extract is directly proportional to its concentration and inversely proportional to solution temperature and mild steel contact time in the test solution. The inhibition efficiency increases gradually reaching a maximum value of 95.53% within the first 24 h at a concentration of 5.0 g/l. The kinetic study shows that the inhibitory action is a first order kinetics with the concentration of the seed extract of *Brachystegia eurycoma* which is best fitted into the Langmuir adsorption isotherm. Thermodynamic parameters indicated that the adsorption of *Brachystegia eurycoma* seed extract onto the metal surface was spontaneous, exothermic and supported the physical adsorption process. FTIR results showed that the inhibition mechanism was an adsorption process through the functional groups present in the seed extract. Surface morphology also revealed that corrosion product confirmed the protection offered by the extract on the surface of the metal immersed in the acid media.

Keywords: Corrosion, inhibitors, mild steel, scanning electron microscopy, weight loss

Introduction

The use of mild steel in chemical industries cannot be overemphasized owing to its mechanical properties and usefulness as structural material for vessels reactor, pipelines, tank, construction works and other industrial equipment which are known to corrode invariably in contact with various solvents (Junaedi *et al.,* 2012). Acid solutions especially sulfuric acid used for industrial processes such as acid pickling, industrial cleaning, acid descaling, etching of metal and acidic operations may cause damage to metal surface (Akalezi *et al.,* 2012; Okorokwo *et al.,* 2015; Peter *et al.,* 2016; Akalezi and Oguzie, 2015). Corrosion degrades the useful properties of materials and structures including strength, appearance and permeability to liquids and gases thereby affecting the tensile strength and utility efficiency of the material (Samuel *et al.,* 2015). In view of the nation's economy and financial implications of corrosion menace, researchers are compelled to do copious scientific studies in an attempt to improve the resistance of metals.

Corrosion inhibitors have proven to be the most convenient means of protecting metals due to their unique properties which enhances their capability to resist the corrosion process as compared to other methods (i.e. electroplating, coatings, alloying elements, and plastic deformation) (Leon-Silva *et al.,* 2010; Gutierrez *et al.,* 2016; EL-Basiony *et al.,* 2019). A corrosion inhibitor is a chemical compound which when added to liquid or gas decreases corrosion rate of a material, typically metal or alloys (Yiguang *et al.,* 2006). The effectiveness of a corrosion inhibitor depends on the fluid composition, quantity of water and flow regime (Umoren *et al.,* 2008; Ulaeto *et al.,* 2012). Corrosion inhibitors could be additives to the fluids that surround the metal (Schmit, 2000).

In recent time, great achievement has been made in developing the efficiency of organic compounds containing hetero-atoms as corrosion inhibitors for mild steel in acidic media (Banu *et al.,* 2016; EL-Basiony *et al.,* 2019). The interaction between the mild steel and hetero-atoms such as O, N, P, S and double/triple bonds or aromatic rings in the form of a wall, shows a vital role in corrosion prevention processes caused by the free electron pairs (Shubham *et al.,* 2018). However, due to the known hazardous effects of most synthetic corrosion inhibitors coupled with increasing ecological awareness and strict environmental regulations, as well as the inevitable drive toward sustainable and environmentally friendly processes, attention has now focused toward the development of nontoxic alternatives. The exploration of natural products of plant origin as inexpensive eco-friendly corrosion inhibitors are becoming more important. In addition to being environmentally friendly and ecologically acceptable, plant products are low-cost, readily available, biodegradable, non toxic and renewable sources of materials, and they are widely used as corrosion inhibitors for the protection of metals in acid and alkaline environment (Akalezi and Oguzie, 2015; Okorokwo *et al.*, 2015).

The use of plant extracts as corrosion inhibitors is not a new phenomenon and the following plants have been investigated and found to possess inhibitory efficacy. *Gliricidia sepium* (Okoronkwo *et al.,* 2015), *Azadirachta indica* (Peter *et al.,* 2017), *Pterocarpus soyauxii* Taul (Onukwube *et al.,* 2016), *Momordica charantia* (Kavitha *et al.,* 2017), *Boscia senegalensis* (Awe *et al.,* 2015) and lots more.

Brachystegia eurycoma (achi as its populary called in eastern part of Nigeria) is an economically valuable tree crop mostly grown in the tropical rain forest of West Africa. In Eastern Nigeria, the edible seed is used in soup making as a thickener and is common among the rural dwellers. It helps in maintaining heat within the body when consumed in other words; it is a good source of nutrient and helps to control body temperature (Ndukwe *et al.,* 2009; Uzoma *et al.,* 2011). Due to their absorption capacity, they are useful as functional agents in fabricated foods such as bakery products and meat formulations (Ndukwe *et al.,* 2009; Uzoma *et al.;* 2011). In Nigeria, the seed is used for its anti-Inflammation, anti-malaria, anti- diabetics and anti- corrosion properties (Michael *et al.,* 2000; Okafor *et al.,* 2008). *Brachystegia eurycoma* seed has been reported to contain 10.47% protein, and 71.94% total carbohydrate content, the timber products are used as building material in carpentry and related applications (Nwosu *et al.,* 2012).

Materials and Methods

Collection of plant material and preparation of seed extracts

The study was carried out on *Brachystegia eurycoma* seeds (*BE*S). The *Brachystegia eurycoma* seeds were purchase from Eke-Okigwe market in Okigwe local government area of Imo state, Nigeria. The sample was dried and grounded into powder. Four hundred and fifty gram (450 g) of the dehydrated and grounded seeds was soaked in a 500ml solution of ethanol for 48hrs. Sequentially, sufficient grams of the grounded seeds were measured into the ethanol and were extracted until the 450 g of the grounded seeds were exhausted. After 48hrs, the samples were filtered using Whatman filter paper No. 1 (QUALIGEN- Germany). The filtrates were further subjected to evaporation by rotatory evaporator at 358K in order to leave the sample free of the ethanol. The stock solutions of the extract obtained were used in preparing different concentrations of the extract by dissolving 1.0, 2.0, 3.0, 4.0 and 5.0 g of the extract in 1 L of 1M HCl acid, respectively.

Phytochemical screening on BES

Screening of phytochemicals is significant for identification of bioactive principles present in plants. Phytochemical screening was carried out on BES extracts by standard procedures (Khadom *et al.,* 2017). Plant extracts were screened for reducing sugar, alkaloids, protein, phenols, flavonoids, amino acids, tannin, steroids, glycosides and carbohydrates. These compounds are potential corrosion inhibitors for many metals in an acidic medium (Verma and Mehta, 1997)

Preparation of specimen

The specimens were cut using a saw into the required dimension of 4 x 3 x 0.017 cm then descaled by brushing with a emery paper. They were cleaned and dried with acetone, then stored properly in desiccators for further use. The elemental composition of mild steel specimen analyzed and used for this study with iron (Fe) having the highest elemental composition of 93.65%.

Gravimetric techniques

One hundred millilitres (100 ml) each of the 1.0M H_2SO_4 solution was measured into six different beakers with one as the blank (uninhibited solution) and the remaining five labeled A to E containing different concentrations of the inhibitors ranging from 1.0 to 5.0 g/100ml, respectively. The test coupons were weighed before immersion in the acid solutions and the measurements were taken down. After weighing, the coupons were immersed in the acids solution. The coupon in each beaker was noted to avoid mix ups during the practical work. The immersion period was 24 h interval, after 24 h the coupons were retrieved from the acids, washed with tab water, degreased with ethanol and dried with acetone before the corresponding weights after immersion were recorded. The procedures were repeated for 96 hours i.e. for 4 days. The corresponding weights after immersion were recorded as well after each day. The differences in weight of the coupons were again taken as the weight loss (Kavitha *et al.*, 2017). The rate of corrosion (CR), inhibition efficiency (IE), and degree of surface coverage (ϴ) were obtained from the weight loss results. Rate constant and half life ($t_{1/2}$) were also determined using the expressions below.

The corrosion rates (C.R) were computed using the formula:

$$C.R = \frac{\Delta W}{A \times T} \quad 1$$

Where: ΔW = weight loss (g), A = total surface area of the test coupon (cm^2), T = immersion time (min)

The inhibitor efficiency (IE) was computed using the relationship in equation 2.

$$\%IE = \frac{(C.R)o-(C.R)inh}{(C.R)o} \times 100 \quad 2$$

Where: $(C.R)_o$ and $(C.R)_{inh}$ are the corrosion rates in the absence and presence of different concentrations of the inhibitor, respectively (Okorokwo *et al.*, 2015).

The surface coverage *(θ)* of the inhibitor was obtained from the experimental data using the equation 3 as follows:

$$\theta = \frac{(C.R)o-(C.R)inh}{(C.R)o} \quad 3$$

The rate of the reaction as well as the values of the rate constant *k* of the reaction were evaluated using the Equation 4 and 5 as follows:

$$\log W_f = \log W_o - kt \quad 4$$

$$k = \frac{1}{t}\log\left(\frac{Wo}{Wf}\right) \quad 5$$

Where: W_f = the final weight of metal after time, t, W_i = the initial weight of metal, *t* = the immersion time (Akalezi *et al.*, 2012).

The half-life of the reaction was evaluated using Equation 6 as follows:

$$t_{1/2} = \frac{0.693}{k} \quad 6$$

Where: *k* = the rate constant of the reaction.

Temperature effect

To study the temperature effect, the mild steel coupons were completely immersed in 100ml of 1M H_2SO_4 solution with and without the various *BE* seed extract concentration using glass hooks and corrosion rate were determined at 313, 323 and 333 K for 2 h to calculate inhibition efficiency, activation energy (E_a), Standard Gibbs free energy change of Adsorption, $\Delta G°_{ads}$ and heat of adsorption (Q_{ads}).

Fourier transform infrared spectroscopy (FTIR) analysis

FTIR analysis was used to ascertain the fact that the corrosion inhibition process takes place through the adsorption of the phytochemical constituents on the mild steel surface. The spectra of *BE* seed extract were recorded in a Perkin-Elmer-1600 spectrophotometer using KBr pellet.

Scanning electron microscopy (SEM) analysis

The surface morphology of the mild steel before and after immersion were examined with scanning electron microscopy to analyse the elements on the surface, using a phenom pro X Scanning Electron Microscope (SEM). The electrons interact with atoms in the sample, producing various signals that can be detected and that contain information about the samples surface topography and composition (Okoronkwo *et al.,* 2012).

Results and Discussion

Phytochemical screening

The phytochemical constituents of *BE* seed extract, as presented in Table 1, indicate the presence of tannins, saponins, et cetera. The presence of these compounds promotes the inhibition of mild steel in sulfuric acid solution. Plant extracts are organic in nature and some of the constituents are tannins, alkaloids, proteins, polysaccharides, polycarboxylic acids, alkaloids, and so forth. These compounds are potential corrosion inhibitors for many metals in an acidic medium (Verma and Mehta, 1997).

Table 1: Phytochemical constituents of *BE* seed extract

Phytochemiacal constituents	Tannins	Flavonol	Amino acids	Alkaloid	Carb.
Ethanolic extract of AAS	+++	++	++	+	+++

Carb. = Carbohydrates; + = Sparingly Present;
++ = Moderately Present; +++ = Highly Present

Table 2: Deduced data for inhibition efficiency, corrosion rate, rate constant and half life obtained from gravimetric method for mild steel in 1M H_2SO_4 after 24 h

Concentration of inhibitor (g/l)	ΔW (g)	Corrosion Rate ($gcm^{-3}hrs^{-1}$) x 10^{-3}	% IE	Rate Constant (day-1) 10^{-3}	Half Life (days)
Blank	0.336	57.76	--------	1.90	3.65
1	0.144	24.75	57.15	0.79	8.77
2	0.096	16.50	71.43	0.52	13.33
3	0.047	8.08	86.01	0.25	27.72
4	0.027	4.64	92.00	0.15	46.20
5	0.015	2.58	95.53	0.08	86.63

Weight loss measurements

The weight loss of mild steel coupons due to their immersion in solutions of 1M H_2SO_4 containing different concentrations of *BE* seed extract was measured as shown in Table 2. The results clearly shows a general reduction in the original weight of the metal coupons in the presence of the inhibitor compared to the uninhibited solution (blank), indicating that ethanol extract of *BE* seed inhibited the corrosion of mild steel in 1M H_2SO_4 at the end of the corrosion monitoring process. This is further supported by the decrease in Corrosion rate and Rate constant as the concentration of the extract increases, this also is in tandem with what was observed in the inhibitory action of *Momordica charantia* seed extracts on the corrosion of mild steel (Kavitha *et al.*, 2017). This may be attributed to the adsorption of inhibitor on the mild steel surface, producing a barrier, which isolates the surface from the corrosion environment.

The corrosion rate for the mild steel and the inhibition efficiency of the plant extract in 1M H_2SO_4 containing different concentrations of the plant extracts as a function of time (in days) are also presented in Figs. 1 – 2.

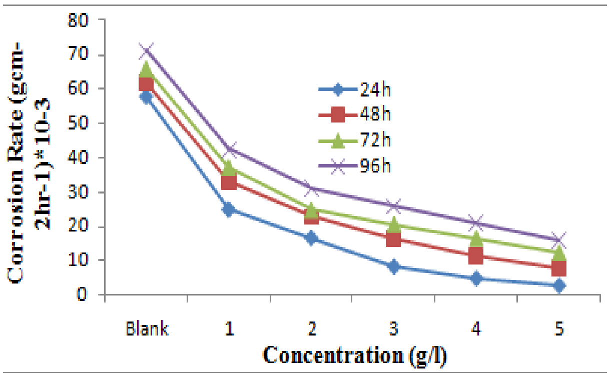

Fig. 1: Variation of corrosion rate of mild steel corrosion in 1M H_2SO_4 with different concentration of *BE* seed extract showing the effect of time

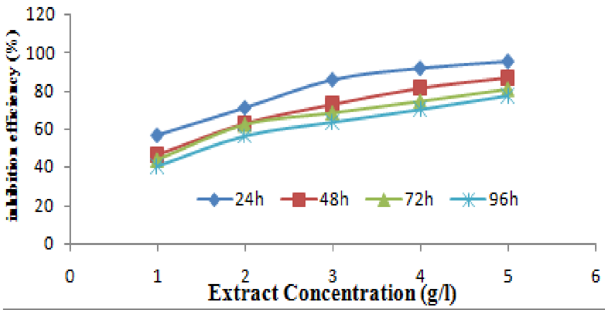

Fig. 2: Variation of inhibition efficiency of *BE* seed with concentration and time

The inhibition efficiency increased with increase in concentration of inhibitor from 1.0 to 5.0g/l at room temperature (Fig. 2). Maximum inhibition efficiency was 95.53% in case of *BES*/1MH_2SO_4 for immersion period of 24 h at a concentration of 5.0 g/l (Fig. 2). These results suggest that adsorption model arrangement and orientation of constituents present in *Brachystegia eurycoma* seed extract on the surface of mild steel may change with time (Rekha *et al.*, 2010). Decrease in inhibition efficiency thereafter with increasing time may be due to shift in adsorption and desorption equilibria which takes place simultaneously on prolonged exposure to corrosive media (Kavitha *et al.*, 2016). Adsorbed organic molecules prevent further interaction of metal with acid (Lahodny-Sarc and Kapor, 2002).

Figure 3 shows the plot of log W_f against Time (hrs), for *BE* seed extracts indicating a linear variation at all concentrations. The linearity of the plots confirmed a first order reaction kinetics with respect to the corrosion of mild steel in the acidic medium (1M H_2SO_4). This implies that the rate of the reaction was directly proportional to the concentration of the extracts (Rozenfeld, 1981). From Table 2, the values of rate constant of the reaction decreases as the concentration of *BE* seed extracts increased and were in agreement with the assertion that the rate of the reaction was directly proportional to the concentration of the of *BE* seed extracts (James and Akaranta, 2009). Since the rate of the reaction was first order, the half-life of the reaction which were determined using the expression for the half-life for a first order reaction, showed the time required for the concentration of *BE* seed extracts to be reduced to half its initial value. Table 2, also shows that the half-life of the reaction increased as the concentration increased. The increase in half-life as the concentration of the extracts increased indicated a decrease in the dissolution rate of the mild steel and hence more protection of the metals by the *BE* seed extracts (Akalezi and Oguzie, 2015; James and Akaranta, 2009).

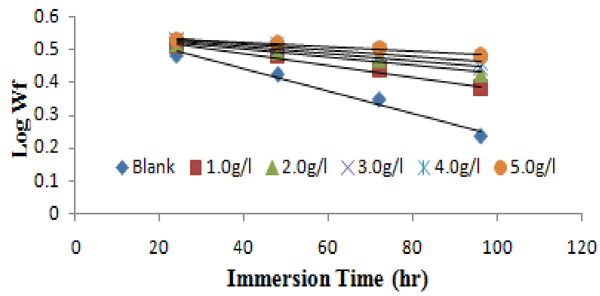

Fig. 3: Variation of logW_f with time for mild steel of in 1M H_2SO_4 solutions containing *BE* seed extract

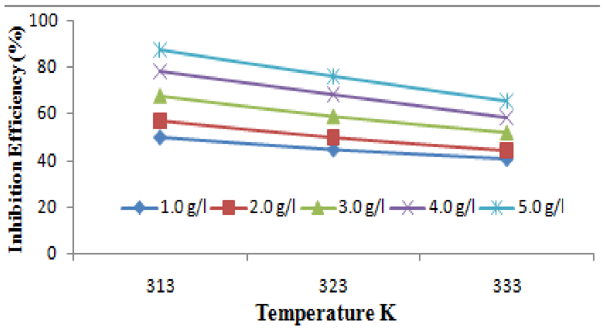

Fig. 4: Effect of Temperature on inhibition efficiency for mild steel corrosion in 1M H_2SO_4 at different concentration of *Brachystegia eurycoma* seed extract for immersion period of 2 h

Temperature effects

The weight loss experiment was also carried out at different temperature range of 313 – 333K in 1M H_2SO_4 to investigate the influence of temperature on the rate of corrosion and inhibition efficiency for immersion time of 2 h. The variation of inhibition efficiency with temperatures at different concentration of *BE* seed extract is shown in Fig. 4. From the plot, the inhibition efficiency increases with an increase in *BE* seed extract concentration but decreases with an increase in temperature.

According to Alinor and Ejimeke (2012), at higher temperatures, the average kinetic energy of components of extracts increases, thus making adsorption between components of extracts and a metal surface insufficient to retain the species at the binding site and this could lead to desorption or cause the species to bounce off the surface of the metal instead of colliding and combining with it. Moreover, the solubility of the protective films on the metal surface would have occurred at a higher temperature, hereby exposing the metal surface to the aggressive medium, leading to more dissolution at this temperature.

The values of the corrosion rate at different temperatures are summarised in Table 3. It is clear from the table that the corrosion rate increases with a rise in temperature. This happened to be the case because, as the temperature increases, the average kinetic energy of the reactant molecules increases, thereby increasing the rate of the reaction. A decrease in inhibition efficiency with a rise in temperature and a corresponding increase in activation energy (E_a) in the presence of an inhibitor is termed physical adsorption mechanism (Ebenso *et al.*, 2008).

Table 3: Temperature effect on corrosion rate (CR), activation energy (E_a), standard free energy (ΔG^o_{ads}) and heart of adsorption for mild steel in 1M H_2SO_4 in absence and presence of *BE* seed extract for an immersion time of 2 h

Concentration of inhibitor (g/l)	Temperature						E_a KJmol^{-1}	K_{ads}	ΔG^o_{ads} KJmol^{-1}	Q_{ads} KJmol^{-1}
	313K		323K		333K					
	CR (gcm^{-3} hrs^{-1})x10^{-3}	IE %	CR (gcm^{-3}hrs^{-1})x10^{-3}	IE %	CR (gcm^{-3} hrs^{-1})x10^{-3}	IE %				
Blank	115.51	–	156.77	–	222.77	–	28.45	–	–	–
1.0	57.76	50.00	86.63	44.74	132.01	40.74	35.81	1.00	-10.45	-16.32
2.0	49.51	57.10	78.38	50.00	123.76	44.44	39.70	0.67	-9.41	-17.19
3.0	37.13	67.86	66.01	58.90	107.26	51.85	46.00	0.71	-9.56	-12.26
4.0	24.75	78.57	49.51	68.42	92.82	58.33	57.26	2.88	-13.21	-41.82
5.0	14.44	87.50	37.13	76.32	76.32	65.74	72.12	4.24	-14.21	-56.19

The values of activation energy (E_a) for the corrosion process were calculated using Arrhenius equation represented by Equation 7;

$$\log\left(\frac{C2}{C1}\right) = \frac{Ea}{2.303R}\left(\frac{1}{T1} - \frac{1}{T2}\right) \qquad 7$$

Where: C_1 is the corrosion rate at temperature, T_1, C_2 is the corrosion rates at temperature, T_2, E_a is the Activation Energy, R is the universal gas constant. Protective films formed on the surface of the mild steel, increases the activation energy of the metal dissolution. In a chemical reaction, when the activation energy increases, the rate of the reaction decreases (Okorokwo *et al.*, 2015). This is also seen in the results shown in Table 3; the addition of the inhibitor increases Ea, thereby reducing the rate of the metal dissolution into the electrolyte.

Thermodynamics and adsorption mechanism

The heat of adsorption (Q_{ads}) of BE seed extract on the surface of mild steel has been calculated using equation 2.5 (Ebenso, 2003a,b, 2004; Umoren *et al*., 2006a, 2006b, 2007).

$$Q_{ads} = 2.303R\left(\log\left[\frac{\theta 2}{1-\theta 2}\right] - \log\left[\frac{\theta 1}{1-\theta 1}\right]\right) \times \left[\frac{T1T2}{T2-T1}\right] \quad 8$$

Values of Q_{ads} calculated through equation 8 are recorded in Table 3. These values are negative and ranged from -16.32 to -56.19 KJ/mol indicating that the adsorption of the extract is exothermic (Ebenso, 2003a,b, 2004; Bhajiwala and Vashi, 2001). Values of free energy of adsorption of *BE* seed extract were calculated using equation 9.

$$\Delta G^\circ_{ads} = - RTIn(55.5K_{ads}) \qquad 9$$

Where: $K_{ads} = \frac{\theta}{C(\theta-1)}$ is the adsorption equilibrium constant, C is the concentration of the inhibitor, R is the universal gas constant. The calculated values of ΔG°_{ads} for the plant extract are also recorded in Table 3. From the result obtained, The values are found to be negatively less than the threshold value of -40 kJ mol^{-1} required for the mechanism of chemical adsorption to take place. This indicates that the adsorption of the studied plant extract on the mild steel surface is spontaneous and is consistent with the mechanism physical adsorption (Ebenso, 2003a, b, 2004; Bhajiwala and Vashi, 2001; Loto, 2011).

Adsorption isotherms are very important in determining the mechanism of corrosion reactions. The most frequently used isotherms are Langmuir, Frumkin, Hill de-Boer, Parsons, Temkin, Flory-Huggin, Freundlich, Dhar-Flory-Huggin, Kinetic/Thermodynamic model of El-Awady *et al*. and Bockris-Swinkels. All these isotherms are of the general form:

$$f(\theta,\chi)\exp(-2\alpha\theta) = KC \qquad 10$$

Where: f (θ, χ) is the configurational factor which depends upon the physical model and the assumptions underlying the derivation of the isotherm, θ, the surface coverage, C, the inhibitor concentration in the electrolyte, χ, the size factor ratio, α the molecular interaction parameter and K the equilibrium constant of the adsorption process. The degree of surface coverage (θ) was evaluated from the weight loss measurements. In this study, Langmuir adsorption isotherm was found to be suitable for the experimental findings and has been used to describe the adsorption characteristic of this inhibitor.

Figure 5 shows the linear plots for Langmuir adsorption isotherm. The plots clearly revealed that the surface adsorption process of the *BE* seed extracts on the mild steel surface obeyed the Langmuir adsorption isotherm as their linear regression approaches unity (Bammou *et al.*, 2014). The plots support the assertion that the mechanism of corrosion inhibition is due to the formation and maintenance of a monolayer protective film on the metal surface and producing uniform energies of adsorption onto the surface of the metal following Langmuir isotherm. It can therefore be inferred that physisorption occurred (James and Akaranta, 2009; Okoronkwo *et al.*, 2015). Assumptions of Langmuir adsorption isotherm is expressed in equation 11 below (Shockry *et al*., 1998):

$$C/\theta = 1/k + C \qquad 11$$

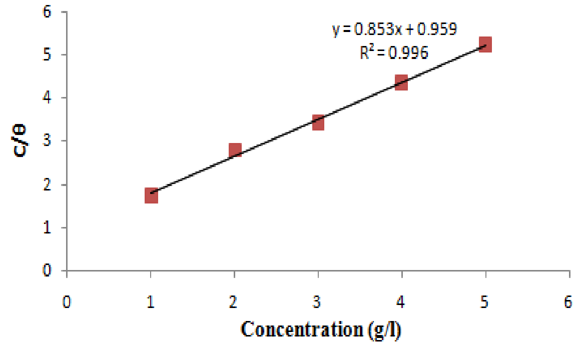

Fig. 5: Langmuir adsorption isotherm plot for the adsorption of *BES* on the surface of mild in 1M H_2SO_4 acid solution

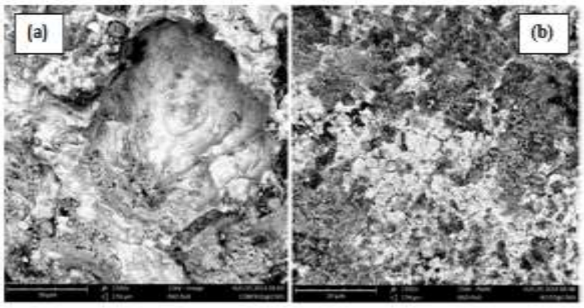

Fig. 6: (a) SEM of the mildsteel immersed in 1M H_2SO_4 solution without inhibitor for 5 hrs at 50 magnification and (b) SEM of the mild steel alone and in the presence of *BE* seed extract

Surface studies by scanning electron microscopy

Morphological analysis using SEM shows differences in the morphologies of the samples in the uninhibited and inhibited medium. Fig. 6 showed the SEM image of the mild steel surface immersed in the uninhibited medium for 5 h, big pits and cracks observed in the image are due to the effect of corrosion on the specimen infused by the acid. Similar image of mild steel immersed in the inhibited medium are also shown in Fig. 6, Smother surfaces with little cracks observed are due to the formation of a thin film layer infused by the complexation between the mild steel and the phyto-chemical constituents in the extract. This implies corrosion rate was lowered by the extract which is in agreement with the results obtained from the weight loss analysis.

Infrared spectroscopy analysis

FTIR analysis is used to ascertain the fact that the corrosion inhibition process takes place through the adsorption of the phytochemical constituents on the mild steel surface. The spectra of the extract are presented in Fig. 7. From the result obtained, the strong and broad peak of O–H stretching that obscured the appearance of other peaks basically N-H peak occurs at 3419 cm^{-1} with C-H stretching vibration occurring at 2927 cm^{-1}. The strong band at 1630 cm^{-1} is assigned to C=C and C=O stretching vibration. Owing to the conjugation effect of flavonoids of *BE* seed extract, the C=O peak shifts from about 1700 cm^{-1} to lower wave number (approximately 1630 cm^{-1}), C=C and C=O stretching vibration bands are superposition (Deng *et al.*, 2007). The C-H bending bands in $-CH_2$ and $-CH_3$ are found to be at 1409 cm^{-1}. The absorption bands at 1272 cm^{-1} could be assigned to the framework vibration of aromatic ring.

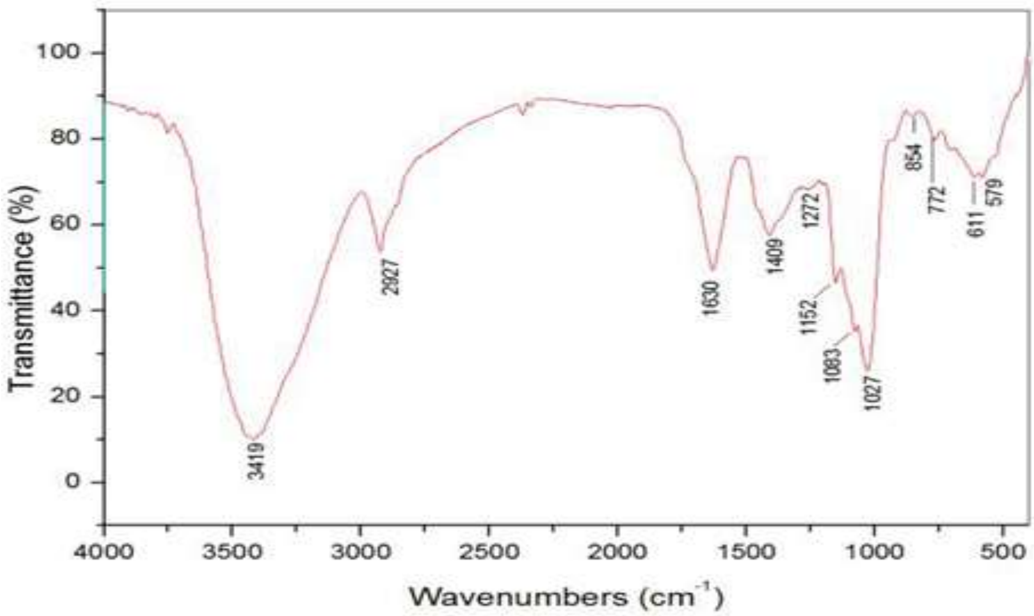

Fig. 7: FTIR spectra of *Brachystegia eurycoma* seed extract (*BE*SE)

The IR spectra of the extracts showed peaks attributed to the characteristics of the functional groups. The presence of these functional groups indicates the effectiveness of the extract constituents to interact with the mild steel surface and that adsorption between the extract and the mild steel occurs through the identified functional groups (Okoronkwo *et al.*, 2015). Hence, protection of metallic surface is done via the functional groups presented in the flavonoids, tannin, carbohydrates, alkaloid and amino acids as the main constituents of *Brachystegia eurycoma* seed extracts.

Conclusion

From the above results and discussions, the following conclusion was drawn:

All the studied phytochemical constituent of the seed extracts acts as an effective corrosion inhibitor of mild steel in 1M

H_2SO_4 acid solution and their inhibition efficiency increases with increase in the concentration of the seed extracts with maximum efficiency obtained at an optimum concentration of 5.0g/l within the first 24 hours. The adsorption data was best fitted into Langmuir adsorption models. The results of SEM and Fourier transform infrared spectroscopy (FTIR) all indicate that the corrosion reaction was inhibited by the adsorption of the extract's organic matter onto the corroding mild steel surface.

The trends of inhibition efficiency with temperature as well as values of kinetic and activation parameters for corrosion and corrosion inhibition processes point toward significant physiosorption of the extract constituents on the mild steel surface.

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Conflict of Interest

Authors have declared that there is no conflict of interest reported in this work.

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