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ORIGINAL RESEARCH ARTICLE

ADSORPTION AND THERMODYNAMICS STUDIES OF CORROSION INHIBITION ON CARBON STEEL USING PUMPKIN POD EXTRACT (*Telfairia occidentalis*)

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ABSTRACT

In this study, the inhibition effect of ethanolic extract of pumpkin pod (Telfairia occidentalis) on the corrosion of carbon steel in acidic medium was investigated using weight loss method at 308K - 348K. The energy of activation, adsorption and thermodynamics parameters such as enthalpy, entropy, and Gibb's free energy were evaluated from the results of temperature studies. The activation enthalpy of corrosion process increases from 28.782kJ/mol to 62.678kJ/mol. As the temperature increased, the inhibition efficiency decreased. The adsorption of pumpkin pod extract on carbon steel was found to best fit Langmuir, and Freundlich adsorption isotherms. The activation energy of adsorption and Gibb's free energy values indicated an endothermic and strong spontaneous adsorption of the pumpkin pod extract on the surface of carbon steel respectively. Scan Electron Microscope (SEM) analyses showed that Pumpkin pods (Telfairia occidentalis) extract protected the surface of the metal from corrosion by forming a protective layer on the metal surface.

1.0 Introduction

Corrosion is a natural occurrence which results in the deterioration of metals by chemical attack or reaction with its environment. Corrosion is inevitable for metals, therefore its control and management are more practicable than complete elimination. Inhibitors are often added in industrial processes to secure metal dissolution from acid solutions. The known hazardous effects of most synthetic organic inhibitors and the need to develop cheap, nontoxic and ecofriendly processes have now made researchers to focus on the use of natural products.
The performance of an organic inhibitor is related to the chemical structure and physicochemical properties of the compound like functional groups, electron density at the donor atom, p-orbital character, and the electronic structure of the molecule. The inhibition could be due to adsorption of the molecules or its ions on anodic and/or cathodic sites, increase in cathodic and/or anodic over voltage, and the formation of a protective barrier film (Rani and Basu, 2012). Organic inhibitors generally have heteroatoms; O, N, and S are found to have higher basicity and electron density and thus act as corrosion inhibitors. The heteroatoms are the active centre for the process of adsorption on the metal surface. The use of organic compounds containing oxygen, sulphur, and especially nitrogen to reduce corrosion attack on steel has been studied.

The previous research work carried out on most organic inhibitors showed that organic inhibitors are adsorbed on the surface of metal by displacing water molecules on the surface and forming a compact barrier. Availability of non-bonded (lone pair) and p-electrons in inhibitor molecules facilitate electron transfer from the inhibitor to the metal. A coordinate covalent bond involving transfer of electrons from inhibitor to the metal surface may be formed (Evans, 1976; Rani and Basu, 2012). In a bid to have less expensive, environmentally friendly, readily available and less toxic inhibitors, researchers have used various plant materials as corrosion inhibitors. Pumpkin (*Telfairia occidentalis*) is a tropical vine grown in Nigeria and other West African region for its leaf and edible seeds. The phyto-chemical composition of the leaf, root, pod and stem were investigated (Ogbonnaya and Uadia, 2016). Akwukwaegbu et al. (2016) investigated the phytochemical composition of the pumpkin pod, it was found out that it contains tannins, saponins, alkaloids, and flavonoids. This present study investigated the use of pumpkin pod extract as an inhibitor, its mechanism of adsorption, and adsorption isotherms.

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2. Materials and Methods

2.1 Materials

Pumpkin pods (*Telfairia occidentalis*) were obtained from Agbarho Community in Effurun, Delta State, Nigeria. Carbon steel was procured from accredited iron sheet dealer in Effurun and machined in Mechanical Workshop at Federal University of Petroleum Resources, Delta State. HANNA model pH – 211 (pH meter), Genlab oven model Mino/75/f (oven), weighing balance of model (BH – 600), and beakers, were employed for this corrosion study. Hydrochloric acid, acetone, and ethanol solutions used were of analytical grades (Sigma Aldrich). Distilled water was procured from the Department of Chemical Engineering Laboratory, Federal University of Petroleum Resources, Effurun Delta, State, Nigeria for both sample preparation and solutions.

2.2 Methods

2.2.1 Pre-treatment of sample and sample characterization

Pumpkin pods were thoroughly washed thereafter sun dried and pulverized into powdery form with the aid of laboratory blender. It was then sieved with a sieve of 0.143µm mesh. The sample was later stored in a desiccator prior to use.

2.2.2 Fourier Transform Infrared Spectroscopy (FTIR)

Pumpkin pods (*Telfairia occidentalis*) 0.143µm particle size was observed with FTIR spectroscopy (Buck Scientific model 530) with the range 500 - 4000 cm^{-1} (wavelength). The background material used in the analysis is potassium bromate (KBr).

2.2.3 X – ray Fluorescence Analysis (X – RF)

The elemental compositions of the carbon steel used was observed with X – supreme 800, Oxford instrument. The metal was machined to flat shape of 20 – 50 mm diameter. Sample cup was cleaned and filter fixed in it shape thereafter the metal sample was placed in the cup to cover the filter and ensure a thickness of 3mm at the bottom. The instrument was switched on, the elemental composition method was selected, and the sample identity was then level in the position selected with reading accepted. The instrument was rotated to the position of the sample in the tray at X – ray position after the start button was pressed while the intensity of radiation was now converted to the weight percentage.

2.2.4 Extraction of Pumpkin pods (Telfairia occidentalis) extract

50 g of the dried Pumpkin pods (*Telfairia occidentalis*) powder was transferred into a 500 mL Soxhlet extractor and 500 mL of 70% ethanol reflux continuously for 3 hours at 78 °C. The set-up was placed on a heating mantle and the Pumpkin pods (*Telfairia occidentalis*) extract was extracted exhaustively by heating the solution. The extract was obtained after recovering ethanol in a Rotary evaporator (model R-210) at 40 °C.

2.3 Weight loss measurement

The gravimetric or weight loss method was used. The carbon steel was mechanically polished with silicon carbide abrasive paper, degreased with ethanol, washed in distilled water and dried in acetone. Each carbon steel coupon was sized 40 mm × 20 mm × 2 mm. Before polishing, a hole of 0.1 cm was drilled on each coupon. The coupon was suspended with the aid of a nylon thread in a 100 ml beaker with 100ml of 1.5M HCl at different inhibitor concentrations. The mechanism of inhibition and thermodynamic parameters were studied at 308, 318, 328, 338, and 348 K temperature at contact time of 7 hours.

Each of the carbon steel metal coupon after the corrosion process was dipped in both distilled water and ethanol solutions. This was scrubbed to remove any remaining residual inhibitor concentration and HCl. Thereafter, the coupon was then washed thoroughly with washing liquor, rinsed with distilled water and later dried in acetone before been reweighed.

2.4 Determination of weight loss

The weight loss of the carbon steel coupon was determined using Equation 1 below:

$$\text{Weight loss, (g)} = W - W_i \quad (1)$$

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where: W is the initial weight of the mild steel coupon, W_i is the weight of the carbon steel coupon after corrosion study.

2.5 Determination of inhibitor efficiency

The efficiency of corrosion inhibition was obtained using Equation 2

$$E(\%) = \frac{W_b - W_c}{W_b} \times 100 \quad (2)$$

where: W_b is the loss in weight in uninhibited medium (blank), and W_c is the loss in weight in inhibited medium.

2.6 Corrosion rate determination

The expression for measurement of corrosion rate (C.R) in millimeters penetration per year (mm/yr) was used to measure the rate of corrosion rate for the specimens, which was expressed in equation 3 (Callister, 1997).

$$C.\ R. = \frac{87.6w}{atρ} \quad (3)$$

where: w is corrosion weight loss of carbon steel (mg), a is the total surface area of the specimen in (cm^2), t is the exposure time in hours (h), and ρ is the density of the specimen (g/cm^3).

2.7 Determination of Activation Energy

The activation energy parameter of the corrosion inhibition process on carbon steel surface was gotten using Equation (4) below

$$\log CR = \log A - \frac{E_a}{2.303RT} \quad (4)$$

where: CR is the rate of corrosion, E_a is the apparent activation energy, R is the universal gas constant, T is the absolute temperature, and A is the frequency factor.

2.8 Determination of Thermodynamic parameters

The thermodynamic parameters such as enthalpy, and entropy of carbon steel corrosion inhibition in acidic medium was calculated using Equation (5) while the Gibb's free energy was calculated using Equation (6).

The transition state theory equation given by equation 5 was used (Mouheddin et al. 2018; Ogoke et al. 2009).

$$\log\left(\frac{C_R}{T}\right) = \left[\log\left(\frac{R}{Nh}\right) + \frac{\Delta S^o}{2.303R}\right] - \frac{\Delta H^o}{2.303RT} \quad (5)$$

where: h is the Planck's constant (6.626176×10^{-34} Js), N is the Avogadro's number, (6.022×10^{23} mol^{-1}), R is the Universal gas constant (8.314 J/Kmol) and T is the temperature of the medium.

The Gibb's free energy of adsorption ($\Delta G°_{ads}$) which can characterize the interaction of adsorbed molecules and metal surface

$$\Delta G°_{ads} = - RT \ln (55.5 \times k_{ads}) \quad (6)$$

where: k_{ads} is the adsorption equilibrium constant, R is the gas constant (8.314 J/mol.K), T is the absolute temperature in Kelvin and the value 55.5 is the concentration of water in solution expressed in mol/L..

2.9 Adsorption Isotherms

Four different adsorption isotherms were tested so as to have an understanding on the interface between the inhibitor and carbon steel surface. The isotherms tested were Langmuir,

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Freundlich, Temkin, and El - Awady adsorption isotherms. The linear regression coefficient of determination (R^2) was used to determine the model that fitted best to the experimental values.

2.9.1 Langmuir isotherm

Langmuir relationship is represented by equation (7)

$$\frac{C}{\theta} = \frac{1}{K} + C \qquad (7)$$

where: K is the equilibrium constant of adsorption (M^{-1}) which was employed to obtain the Gibb's free energy, C is the inhibitor concentration ppm, and Θ is the degree of surface coverage (Rajendran et al. 2000; Nnanna et al. 2014).

2.9.2 Freundlich isotherm

The fitting of non – ideal system can be done sometimes by fitting the experimental data to Freundlich adsorption isotherm as seen in figure 6 (Yaro and Khadom, 2008). This is expressed in equation 8:

$$\theta = KC^n \qquad (8)$$

Equation 8 can be re – written

$$\ln\theta = \ln K + n\ln C \qquad (9)$$

where: Θ is the degree of surface coverage, C is the inhibitor concentration, in ppm, K is the adsorption constant which is a measure of adsorption capacity, (L/g), and n is the positive constant called the Freundlich exponent which talks about the intensity of adsorption process on the carbon steel surface.

2.9.3 Temkin isotherm

This is expressed in equation (10) while the linear form of equation (10) is given by equation (11)

$$\theta = \frac{1}{f}\ln(K_{ads}C) \qquad (10)$$

Equation 10 can be re - written as $\theta = \frac{1}{f}\ln C + \frac{1}{f}\ln K$ (11)

where: Θ is a linear function of ln C (Nnanna et al. 2010), K is the equilibrium constant of adsorption, (L/g), C is the inhibitor concentration, (g/L), and f is a coefficient of inhomogeneity connected with the range of inhomogeneity C by equation 12.

$$f = C/RT \qquad (12)$$

2.9.4 El-Awady isotherm

This model is also referred to as the kinetic/thermodynamic model and is written as follows;

$$\log\left(\frac{\theta}{1-\theta}\right) = \log k + y\log C \qquad (13)$$

where: y represents the number of inhibitor molecules occupying one active site of the metal surface, Θ is the degree of surface coverage, C is the inhibitor concentration, ppm. y can be related to the binding constant, B, according to equation (14).

$$B = k^{1/y} \qquad (14)$$

When 1/y>1, each inhibitor molecule is believed to occupying more than one active site on the metal surface and vice – versa (Fouda and Ellithy, 2009).

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3. Results and Discussion

3.1 Characterization of carbon steel and Pumpkin pods (*Telfairia occidentalis*) extract

Table 1 shows the result of the X – ray fluorescence of the carbon steel used.

Table 1: Result of the X – RF Analysis on carbon steel

Elements	Concentration (mg/kg)
Magnesium	81.865
Aluminium	685.113
Silicon	281.657
Sulphur	164.989
Chlorine	363.401
Calcium	113.130
Titanium	161.193
Chromium	191.483
Manganese	733.821
Iron	173710.764
Cobalt	132.529
Lead	26.057
Bromine	47.343

FTIR analysis of Pumpkin pod (*Telfairia occidentalis*) extract

The FTIR spectrum of Pumpkin pods (*Telfairia occidentalis*) extract is shown in Figure 1. At broad band of 3324 cm^{-1} corresponds to an alcoholic –OH stretching group. The peak at 2974 cm^{-1} can be assigned to alcoholic C-H group. 1639 cm^{-1} wavelength indicates an aromatic (C=C) stretching while the value of 1728 cm^{-1} suggest (C=O) stretching frequency. Aromatic rings due to aromatic skeletal vibrations is noticed at 1508 cm^{-1} and 1421cm^{-1} can be assigned to aromatic rings due to aromatic skeletal vibrations. The broad band of 1329 cm^{-1} seen in the spectrograph is due to bending vibrations of OH group while 1209 cm^{-1} is due to guaicynl ring in conjunction with C-O stretching group. The presence of aromatic, and carbonyl groups in the extract suggest that it can be used as an inhibitor.

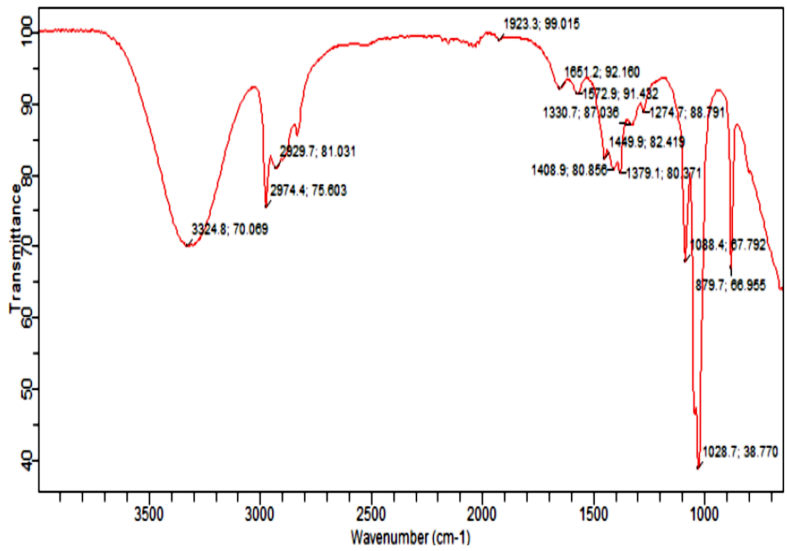

Figure 1: FTIR spectra of Pumpkin pod extract

3.2 Effect of Temperature

Figure 2 shows inhibition efficiency against temperature at 7 h immersion time. The results show that with increase in temperature the percentage of inhibition efficiency for the inhibitor at different concentration decreases, a trend that supports physical adsorption mechanism. This can be explained that the protective films of the inhibitor are formed on the surface of the carbon steel are less stable at higher temperature. It can be due to desorption of some

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adsorbed molecules from the surface of the carbon steel at higher temperature thereby leading to the greater area of carbon steel been exposed to attack from the acidic environment. The results obtained in this work is similar to that reported by Abd El-Hameed, (2011).

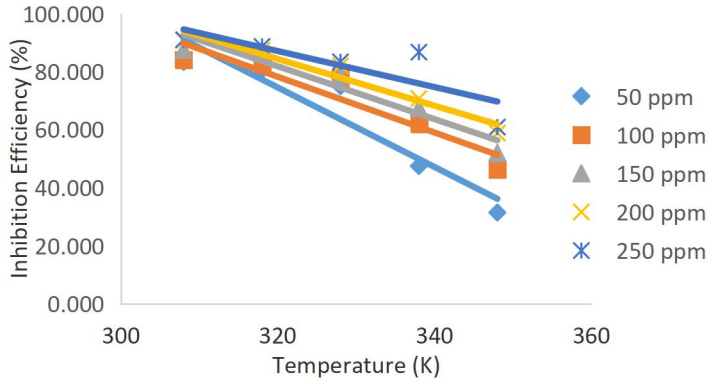

Figure 2: Effect of temperature on inhibition efficiency of Pumpkin Pod Extract

3.3 Thermodynamic activation parameters of the corrosion process

Arrhenius equation represented by Equation (4) was used to calculate the activation energy Ea in the presence and absence of cocoa leaf extract inhibitor. The Arrhenius plot of log CR against reciprocal of absolute temperature (1/T) is shown in Figure 3 which gives a straight-line graph with slope equal to $-E_a/2.303R$ and the intercept equal to log A.

Hence, the activation energy (E_a) and the pre-exponential factors (A) were calculated and tabulated in Table 2. These activation energy values were found to range from 58.75 kJ/mol - 65.511 kJ/mol. The value obtained for Pumpkin pods (*Telfairia occidentalis*) inhibitor used was higher than that of the blank, indicating that the corrosion of carbon steel is retarded by the presence of Pumpkin pods (*Telfairia occidentalis*) extract in HCl. It can also be observed that the activation energy value obtained is lower than the threshold value of 80 kJ/mol that is required for chemical adsorption mechanism. It can be suggested that the inhibitor adsorption mechanism on the carbon steel surface is physisorption. Higher values of E_a in the presence of inhibitor is a good indication that the extract increases the energy barrier for the corrosion process. This process occurs because the pumpkin pod extract (inhibitor) forms a passive layer on the surface of the carbon steel, thereby making the solubility of iron (Fe) to be reduced (Yetri et al., 2015). Similar results were reported in findings of Eddy et al. (2009).

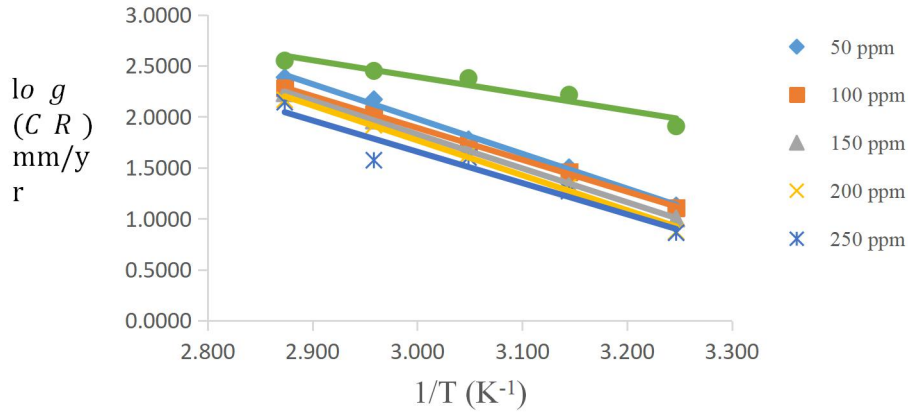

Figure 3: Plot of log corrosion rate against the inverse of absolute temperature

Thermodynamic properties such as Enthalpy (ΔH°) and Entropy of Activation (ΔS°) are studied so as to determine the mechanism of adsorption process involved in the corrosion process. In other to calculate the thermodynamic parameters like enthalpy (ΔH_{ads}), and entropy (ΔS_{ads}) of corrosion process in the presence and absence of Pumpkin pods (*Telfairia occidentalis*) extract in acidic environment. The plot of log (CR/T) against 1/T is seen to be linear in figure 4 from which (ΔH°) and (ΔS°) values were deduced from the slopes and intercept of the graph respectively and listed in Table 2. The enthalpy of activation (ΔH_{ads}) and the entropy of

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activation (ΔS_{ads}) were calculated, alongside their linear regression coefficient which is indicated in Table 3. The large positive values of ΔH_{ads} and the negative value of ΔS_{ads} indicate that the adsorption of Pumpkin pods (*Telfairia occidentalis*) extract on the surface of carbon steel is endothermic in nature. It is also noted that the values of activation energy (E_a) are larger than the corresponding values of (ΔH_{ads}) which indicate that the corrosion process might have involved a gaseous reaction, like the evolution of hydrogen reaction, associated with a decrease in the total reaction volume (Andreani, 2016). Also, the average difference in the value of the ($Ea - \Delta H_{ads}$) is 2.72 kJ/mol which is approximately equal to the value of RT (2.73 kJ/mol) at the average temperature (328 K) used in the study. This result is in agreement with known perfect gas equation which suggest that the corrosion process is a unimolecular reaction. The result obtained shows that the inhibitor acted equally on Eads, and ΔH_{ads}. The result of this work corroborate the findings of Zarrouk et al. (2011).

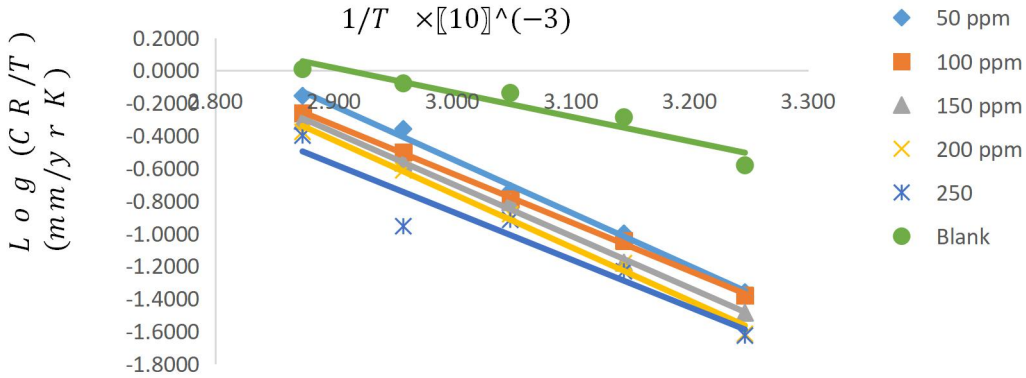

Figure 4: Showing the plot of Log CR/T against the inverse of Absolute Temperature

Table 2: Activation energy, enthalpy and entropy of corrosion inhibition using pumpkin pods (*Telfairia occidentalis*) on carbon steel.

Inhibitor Concentration (ppm)	E_a (kJ/mol)	$\Delta H°$ (KJ/mol)	$E_a - \Delta H°$	$\Delta S°$ (J/mol K)
50	65.399	62.678	2.721	- 19.966
100	59.856	57.135	2.721	- 38.284
150	63.685	60.965	2.72	- 28.025
200	65.512	62.793	2.72	- 23.66
250	59.088	56.034	3.054	- 46.069
Blank	31.503	28.782	2.721	- 113.786

Large and negative values of entropies show that the activated complex in the rate determining step represents an association rather than a dissociation step, meaning that a decrease in disordering takes place on going from reactants to the activated complex (Dahmani, et al., 2010).

Table 4 depicts adsorption thermodynamic parameters of the Pumpkin pods (*Telfairia occidentalis*). The negative value of ($\Delta G°_{ads}$) ensures stability, strong and spontaneous adsorption of the Pumpkin pods (*Telfairia occidentalis*) on the metal surface, which explains its high corrosion inhibition efficiency of absorbed layer on the metal surface for the adsorption process. It can be seen that there was a decrease in the absolute value of free energy ($\Delta G°_{ads}$) with rise in temperature which implied a physical adsorption mechanism. Generally, the values of (ΔG_{ads}) up to -20 KJ/mol are associated with the electrostatic interaction between the charged molecules and charged metal (physisorption), while those negative values higher than -40 KJ/mol involve sharing or transfer of electrons from the inhibitor to the metal surface to form a co-ordinate type of bond (Chemisorption). The calculated value of ($\Delta G°_{ads}$) was found to be negatively less than 40 KJ/mol. In general, the adsorption may be enhanced by the presence of hetero atoms like N / O / S atoms with lone pair of electrons, in the inhibitor molecules that makes it adsorbed electrostatically on the metal surface forming insoluble stable films and thus decreasing metal dissolution.

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3. 4 Adsorption Isotherm

For Langmuir isotherm a plot of C/Θ against C as depicted in figure 5 gave a reciprocal of intercept as the adsorption constant.

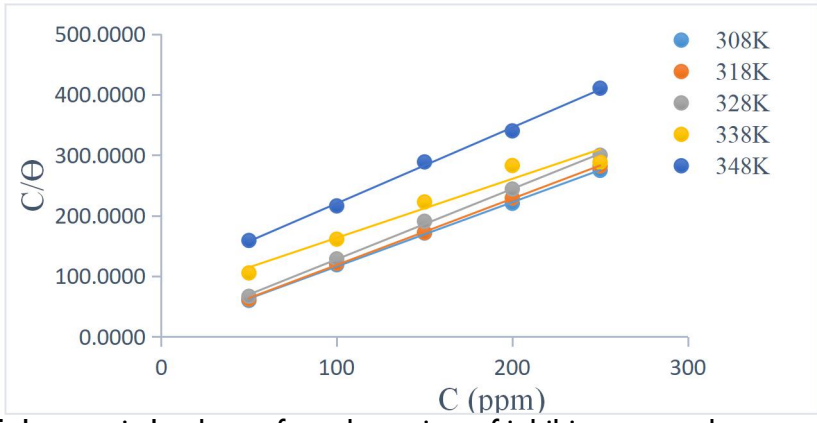

Figure 5: Langmuir Isotherm for adsorption of inhibitor on carbon steel surface

Freundlich isotherm as seen in Figure 6 is a plot of log Θ against log C which gave a straight line.

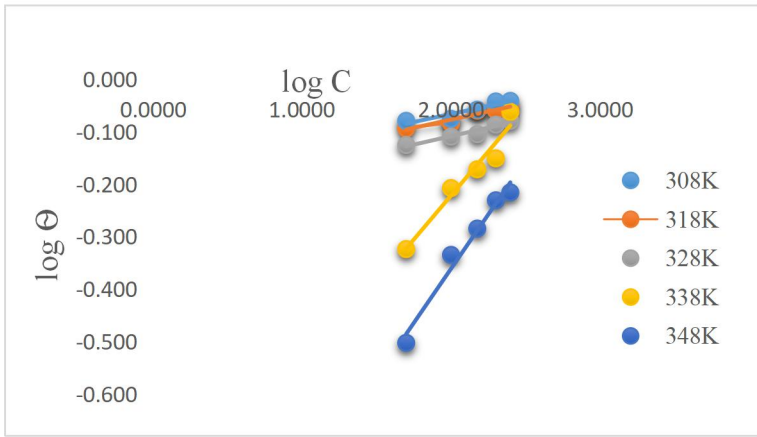

Figure 6: Freundlich Isotherm for adsorption of inhibitor on carbon steel surface

Temkin isotherm is depicted in Figure 7 which showed a plot of Θ against lnC that gave a straight line which is an indication that Temkin isotherm model is followed.

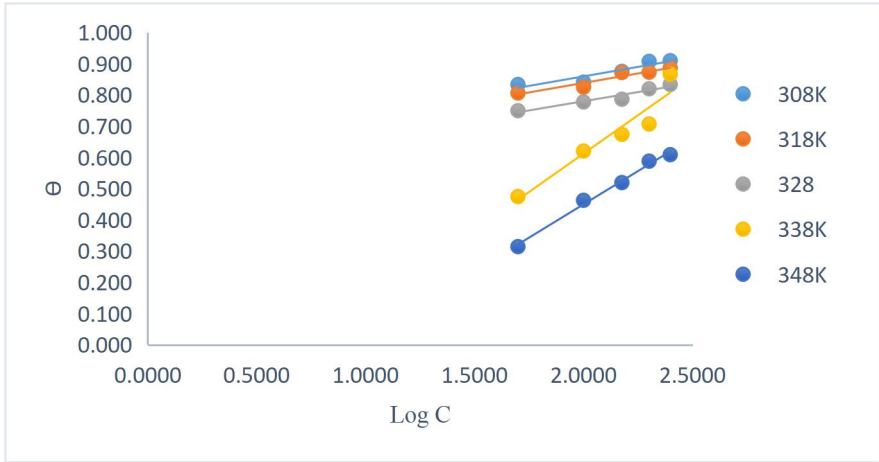

Figure 7: Temkin Isotherm for adsorption of inhibitor on carbon steel surface

El – Awady isotherm is a plot of log (Θ/1-Θ) against log C which is shown in Figure 8. It can be used to determine the associated parameters such as the reciprocal of y which is used to describe the number of active sites on the surface occupied by one molecule of the inhibitor on the surface of steel metal.

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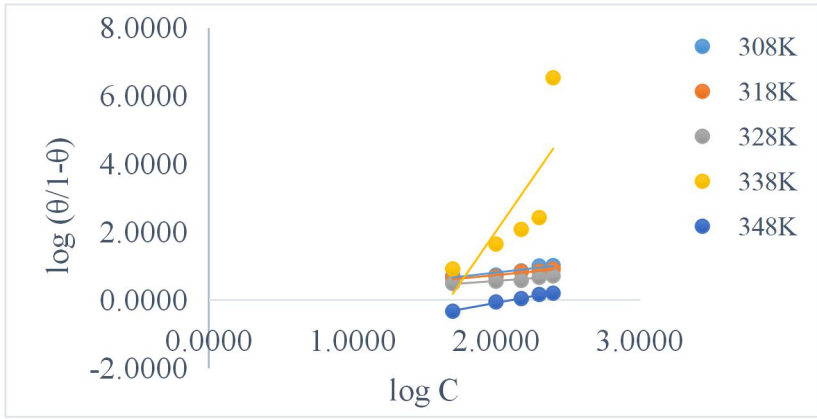

Figure 8: El - Awady Isotherm for adsorption of inhibitor on carbon steel surface

Table 3: Langmuir Adsorption Isotherms Parameters

Temperature (K)	K_{ads} (L/g)	R^2	ΔG (KJmol^{-1})
308	0.1025	0.9991	-4.452
318	0.1119	0.9995	-4.828
328	0.0875	0.9989	-4.309
338	0.015	0.9543	0.515
348	0.011	0.9977	1.428

Table 4: Freundlich Adsorption Isotherm Parameters

Temperature (K)	K_{ads} (L/g)	R^2	ΔG (KJmol^{-1})
308	0.6494	0.8825	-9.179
318	0.6286	0.9287	-9.391
328	0.5776	0.9394	-9.455
338	0.1281	0.9484	-5.512
348	0.0649	0.9739	-3.708

Table 5: Temkin Adsorption Isotherm Parameters

Temperature (K)	K_{ads} (L/g)	R^2	ΔG (KJmol^{-1})
308	4.13	0.8792	-13.916
318	3.942	0.9271	-14.045
328	3.506	0.9331	-14.373
338	2.349	0.9117	-13.686
348	2.526	0.9918	-14.301

Table 6 El - Awady Adsorption Isotherm Parameters

Temperature (K)	K_{ads} (L/g)	R^2	ΔG (KJmol^{-1})
308	0.682	0.8583	-9.305
318	0.803	0.9201	-10.039
328	0.855	0.9193	-10.525
338	$6.35E^{-11}$	0.5831	54.695
348	0.0237	0.9903	-0.793

Tables 3 – 6 shows the various parameters of adsorption isotherms studied. The adsorption equilibrium constant (K_{ads}) value was seen to decrease with increase in temperature, this indicates that, the inhibitor is easily adsorbed on the carbon steel surface at lower temperature. But when the temperature was higher, the adsorbed inhibitor tended to desorb from the carbon steel surface. The result obtained in this work is similar to that reported by Manimegalai and Manjula (2015). Langmuir adsorption isotherm indicated that the PPE extract contains organic compounds having polar atom or groups which are adsorbed on the metal surface and may interact by mutual repulsion or attraction (Subhashini, 2004; Sivaraju and Kannan, 2010).

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3.5 Surface morphology analysis

Scanning electron microscope (SEM) images were taken in order to study the surface morphology of carbon steel in absence and presence of Pumpkin pods (*Telfairia occidentalis* inhibitor. Figure 9a revealed that in the presence of Pumpkin pods (*Telfairia occidentalis*) inhibitor in 1.5M HCl solution while Figure 9b showed the carbon steel without inhibitor. Figure 9a is the carbon steel metal in 250ppm of Pumpkin pods (*Telfairia occidentalis*) after 120 hr. It showed a surface with fibre –like protective layer as a result of the Pumpkin pods (*Telfairia occidentalis*) extract deposition on the metal surface. Figure 9b shape is that typical to pitting corrosion (Andreani, et al., 2016). Comparison of both Figure 9a and 9b showed that the pits had disappear and carbon steel surface is almost free from corrosion in HCl due to the formation of an adsorbed film (protective layer) of Pumpkin pods (*Telfairia occidentalis*) on the carbon steel surface.

(a)

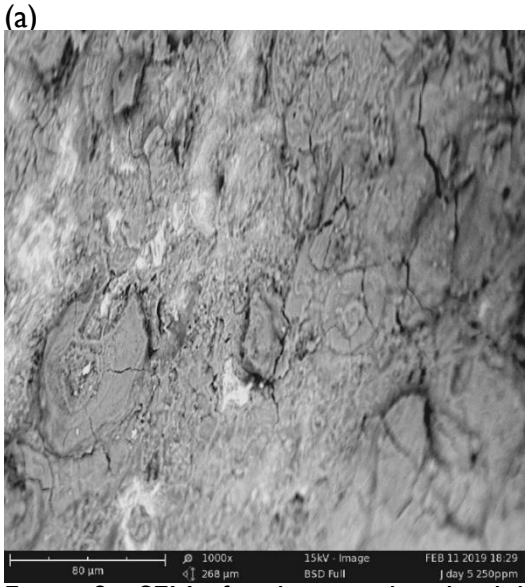

Figure 9a: SEM of carbon steel with inhibitor

(b)

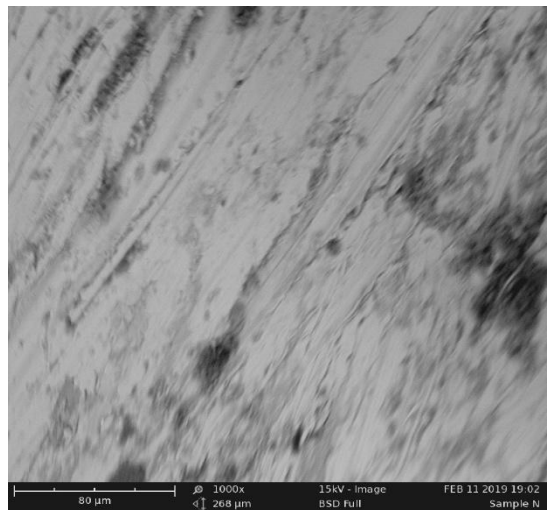

Figure 9b: SEM of carbon steel without inhibitor

Conclusion

Pumpkin pod (*Telfairia occidentalis*) was extracted and characterized using FTIR spectroscopy and was subsequently used as a corrosion inhibitor on carbon steel metal. Weight loss method was employed in corrosion study. Adsorption and thermodynamics studies were carried out to estimate the mode of adsorption mechanism for the inhibitor molecules on the carbon steel surface. The inhibition efficiency increases with increase in the inhibitor concentration but decreases with rise in temperature while corrosion rate decreased as inhibitor concentration is increased. The corrosion inhibition performance of Pumpkin pods (*Telfairia occidentalis*) extract was found to depend on temperature and its concentration. The inhibition by Pumpkin Pod extract occurred through physisorption as evidenced in increase of the activation energy for the inhibited medium which was higher than the one without an inhibitor (blank). The activation enthalpy increases from 28.782kJ/mol to 62.678kJ/mol. The positive values of the enthalpy signified an endothermic adsorption process. The activation entropy (ΔS^o) values in the absence and presence of inhibitor were all negative which implied that the activated complex in the rate determining step represents association rather than a dissociation step. This indicates that during the adsorption process, an increase in the degree of disorderliness occur. Experimental data fitted well to Langmuir, and Freundlich isotherms in comparison to both Temkin and El – Awady isotherms. The adsorption process is strong, feasible, and spontaneous with the negative value of free energy (ΔG^o_{ads}) obtained.

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