

# Inhibition of the Corrosion of Zinc in 0.1M HCl by Ethanol Extract of Honey

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## Abstract

The inhibition of the corrosion of zinc in solution of HCl was studied using gravimetric method. The results obtained indicated that ethanol extract of honey (EEH) exhibited minimum and maximum inhibition efficiencies of 30.57 and 72.01 % at 333 and 303 K, respectively. Generally, the inhibition efficiency of the extract was found to increase with increasing concentration but decreases with increase in temperature. Kinetic consideration revealed that the EEH increases the half-life of zinc in solution of HCl. Calculated values of activation for the blank was lower than those obtained for the inhibited systems (which ranged from 12.34 to 19.03 kJ/mol). From the range of values obtained for the activation energy, the pattern of variation of the inhibition efficiency of the extract with temperature and the range of values obtained for standard free energy of adsorption, the mechanism of physical adsorption was upheld for the adsorption of honey on mild steel surface. Although, the adsorption behavior of the inhibitor fitted the Langmuir model with high degree of linearity, the deviation of calculated slope values from unity was compensated by the fitness of the adsorption data to the Temkin adsorption isotherm, which indicated attractive behavior of the inhibitor. From the El awardy *et al.* adsorption model, the adsorption of EEH on the surface of zinc favours multilayer of adsorption characterized by a decrease in adsorption strength with temperature.

**Keywords:** Honey, corrosion inhibition, zinc, adsorption, kinetics, isotherm

## 1. Introduction

Corrosion is an electrochemical process that leads to disintegration of the metal or metallic alloy. In most industries including fertilizer, oil and metallurgical industries [1], processes such as acid cleaning, annealing and scale removal often involves contact between acidic medium and the metal. This will render the metal to be susceptible to corrosion. Hence, it is necessary to adopt significant methods that can be used to protect metals (in such industrial fabrications) against corrosion attack [2]. Some available options include galvanizing, cathodic/anodic protection, lubrication and the use of inhibitors [3]. However, the use of corrosion inhibitors has been found to be one of the best options [4]. Corrosion inhibitors are substances, which when added in minute concentration, are able to retard the rate of corrosion by been adsorbed on the surface of the metal through the mechanism of physical or chemical adsorption [5].

Generally, most viable corrosion inhibitors are compounds that have suitable functional groups, hetero atoms in their aromatic or long carbon chain and are rich in  $\pi$ -electrons [6]. Success has also been recorded in the use of some inorganic compounds such as chromates and others [7]. Nevertheless, there is increasing concern about the toxicity of most of these compounds because some are toxic [8]. In view of this, many green corrosion inhibitors have been developed, mostly from

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extract of plants or animal [10]. Green corrosion inhibitors are less toxic, easily accessible, less expensive and are biodegradable [11].

Natural honey is one of the most widely sought products due to its unique properties, which are attributed to the influence of the different groups of substances it contains. Honey is used for nutritional, medicinal and industrial purposes and it is an important commodity in the international market; serving as foreign exchange earner for many countries. One of the most comprehensive reports on the chemical composition of honey was conducted by Buba *et al.* [12]. They reported that the mean moisture and ash contents of some honey samples, obtained from various locations are  $16.00 \pm 2.19$  g/100 g and  $0.47 \pm 0.09$  g/100 g, respectively. The protein contents ranged between 0.35 and 1.08 g/100 g with a mean value of  $0.67 \pm 0.25$  g/100 g while the fat ranged between 0.10 and 0.50 g/100 g with a mean value of  $0.29 \pm 0.11$  g/100 g. Total mean values for carbohydrate and energy were  $82.30 \pm 2.03$  g/100 g and  $1,401.33 \pm 33.71$  kJ/100 g, respectively. Fructose contents gave an average of  $38.94 \pm 0.90$  g/100 g, while glucose contents had a mean value of  $31.65 \pm 2.79$  g/100 g. The sucrose contents of the honey samples was found to be  $1.84 \pm 0.79$  g/100 g. Total polyphenol and vitamin C contents were  $65.31 \pm 19.50$  mg gallic acid equivalent (GAE)/100 g and  $21.15 \pm 3.99$  mg/100 g, respectively.

Judging from its chemical composition, honey is rich in compounds that have suitable functional groups, hetero atoms and  $\pi$ -electrons that can facilitate their corrosion inhibition potentials. For example, Radojcic *et al.* [13] studied the influence of natural honey (chestnut and acacia) and natural honey with black radish juice, on the corrosion of tin in aqueous and sodium chloride solutions using weight loss and polarization techniques. It was found that both samples of honey were good inhibitors and the process of inhibition was attributed to the formation of multilayer adsorbed film on the tin surface. The adsorption of natural honey and honey with black radish on tin was found to follow the Langmuir adsorption isotherm. The inhibitive action of natural honey on the corrosion of C-steel, which is used in the manufacture of petroleum pipelines, in high saline water was studied by El-Etre and Abdallah [14] using the weight loss measurements and potentiostatic polarization technique and it was found that natural honey exhibited a very good performance as an adsorption inhibitor for steel corrosion in high saline water. The adsorption of natural honey on the C-steel was found to follow the Langmuir adsorption isotherm. The inhibition effect of mad honey on the corrosion of 2007-type aluminium alloy in 3.5% NaCl solution was investigated by Gerengi *et al.* [15] using Tafel extrapolation (TP), electrochemical impedance spectroscopy (EIS) and dynamic electrochemical impedance spectroscopy (DEIS). All the studied parameters exhibited good anti-corrosive properties against corrosion of 2007-type aluminium alloy in the test solution and the adsorption behavior of mad honey on the 2007-type aluminium alloy surfaces was also found to be conformed to the Langmuir adsorption isotherm.

Available literatures thus revealed that extracts of some plants and animals have been successfully tested and utilized as green corrosion inhibitors for various metals, however, literature is scanty on the use of natural honey as a corrosion inhibitor for zinc. Therefore, the present study is aimed at investigating the corrosion inhibition efficiency of honey for the corrosion of zinc using weight loss and hydrogen evolution methods.

## 2. Materials and Methods

### 2.1. Collection of Materials

The sample used for the study was purchased directly from Michael Okpara University bee farm, where they are produced in sufficient quantity. EEH was produced using Soxhlet extractor. Zinc sheet of known composition (99.90 % pure zinc) was used for the corrosion study. The sheets were mechanically pressed cut into different coupons, each of dimension, 5 x 4 x 0.11 cm. Each coupon was degreased by washing with ethanol, cleaned with acetone and allowed to dry in the air before preservation in a desiccator. All reagents used for the study were Analar grade and double distilled water was used for their preparation.

### 2.2. Gravimetric Studies

The clean and dried previously weighed zinc coupon was completely immersed in 250 mL of the test solution in an open beaker. After every 24 h the corrosion product was withdrawn from the electrolyte, kept for 3-4 min in 70 % nitric acid, washed thoroughly with distilled water and then dried and weighed. The experiment was repeated at 333 K. In each case, the difference in weight for a period of 168 h was taken as the total weight loss. From the average weight loss (mean of three replicate analysis) results, the inhibition efficiency (%I) of the inhibitor, the degree of surface coverage ( $\theta$ ) and the corrosion rate of aluminium ( $CR$ ) were calculated using Equations 1, 2 and 3, respectively [16].

$$\%I = \left( 1 - \frac{W_1}{W_2} \right) \times 100$$

$$\theta = \left(1 - \frac{W_1}{W_2}\right) \quad 2$$

$$CR = \frac{W_2 - W_1}{At} \quad 3$$

where  $W_1$  and  $W_2$  are the weight losses (g) for zinc in the presence and absence of the inhibitor,  $\theta$  is the degree of surface coverage of the inhibitor,  $A$  is the area of the zinc coupon (in  $\text{cm}^2$ ) and  $t$  is the period of immersion (in hours).

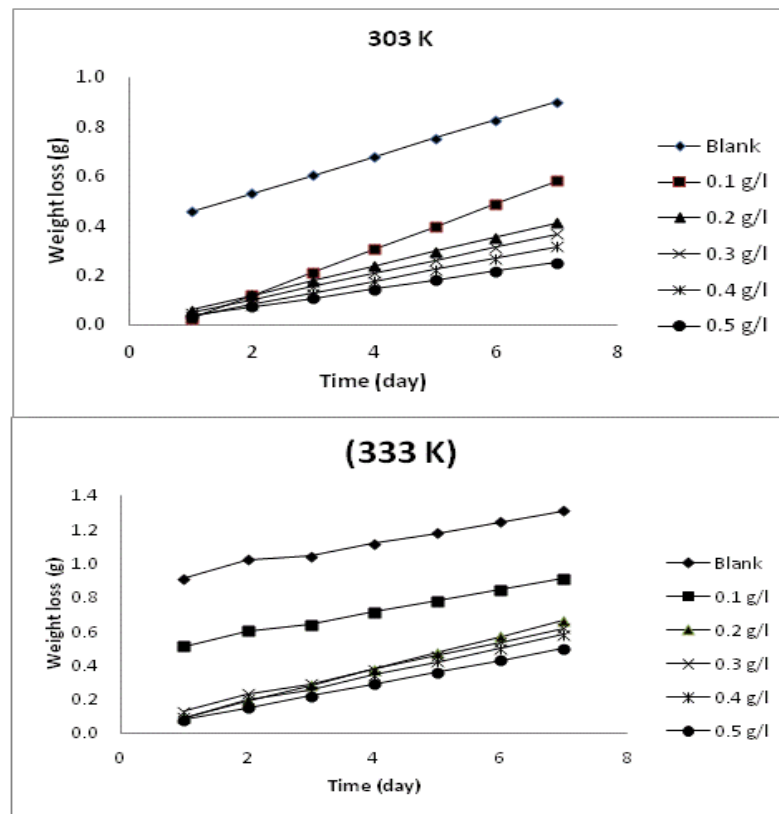
### 2.3. GC-MS Analysis

GC-MS analysis was carried out on a GC Clarus 500 Perkin Elmer system comprising of a AOC-20i auto-sampler and gas chromatograph interfaced to a mass spectrometer (GC-MS) instrument employing the following conditions: column Elite-1 fused silica capillary column (30 x 0.25 mm ID x 1  $\mu\text{M}$  df, composed of 100 % dimethylpoly dioxane), operating in electron impact mode at 70 eV; helium (99.999 %) was used as carrier gas at a constant flow of 1 mL/min and an injection volume of 0.5  $\mu\text{L}$  was employed (split ratio of 10:1) injector temperature 250  $^\circ\text{C}$ ; ion-source temperature of 280  $^\circ\text{C}$ . The oven temperature was programmed from 110  $^\circ\text{C}$  (isothermal for 2 min), with an increase of 10  $^\circ\text{C}/\text{min}$ , to 200  $^\circ\text{C}$ , then 5  $^\circ\text{C}/\text{min}$  to 280  $^\circ\text{C}$ , ending with a 9 min isothermal at 280  $^\circ\text{C}$ . Mass spectra were taken at 70 eV; a scan interval of 0.5 s and fragments from 40 to 450 Da. Total GC running time was 36 min.

## 3. Results and Discussions

### 3.1. Effect of the Concentration of EEH

Figure 1 shows the variation of weight loss with time for the corrosion of zinc in solutions of HCl containing various concentrations of EEH at 303 and 333 K, respectively. The Figure reveals that the weight loss of zinc increases with increase in the period of contact but decreased with increase in the concentration of EEH.



**Figure 1.** Variation of Weight Loss with Time for the Corrosion of Zinc in 0.1 M HCl Containing Various Concentrations of Ethanol Extract of EEH at 303 and 333 K

Therefore, the rate of the corrosion of zinc in solutions of HCl increases with increase in the period of contact but decreased with increase in the concentration of EEH. The results obtained also indicated that EEH retarded the corrosion of zinc in solutions of HCl and that it is an adsorption inhibitor for the corrosion of zinc in solution of HCl. A close examination of the Figure also reveals that the weight loss of the metal in solution of HCl also increases with increase in temperature indicating that the rate of corrosion of the metal increases with increase in temperature; hence, the inhibition efficiency of EEH decreases with temperature, which implies that EEH inhibited the corrosion of zinc through the mechanism of physisorption. Table 1 presents values of corrosion rates of zinc in solutions of HCl in the absence and presence of various concentrations of EEH at 303 and 333 K. Moreover, the inhibition efficiencies of various concentrations of EEH for the corrosion of zinc in solution of HCl are also presented in the Table 1. From the results obtained, the corrosion rate of zinc increases with increase in temperature but decreases with increase in the concentration of EEH. On the other hand, the inhibition efficiency of the EEH increases with increase in its concentration but decreases with increasing temperature, confirming that the adsorption of EEH on the surface of zinc favours physisorption mechanism. It has been established that a physisorption mechanism is characterised by a decrease in the extent of adsorption (hence inhibition efficiency) with increase in temperature as opposed to a chemisorptions mechanism, which is characterised with an increase in inhibition efficiency with increasing temperature [17].

Table 1: Corrosion Rate (CR) of Zinc in 0.1 M HCl, Inhibition Efficiency (IE%) and Degree of Surface Coverage ( $\theta$ ) of EEH

System	CR (303 K)	CR (333 K)	IE % (303K)	IE % (333K)	$\theta$ (303K)	$\theta$ (333 K)
Blank (0.1 M HCl)	0.000268	0.000389	-	-	-	-
0.1 g EEH + 0.1 M HCl	0.000173	0.00027	35.45	30.57	0.3545	0.3057
0.2 g EEH + 0.1 M HCl	0.000123	0.000197	54.13	49.43	0.5413	0.4943
0.3 g EEH + 0.1 M HCl	0.000109	0.000184	59.15	52.87	0.5914	0.5287
0.4 g EEH + 0.1 M HCl	0.000095	0.000173	64.90	55.67	0.6490	0.5567
0.5 g EEH + 0.1 M HCl	0.000075	0.000149	72.01	61.78	0.7201	0.6178

### 3.2. Kinetic Study

Most corrosion reactions are characterized as a first order kinetics. In order to verify the order of reaction for the corrosion of zinc in solutions of HCl containing various concentrations of EEH, weight loss data were substituted into the following equation [18].

$$-\log(\text{weightloss}) = \frac{k_1 t}{2.303} \quad 4$$

where  $k_1$  is the first order rate constant and  $t$  is the time in day. From Equation 4, a plot of  $-\log(\text{weight loss})$  versus  $t$  should be linear with slope equal to  $k_1/2.303$ .

Table 2. First Order Reaction Parameters for the Corrosion of Zinc in Solutions of HCl Containing Various Concentrations of EEH at 303 and 333 K

System	Slope	Intercept	$k_1$	$t_{1/2}$ (day)	$R^2$
0.1 M HCl at 303 K	0.250	0.055	0.5758	1	0.981
0.1 g/l EEH + 0.1 M HCl at 303 K	0.040	0.316	0.0921	2	0.986
0.2 g/l EEH + 0.1 M HCl at 303 K	0.134	1.038	0.3086	2	0.921
0.3 g/l EEH + 0.1 M HCl at 303 K	0.105	0.895	0.2418	3	0.942
0.4 g/l EEH + 0.1 M HCl at 303 K	0.123	1.025	0.2833	3	0.912
0.5 g/l EEH + 0.1 M HCl at 303 K	0.125	1.106	0.2879	3	0.934
0.1 M HCl at 333 K	0.480	0.374	1.1054	1	0.99
0.1 g/l EEH + 0.1 M HCl at 333 K	0.198	1.460	0.4560	2	0.836
0.2 g/l EEH + 0.1 M HCl at 333 K	0.132	1.230	0.3040	3	0.926
0.3 g/l EEH + 0.1 M HCl at 333 K	0.139	1.321	0.3201	3	0.919
0.4 g/l EEH + 0.1 M HCl at 333 K	0.149	1.445	0.3431	3	0.906
0.5 g/l EEH + 0.1 M HCl at 333 K	0.132	1.445	0.3040	3	0.926

Kinetic plots for the corrosion of zinc in solutions of HCl, containing various concentrations of EEH at 303 and 333 K,

respectively were linear (plots not shown) and displayed excellent degree of linearity ( $R^2$ ) as presented in Table 2. Values of rate constants deduced from the plots and half-life ( $t_{1/2}$ ) calculated through the relation,  $t_{1/2} = 0.693/k_1$  are also presented in Table 2. From the results obtained, various concentrations of EEH extended the  $t_{1/2}$  of zinc in solution of HCl. Therefore, EEH is a good inhibitor for the corrosion of zinc in acidic medium.

### 3.3. Effect of Temperature

The effect of temperature on the rate of corrosion of zinc in solutions of HCl was studied using the logarithm form of the Arrhenius equation, which can be written as follows [19].

$$\log \frac{CR_2}{CR_1} = \frac{E_a}{2.303R} \left( \frac{1}{T_1} - \frac{1}{T_2} \right) \quad 5$$

where  $E_a$  is the activation energy,  $CR_1$  and  $CR_2$  are the corrosion rate of zinc at the temperatures  $T_1$  and  $T_2$ , respectively. Calculated values of  $E_a$  are presented in Table 3.

**Table 3.** Activation Energy and Heat of Adsorption of EEH on the Surface of Zinc

System	$E_a$ (kJ/mol)	$Q_{ads}$ (kJ/mol)
Blank	10.33	-
0.1 g/l of EEH	12.34	4.22
0.2 g/l of EEH	13.06	3.60
0.3 g/l of EEH	14.51	4.86
0.4 g/l of EEH	16.61	7.38
0.5 g/l of EEH	19.03	8.87

The results revealed that the  $E_a$  for the blank (10.33 kJ/mol) is lower than those of the systems containing various concentrations of EEH, whose activation energies range from 12.34 to 19.03 kJ/mol. These values tend to increase with increase in concentration of the EEH indicating that the strength of adsorption of the inhibitor increases with increase in concentration. It is generally accepted that  $E_a$  value lower than 80 kJ/mol is consistent with the mechanism of charge transfer from charged inhibitor to charged metal surface, while  $E_a$  values greater than 80 kJ/mol points toward chemisorptions mechanism [20]. From the results obtained, it is evident that the adsorption of EEH on the surface of zinc supports the mechanism of physical adsorption.

### 3.4. Thermodynamic and Adsorption Considerations

The heat of adsorption of the inhibitor on the surface of zinc was estimated using the following equation [21].

$$Q_{ads} = 2.303R \left[ \log \left( \frac{\theta_2}{1-\theta_2} \right) - \log \left( \frac{\theta_1}{1-\theta_1} \right) \right] \times \left( \frac{T_1 T_2}{T_2 - T_1} \right) kJmol^{-1} \quad 6$$

where  $Q_{ads}$  is the heat of adsorption of the inhibitor,  $\theta_1$  and  $\theta_2$  are the degrees of surface coverage of the inhibitor at temperatures,  $T_1$  and  $T_2$ , respectively. Calculated values of  $Q_{ads}$  were positive and ranged from 3.30 to 8.87 kJ/mol (Table 3) indicating that the adsorption of EEH on the surface of zinc is endothermic and supports the mechanism of physical adsorption (since values of  $Q_{ads}$  are low).

The adsorption characteristics of EEH on zinc surface was also investigated by fitting data obtained for degrees of surface coverage at various concentrations of the inhibitor, into various adsorption isotherms including Langmuir, Freundlich, Temkin, El awardy, Frumkin and Flory Huggins adsorption isotherms. The tests revealed that the Langmuir model best fitted the adsorption characteristics of the inhibitor. The assumptions establishing the Langmuir adsorption model can be written as follows [22].

$$\frac{C}{\theta} = C + \frac{1}{b_{ads}} \quad 7$$

$$\log \frac{C}{\theta} = \log C - \log b_{ads} \quad 8$$

where  $C$  is the concentration of the inhibitor in the bulk electrolyte,  $b_{ads}$  is the adsorption equilibrium constant and  $\theta$  is

the degree of surface coverage of the inhibitor. Figure 2 presents the Langmuir isotherm for the adsorption of EEH on zinc surface. Adsorption parameters calculated from the plots (Table 4) revealed that  $R^2$  values are very close to unity. Therefore the adsorption of EEH on the surface of zinc is consistent with the Langmuir adsorption model. However, calculated slope values are less than unity indicating that there are some interactions between the adsorbed species. The ideal Langmuir adsorption isotherm is applicable to physical or chemical adsorption where there is no interaction between the adsorbed species. The fitness of the data to the Temkin adsorption model also confirmed and accounted for the interaction between the adsorbed inhibitor and the surface of zinc [23].

Temkin adsorption isotherm operates on the assumptions that relate the concentration of the inhibitor to the degree of surface coverage according to Equation 9 [24].

$$e^{-2a\theta} = b_{ads} C \tag{9}$$

where  $a$  is the molecular interaction parameter,  $\theta$  is degree of surface coverage,  $C$  is inhibitor concentration and  $b_{ads}$  is equilibrium constant of the adsorption process.

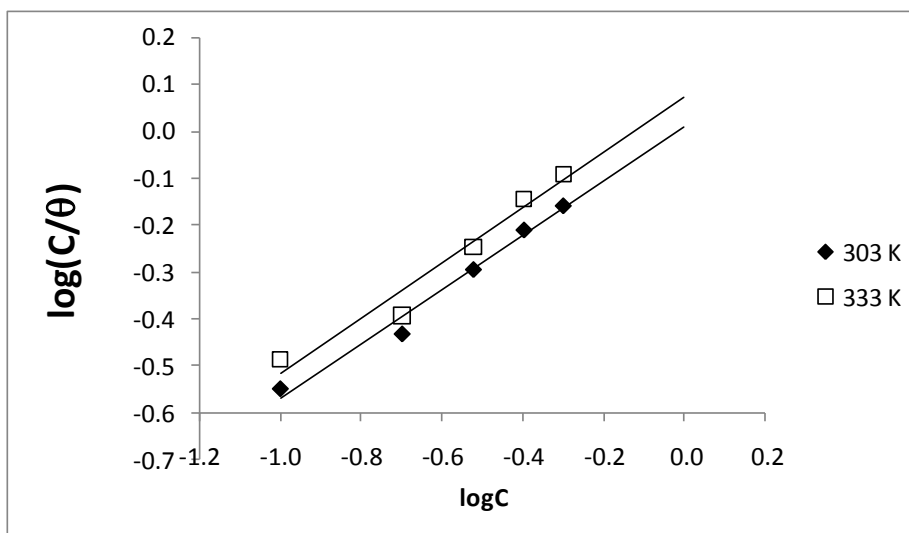


Figure 2. Langmuir isotherm for the adsorption of EEH on the surface of zinc at 303 and 333 K

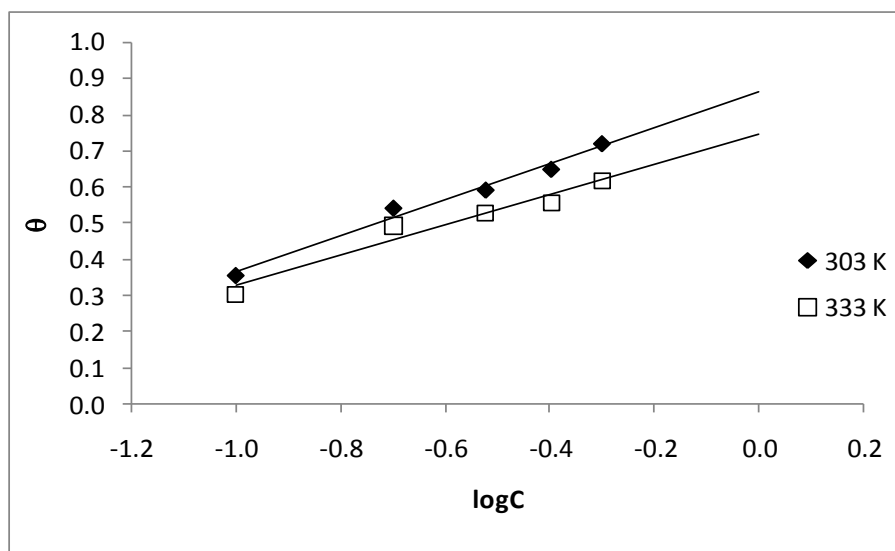
Table 4. Adsorption Parameters for EEH, Deduced from Langmuir, Temkin and El Awwady *et al.* Isotherms at 303 and 333 K

Isotherm	T (K)	Slope	Intercept	'a'/1/y	log k/B	$\Delta G^o_{ads}$ (kJ/mol)	$R^2$
Langmuir	303	0.497	0.861	-	1.732	-20.17	0.982
	333	0.417	0.744	-	1.784	-22.50	0.952
Temkin	303	0.578	0.008	0.43	0.008	-10.17	0.981
	333	0.587	0.071	0.36	0.071	-11.57	0.959
El-wardy et al.	303	0.904	0.658	1.106	2.124	-32.04	0.982
	333	0.754	0.438	1.326	1.260	-29.48	0.948

From the logarithm of both sides of Equation 9, Equation 10 was obtained.

$$\theta = -\frac{\ln k}{2a} - \frac{\ln C}{2a} \tag{10}$$

The implication of Equation 10 is that a plot of  $\theta$  versus  $\log C$  should be linear with slope and intercept equal to  $2.303 \times a/2$  and  $2.303a \log b_{ads}/2$ , respectively. Figure 3 presents the Temkin isotherm for the adsorption of EEH on the surface of zinc.



**Figure 3.** Temkin Isotherm for the Adsorption of EEH on the Surface of Zinc

The plots reveal excellent degree of linearity (Table 4, i.e,  $R^2 = 0.983$  and  $0.952$  at  $303$  and  $333$  K, respectively). Calculated values of the interaction parameters are positive (Table 4) indicating the attractive behavior of the inhibitor. An investigation into the strength of adsorption of EEH on zinc surface and the possibility of formation of multimolecular layer of adsorption were upheld using the El-Awady *et al* kinetic isotherm (Equation 11) [25].

$$\log\left(\frac{\theta}{1-\theta}\right) = \log b + y \log C \quad (11)$$

where  $y$  is the number of inhibitor molecules occupying one active site and  $1/y$  represents the number of active sites on the surface occupied by one molecule of the inhibitor. 'y' is also related to the binding constant,  $B$  through  $B = b^{1/y}$ . Figure 4 shows El-Awady *et al* plots for the adsorption of EEH on the surface of zinc. Adsorption parameters deduced from the plots are also presented in Table 4. From the slopes of the plots, values of  $1/y$  are greater than unity indicating the existence of multimolecular layer of adsorption. Also, calculated values of  $B$  were found to decrease with temperature suggesting that at lower temperature, the adsorption is better and may be attributed to stronger electrical interaction between the double layer existing at the phase boundary and the adsorption molecule. On the other hand, at higher temperature, the interaction between the adsorbing molecules and the metal surface is weak, which justified the mechanism of physisorption.

The equilibrium constant of adsorption is related to the standard free energy according to the following equation [26].

$$b_{ads} = \frac{1}{55.5} \exp\left(\frac{-\Delta G^{\circ}_{ads}}{RT}\right) \quad (12)$$

where  $b_{ads}$  is the equilibrium constant of adsorption,  $55.5$  is the molar concentration of water in the acid,  $\Delta G^{\circ}_{ads}$  is the standard free energy of adsorption,  $R$  is the gas constant and  $T$  is the temperature. Calculated values of  $\Delta G^{\circ}_{ads}$  for the corresponding isotherms are recorded in Table 4. The free energies are negatively less than the threshold value of  $-40$  kJ/mol required for the mechanism of chemical adsorption. Therefore, the adsorption of EEH is spontaneous and is consistent with the mechanism of charge transfer from charged inhibitor to charged metal surface, which favours physical adsorption mechanism

### 3.5. Mechanism of adsorption

The initial mechanism in any corrosion inhibition reaction is the adsorption of the inhibitor on the surface of the metal [27]. This adsorption may be brought about by the transfer of electron to the metal surface (chemisorptions) or by the transfer of charge from charged inhibitor to charged metal surface (physisorption). In some cases, both mechanisms may be feasible but physisorption will inherently precede chemisorptions. Several researches carried out on the adsorption of a corrosion inhibitor on the surface of the metal have shown that the presence of hetero atom (N, S, O or P) in an aromatic system or long carbon chain, as well as  $\pi$ -electron will facilitate the adsorption of the inhibitor on the metal surface.

In order to investigate the mechanism involves in the adsorption of EEH on zinc surface, GCMS analysis of the inhibitor was carried out and the spectrum obtained is presented in Figure 5. The chromatogram revealed three major peaks,

which corresponded to retention time values of 5.458, 5.667 and 5.858 s, respectively. The identified compounds were diethylene glycol (49.63 %), 3-methyl-1,2-propanediol (20.97 %) and 1-deoxy-d-arabitol (29.40 %).

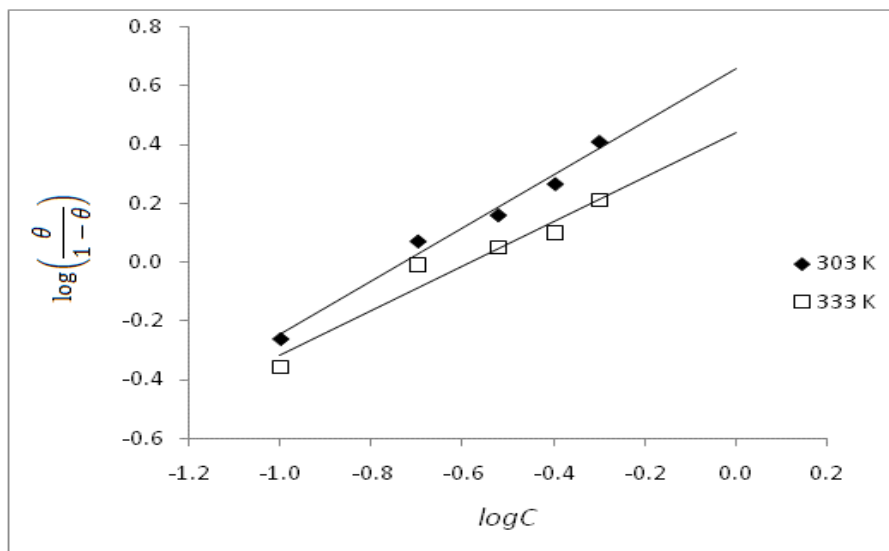


Figure 4. El Awardy *et al.* Isotherm for the Adsorption of EEH on the Surface of Zinc

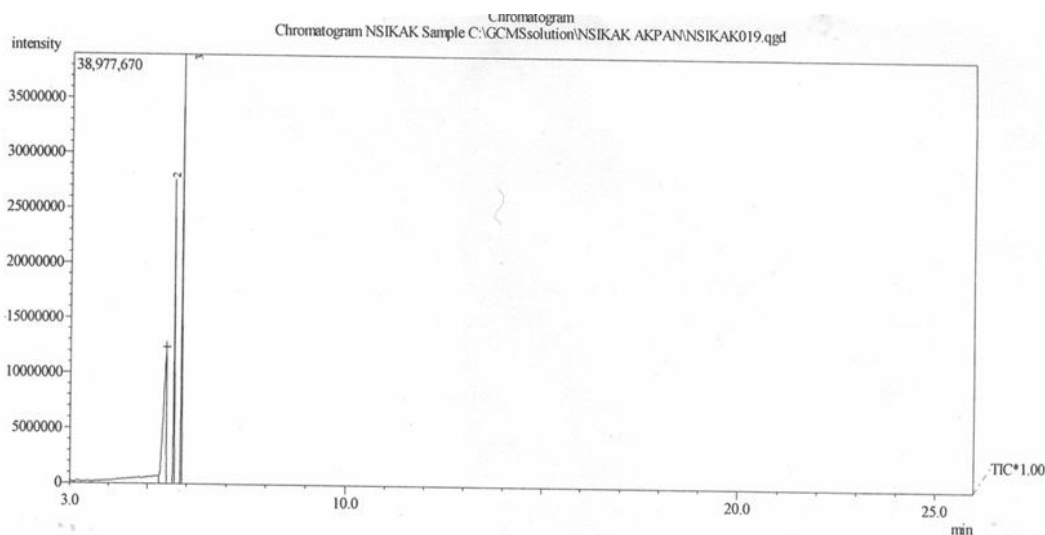


Figure 5. Chromatogram of Honey Sample

The chemical structures of these compounds (not shown) reveal the presence of hetero atoms and hydroxyl functional groups. This suggests that the inhibition of the corrosion of zinc in solutions of HCl by EEH involves synergistic adsorption of some component of the EEH on the surface of the zinc.

## 4. Conclusions

The present study revealed that EEH is a good inhibitor for the corrosion of zinc in solutions of HCl. The adsorption of the inhibitor is thermodynamically feasible and supports the mechanism of physical adsorption. EEH has the potential of increasing the  $t_{1/2}$  of the metal in acidic medium. Inhibition of zinc corrosion by EEH is believed to be effective through the presence of hetero atoms in its chemical constituents. These hetero atoms provide active sites for the adsorption of the inhibitor. From the findings of the present study, we hereby recommend the adoption of other experimental methods including electrochemical methods, to further confirm the inhibition effectiveness of EEH for industrial purposes.



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## REFERENCES

- [1] Zarasvand K.A., Rai V.R., 2014. Microorganisms: Induction and inhibition of corrosion in metals. Intern. J. biodeter. Biodegrade., 87, 66-74.
- [2] Eddy N.O., 2010. Adsorption and inhibitive properties of ethanol extract of *Garcinia kola* and *Cola nitida* for the corrosion of mild steel in H<sub>2</sub>SO<sub>4</sub>. Pigment and Resin Technol., 39 (6), 347-353.
- [3] Eddy N.O., 2011. Experimental and theoretical studies on some amino acids and their potential activity as inhibitors for the corrosion of mild steel, Part 2. J. Adv. Res, 2, 35-47.
- [4] Quraishi M.A, Singh A.K., 2010. Piroxicam; A novel corrosion inhibitor for mild steel corrosion in HCl acid solution. J. Mat. Environ. Sci., 2, 101-110.
- [5] Douadi T., Issaadi S., Chafaa S., 2014. Adsorption and corrosion inhibition of new synthesized thiophene Schiff base on mild steel X52 in HCl and H<sub>2</sub>SO<sub>4</sub> solutions. Corros. Sci., 79, 50-58.
- [6] Fouda A.S., Bad A.H., 2013. Aqueous extract of propolis as corrosion inhibitor for carbon steel in aqueous solutions. African J. Pure Appl. Chem., 7(10), 350-359.
- [7] Döner A., Solmaz R., Özcan M., Kardas G., 2011. Experimental and theoretical studies of thiazoles as corrosion inhibitors for mild steel in sulphuric acid solution. Corros. Sci., 53, 2902-2913.
- [8] Oguzie E.E., 2008. Corrosion inhibitive effect and adsorption behaviour of *Hibiscus sabdariffa* extract on mild steel in acidic media. Port. Electrochim., 26, 303-314.
- [9] Sangeetha M., Rajendran S., Sathiyabama J., Prabhakar P., 2012. Eco-friendly extract of Banana peel as corrosion inhibitor for carbon steel in sea water. J. Nat. Prod. Plant Resour., 2(5), 601-610.
- [10] Ebenso E.E., Eddy N.O., Odiongenyi A.O., 2008. Corrosion inhibitive properties and adsorption behaviour of ethanol extract of *Piper guinensis* as a green corrosion inhibitor for mild steel in H<sub>2</sub>SO<sub>4</sub>. Afri. J Pure Appl. Sci, 4(11), 107-115.
- [11] Eddy N.O, Ebenso E.E, Ibok U.J., 2010. Adsorption, synergistic, inhibitive effect and quantum chemical studies on ampicillin and halides for the corrosion of mild steel. J. Appl. Electrochem., 40, 445-456.
- [12] Buba F., Gidado A., Shugaba A., 2013. Analysis of Biochemical composition of honey samples from North-East Nigeria. Biohem. Analt. Biochem., 2, 139-146.
- [13] Radojic, I., Berkovic, K., Kovac, S. and Vorkapic-Furac, J. 2008. Natural honey and black radish juice as corrosion inhibitors. Corros. Sci., 50(5), 1498-1504.
- [14] El-Etre A.Y., Abdallah M., 2000. Natural honey as corrosion inhibitor for metals and alloys. II. C-steel in high saline water. Corros. Sci., 42(4), 731-738.
- [15] Gerengi H., Goksu H., Slepski, P., 2014. The inhibition effect of mad honey on corrosion of 2007-type aluminium alloy in 3.5 % NaCl solution. Mat. Res., 17(1), 255-264.
- [16] Ameh P.O., Odiongenyi A.O., Eddy N.O., 2012. Joint Effect of *Anogessius leocarpus* Gum (AL Gum) exudate and halide ions on the corrosion of mild steel in 0.1 M HCl. Port. Electrochim., 30(4), 235-245.
- [17] Eddy N.O., Ibok U.J., Ameh P.O., Alobi NO., Musa MS., 2014. Adsorption and quantum chemical studies on the inhibition of the corrosion of aluminum in HCl by *Gloriosa superba* (GS) gum. Chem. Eng. Comm., DOI:10.1080/00986445.2013.809000.
- [18] Odiongenyi A.O., Odoemelam S.A., Eddy N.O., 2009. Corrosion inhibition and adsorption properties of ethanol extract of *Vernonia amygdalina* for the corrosion of mild steel in H<sub>2</sub>SO<sub>4</sub>. Port. Electrochim. Acta, 27(1), 33-45.
- [19] Eddy N.O., Momoh-Yahaya H., Oguzie E.E., 2014. Theoretical and experimental studies on the corrosion inhibition potentials of some purines for aluminum in 0.1 M HCl. J. Adv. Res, DOI:10.1215-14-00237-0.
- [20] Solomon M.M., Umoren S.A., Udosoro I. I., Udoh, A.P., 2010. Inhibitive and adsorption behaviour of carboxymethyl cellulose on mild steel corrosion in sulphuric acid solution. Corros. Sci., 52, 1317-1325.
- [21] Umoren S.A., Ebenso E.E., Okafor P.C., Ogbobe O., 2006. Water soluble polymers as corrosion inhibitors. Pigment and Resin Technol., 35(6), 346-352.

- [22] Umoren S.A., Eduok U.M., Oguzie E.E., 2008. Corrosion inhibition of mild steel in 1 M H<sub>2</sub>SO<sub>4</sub> by polyvinyl pyrrolidone and synergistic iodide additives. *Port. Electrochim. Acta*, 2(2), 533-546.
- [23] Vraca L.M., Draciz D.M., 2002. Adsorption and corrosion inhibitive properties of some organic molecules on iron electrode in sulfuric acid. *Corros. Sci.*, 54, 1669-1680.
- [24] Herle R., Shetty P., Shetty S.D., Kini U.A., 2011. Corrosion inhibition of 304 SS in hydrochloric acid solution by N-furfuryl N'-phenyl thiourea. *Port. Electrochim. Acta*, 29(2), 69-78.
- [25] Olusola J.O., Oluseyi A.K., Kehinde O.O., Olayinka A.O., Oluwatosin J.M., 2009. Adsorption Behaviour of [(4-Hydroxy-6-methyl-2-oxo-2Hpyran-3-yl)-(4-methoxy-phenyl)-1methyl]-urea on Stainless Steel in Phosphoric Media. *Port. Electrochim. Acta*, 27(5), 591-598.
- [26] Torres V.V., Rayol V.A., Magalhaes M., Anguilar L.C.S., Machado S. P., Orofino H., Elia E.D., 2014. Study of thioureas derivatives synthesized from a green route as corrosion inhibitors for mild steel in HCl solution. *Corros. Sci.*, 79, 108-118.
- [27] Solmaz R., 2014. Investigation of adsorption and corrosion inhibition of mild steel in hydrochloric acid solution by 5-(4-Dimethylaminobenzylidene) rhodanine. *Corros. Sci.*, 79, 169-176.