Joint effects of halide ions and Ficus glumosa gum exudate on the inhibition of the corrosion of mild steel in 0.1 M HCl

[*1]Paul Ocheje Ameh and [2]Nnabuk Okon Eddy

[1]Physical Chemistry Unit, Department of Chemistry, Nigeria Police Academy, Wudil, P. M. B. 3474, Kano State, Nigeria.
[2]Department of Chemistry, AkwaIbom State University, IkotAkpaeden, P. M. B. 1167, Uyo, AkwaIbom State, Nigeria

ARTICLE INFO

ABSTRACT

The corrosion inhibition potential of Ficus glumosa gum exudate for mild steel in 0.1 M HCl was investigated using the weight loss and gasometric methods. The results obtained indicated that the inhibition efficiency of Ficus glumosa gum exudate increases with an increase in concentration and in temperature. The synergistic combination of the gum and 0.05 M KI, KCl and KBr respectively revealed an enhancement of inhibition efficiency through the synergistic adsorption of the gum exudate and the corresponding halide. The values obtained for standard enthalpy and entropy changes for the adsorption of the gum, halide and gum halide mixtures, calculated from the transition state equation, indicated that their adsorption is endothermic and occurred with an increase in orderliness. Further investigations into the adsorption characteristics of the gum revealed that the deviation from the ideal Langmuir adsorption isotherm could be attributed to the attractive behaviour of the inhibitor, deduced from the positive values of slopes obtained for the Frumkin adsorption isotherm. Generally, values of the binding constant obtained from all the isotherms indicated that the strength of the adsorption increases with an increasse temperature. Also, the transfer energy per mole obtained from the Dubinin-Radushkevich isotherm were greater than the threshold value of 8 kJ/mol, hence the mechanism of chemisorption was confirmed for the adsorption of FG gum on a mild steel surface.

Introduction

The corrosion inhibition potential of natural gums has attracted significant research interest in recent times because gums have excellent adhesive properties on metal surfaces, form large surface areas for adsorption, and are biodegradable and ecofriendly. In view of these and other advantages, some gums have been found to be efficient corrosion inhibitors, including Mimosa tannin (Martinez and Stern, 2001), guar gum (Abdallah, 2004), gum arabic (Umoren et al., 2008a,b), sodium carboxyl methyl cellulose (Bayolet al., 2008), carboxyl methyl cellulose (Solomon et al., 2010; Umoren et al., 2010), Starch (Mobinet al., 2011), Daniella oliverri gum (Eddy et al., 2012a), Ficus platyphylla gum (Eddy et al., 2012b) and Anogessus leocarpus (AL) gum (Eddy et al., 2011). In spite of their great potential, the low inhibition efficiency that can be achieved from some gums has paved the way to synergistic research, which is aimed at enhancing the inhibition efficiency of an inhibitor through synergism.

Synergism is a combined action of a compound which is greater in total effect than the sum of individual effects. It has become one of the most important factors in inhibition processes and serves as a basis for all modern corrosion inhibitor formulation. Synergism of corrosion inhibitors is due to interaction between either the components of the inhibitors or the inhibitor and one of the ions in aqueous solution (Lorber and Loreinz, 1980). Some authors have reported on synergistic inhibition effects between organic inhibitors and halide ions (Cl-, Br -, and I-) (Umoren et al., 2006, 2010; Larabi et al., 2004; Feng et al., 1999; Okafor and Zheng, 2009) as well as on organic inhibitor/organic inhibitor mixtures (Ehteshamzadeh et al., 2006; Qu et al., 2007; Hosseini et al., 2003; Okafor et al., 2010; Rammelt et al., 2008;) on steel corrosion in an acidic solution. The synergistic inhibition effects between halide ion and natural exudate gums of Dacrodyes edulis (Oguzie et al., 2010), Raphia hookeri (Umoren et al., 2008) and Pachylobus edulis (Umoren and Ekanem, 2010) for mild steel in an acidic medium

have also been reported.

The present study is aimed at investigating the synergistic effect of potassium halides (KI, KBr and KCl) and Ficus glumosa gum on the inhibition of the corrosion of mild steel in 0.1 M HCl using the weight loss and gasometric techniques.

Materials and methods
Materials

The materials used for this study were a mild steel sheet of composition (wt%) Mn (0.6), P (0.36), C (0.15) Si (0.03) and Fe(98.86). The sheet was mechanically pressed-cut into different coupons, each with these dimensions: 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 the reagents used for the study were analar grade, and distilled water was used for their preparation. The concentration of HCl used for the weight loss study was 0.1 M.

Gravimetric method

Gravimetric methods were carried out at 303, 313, 323 and 333 K for seven days using the method described in literature (Eddy, 2010). From the average weight loss (mean of three replicate analyses) results, the inhibition efficiency (%I) of the inhibitor, the degree of surface coverage (θ) and the corrosion rate of mild steel (CR) were calculated using equations I to III respectively (Oguzie et al., 2006),

$$\%I = \frac{w_1 - w_2}{w_1} \times 100 \qquad\qquad \text{I}$$

$$\theta = \left[1 - \frac{w_1}{w_2} \right] \qquad\qquad \text{II}$$

$$CR\ (mpy)\ =\ \frac{534W}{DAT}$$

III

where w1 and w2 are the weight losses of the mild steel (in grams) in the absence and presence of the inhibitor respectively, θ is the degree of surface coverage of the inhibitor, CR is the corrosion rate of the mild steel, W is the weight loss (mg), D is the density of the specimen (g/cm3), A is the area of the specimen in square inches and T is the period of immersion in hours.

Gasometric method

In the gasometric experiment, the test solution was poured into the reaction vessel. Upon the introduction of mild steel, the flask was quickly corked and the rise in the volume of the paraffin due to hydrogen evolution was noted after every minute until a steady volume was observed. The inhibition efficiency was calculated as a quotient of the difference between the volume of the hydrogen evolved (by the blank and that of the test solution) to the volume of the hydrogen evolved by the blank.

Results and discussion

Effect of concentration

Figure 1 shows plots for the variation in weight loss with time for the corrosion of mild steel in 0.1 M HCl containing various concentrations of FG gum at 303, 313, 323 and 333 K respectively. From the plots, it can be seen that the weight loss of the mild steel increases with an increase in the period of contact but decreases with an increase in the concentration of FG gum. These indicate that the rate of corrosion of mild steel increases with the period of contact but decreases with an increase in the concentration of FG gum. It can also be deduced from the observed trends that FG gum retarded the rate of corrosion of mild steel in solutions of HCl; therefore, FG gum is an adsorption inhibitor for the corrosion of mild steel in solutions of HCl. A comparison of the pattern of variation of weight loss with time for the various temperature regimes revealed that the weight loss of mild steel increases with an increase in temperature, indicating that FG gum is adsorbed on the surface of mild steel through the mechanism of chemical adsorption, as distinct from physiosorption, where the extent of adsorption is expected to decrease with an increase in temperature.
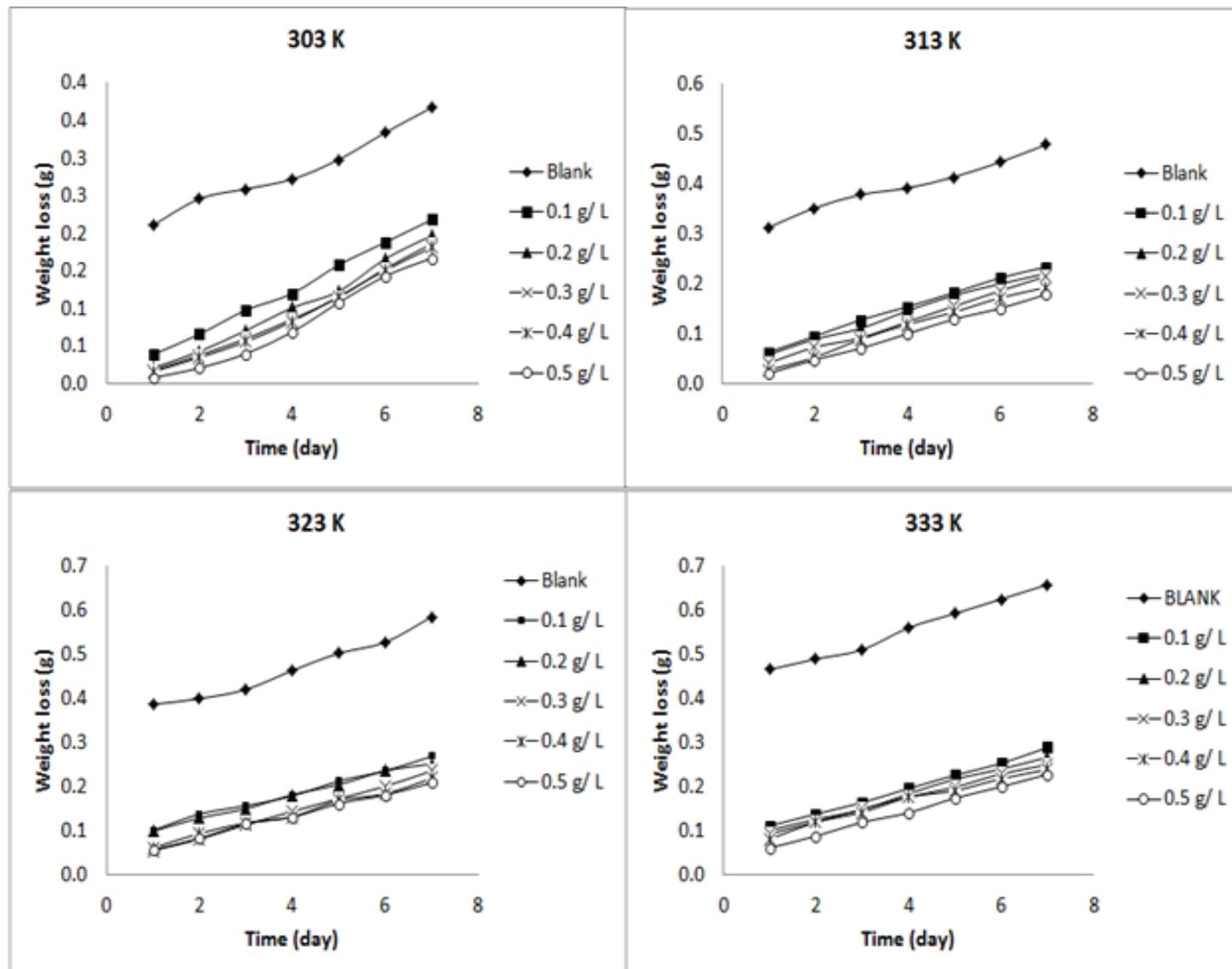

Fig. I: Variation in weight loss with time for the corrosion of mild steel in 0.1 M HCl containing various concentrations of FG gum as an inhibitor at 303, 313, 323 and 333 K

The variation in weight loss with time for the corrosion of mild steel in 0.1 M HCl containing 0.05 M of potassium halides, 0.5 g/L of FG gum and 0.05 M each of the potassium halides, co-employed with 0.5 g/L of FG gum at various temperatures, is shown in Figure II. The figure reveals that the weight losses of the mild steel when FG gum was co-employed with the halides (KI, KBr and KCl) are lower than the weight losses observed for either each of the halides or the gum alone. This indicates that potassium halides enhanced the inhibition potential of FG gum on the corrosion of mild steel in solutions of HCl.

Figure III presents variations in the corrosion rate of mild steel with concentrations of FG gum, halides and FG gum (0.5 g/L)-halide mixtures at various temperature levels. From the figure, it can be seen that the corrosion rate of mild steel decreases with increases in the concentration of FG gum and increases in tandem with temperature.

In Table I, the inhibition efficiencies of FG gum, halides (i.e 0.05 M KI, KBr and KCl respectively) and 0.5 g/L of FG gum co-employed with 0.05 M KCl, 0.05 M KCl and 0.05 M KI are presented. The inhibition efficiency of FG gum, halides and FG gum-halide mixtures were found to decrease with an increase in temperature. These indicate that the chemisorption mechanism is most probable for the adsorption of FG gum, halides and FG gum-halide mixtures. The results obtained from the gasometric experiments (50.23, 58.30, 61.22, 69.45 and 75.10 % for 0.1, 0.2, 0.3, 0.4 and 0.5 g/L of FG gum respectively) were in agreement with those obtained from weight loss measurements at 303 K.
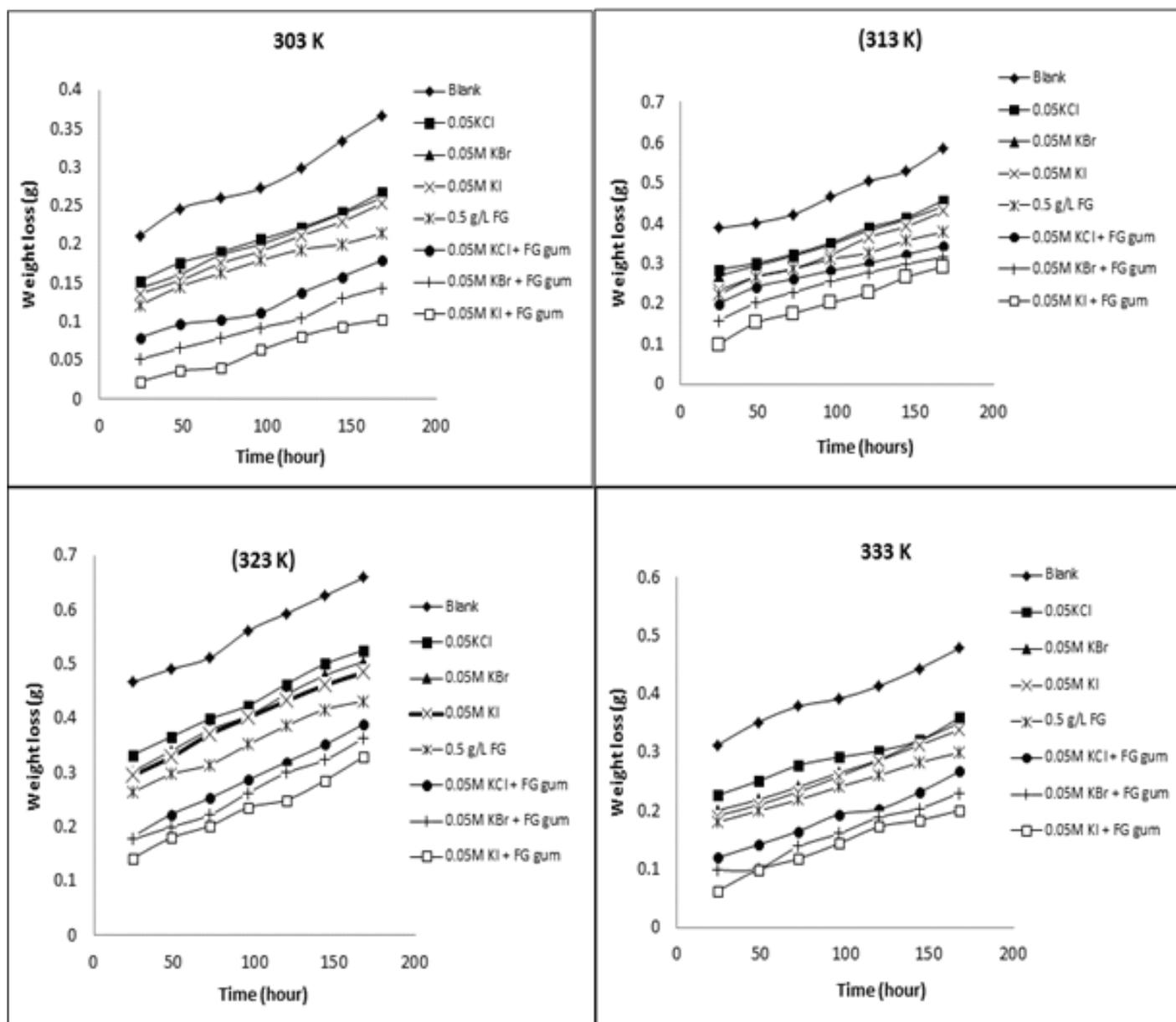

Fig. II: Variation of weight loss with time for the corrosion of mild steel in 0.1 M HCl containing 0.5 g/L FG gum, 0.05 M halides and 0.05 M halides combined with 0.5 g/L FG gum at 303, 313, 323 and 333 K
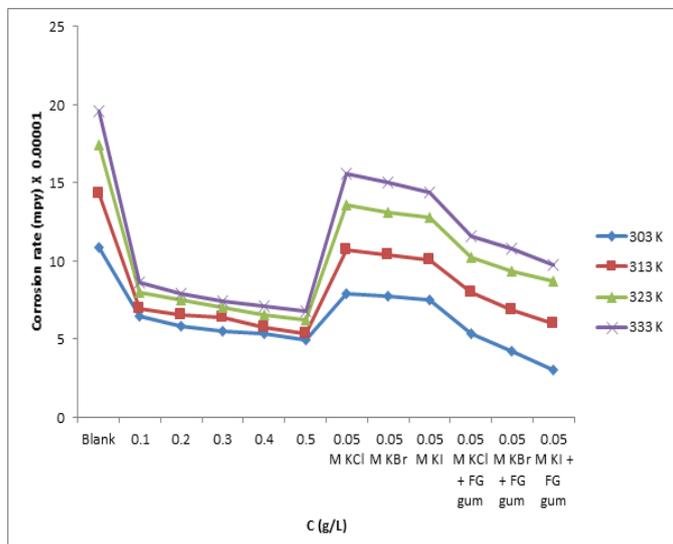
Fig. III: Corrosion rate of mild steel and inhibition efficiency of FG gum, halides and FG gum (0.5 g/L)-halide mixtures

C (g/L) or (M)	Inhibition efficiency (%)			
	303 K	313 K	323 K	333 K
Blank	-	-	-	-
0.1	40.60	51.15	54.10	56.15
0.2	46.32	53.86	57.00	59.48
0.3	49.32	55.11	59.73	62.06
0.4	50.68	59.71	62.63	63.73
0.5	54.50	62.63	64.33	65.40
0.05 M KCl	54.44	45.37	23.89	20.33
0.05 M KBr	55.63	46.74	26.45	23.52
0.05 M KI	56.83	48.56	28.50	26.56
0.05 M KCl + FG gum	69.45	59.33	43.17	40.97
0.05 M KBr + FG gum	75.60	64.95	47.95	44.92
0.05 M KI + FG gum	82.59	69.50	51.88	50.08

Table I: Inhibition efficiency of FG gum, halides and FG gum (0.5 g/L)-halide mixtures on mild steel

System	303 K	313 K	323 K	333 K
0.05 M KCl + 0.5 g/L FG gum	1.42	1.42	1.32	1.35
0.05 M KBr + 0.5 g/L FG gum	1.23	1.24	1.31	1.32
0.05 M KI + 0.5 g/L FG gum	1.06	1.15	1.25	1.23

Table II: Synergistic parameters for joint adsorption of FG gum and halides at various temperatures

Enhancement of the inhibition efficiency of FG gum by joint combination of the gum with halide can be studied using synergistic parameter, which can be calculated using the following equation (Ashassi-Sorkhabi et al., 2005),

$$S = \frac{1 - I_A - I_B - I_A I_B}{I_{AB}} \qquad \text{IV}$$

where IA and IB are the inhibition efficiencies of compound A and compound B respectively, and IAB is the inhibition efficiency of a combination of two inhibitors. The calculated values of S for various FG gum-halide combinations are presented in Table II. The results obtained indicated that all the S values are more than unity, which suggests that the adsorption of FG gum on the mild steel is enhanced by the addition of halide ions to the studied inhibitor and in the order Cl-< Br-< I-. The difference observed may be due to their sizes (Cl = 0.09 nm, Br = 0.114 nm, I=0.135 nm) and ease of polarisability, which is more predisposed to adsorption on metal surfaces.

Effect of temperature

The effect of temperature on the adsorption of FG gum on the mild steel surface was studied using the Arrhenius equation, which relates the rate of corrosion to the activation energy according to equation V (Ebenso et al., 2008)

$$CR = \frac{Aexp(-E_a)}{RT} \qquad \text{v}$$

where CR is the rate of corrosion of mild steel, R is the universal gas constant, A is the pre-exponential constant and T is the temperature. From the logarithm of both sides of equation V, equation VI was obtained,

$$logCR = logA - \frac{E_a}{2.303RT} \qquad VI$$

Using equation VI, plots of log CR against 1/T gave straight lines (Figure IV) and from the slopes and intercepts of the plots, values of E_a and A were calculated. The results obtained are presented in Table III. The results revealed that the activation energies for the blank are greater than those calculated for various concentrations of FG gum but lower than those calculated for the halides and halide-FG gum mixtures. Generally, values of E_a lower than 80 kJ/mol are indicative of the mechanism of physical adsorption, but in this study the mechanism of chemical adsorption has been proposed (Eddy et al. 2011). The low values obtained for the E_a may be attributed to the existence of the mechanism of physiosorption before chemisorption. Secondly, it may be significant to state that the adsorption of the inhibitors is diffusion controlled and not activation controlled. Reactions that are activation controlled are characterised by low values of activation energy, unlike activation controlled reactions.
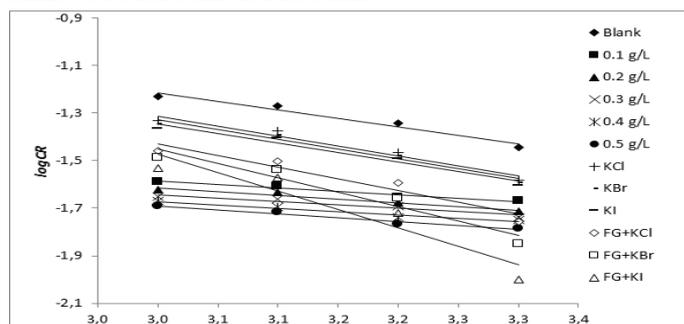

Fig. IV: Variation of logCR with 1/T for the corrosion of mild steel in solutions of HCl containing 0.05 M halide, 0.5 g/L FG gum + 0.05 M and various concentrations of FG gum, halide

Thermodynamic/adsorption studies

Chemical thermodynamics seeks to address the direction of a chemical reaction, expected heat of reactions and changes in state functions. In this study, the changes in enthalpy and entropy of adsorption were calculated using the transition state equation, which can be written as follows,

$$CR = \frac{RT}{Nh} exp\left(\frac{\Delta S^0_{ads}}{R}\right) exp\left(\frac{-H^0_{ads}}{RT}\right)$$

From the logarithm and rearrangement of equation VII, equation VIII was obtained.

$$log\left(\frac{CR}{T}\right) = log\left(\frac{R}{Nh}\right) + \frac{\Delta S^0_{ads}}{2.303R} - \frac{H^0_{ads}}{2.303RT}$$

Equation VIII implies that a plot of $log\left(\frac{CR}{T}\right)$ versus 1/T should be linear

with slope and intercept equal to $[log\left(\frac{R}{Nh}\right) + \frac{\Delta S^0_{ads}}{2.303R}]$ and $\frac{H^0_{ads}}{2.303R}$

respectively. Figure V shows the transition state plots for the adsorption of FG gum, halides, and FG gum-halide mixtures. Values of standard enthalpy and entropy changes calculated from the slope and intercept of the plot are presented in Table IV. The results show that H^0_{ads} values are positive, indicating that the adsorption of the gum, halide and gum-halide mixture is endothermic. H^0_{ads} values for the halides and halide-gum mixtures were also found to be higher than those obtained for various concentrations of the gum, indicating that, in the presence of the halides, a higher amount of heat is adsorbed.

System	Slope	logA	Ea(J/ mol)	A	R2
Blank	0.8497	3.8580	16.27	20.57	0.9705
0.1 g/L FG gum	0.4278	2.2208	8.19	4.00	0.9802
0.2 g/L FG gum	0.4542	2.2713	8.70	4.21	0.9783
0.3 g/L FG gum	0.4243	2.1536	8.12	3.74	0.9623
0.4 g/L FG gum	0.4162	2.1001	7.97	3.55	0.9851
0.5 g/L FG gum	0.4736	2.2540	9.07	4.14	0.9799
0.05 M KCl	0.9824	4.1588	18.81	27.79	0.9753
0.05 M KBr	0.9623	4.0810	18.43	25.71	0.9744
0.05 M KI	0.9476	4.0216	18.14	24.23	0.9678
0.5 g/L FG gum + 0.05 M KCl	1.1198	4.4528	21.44	37.28	0.946
0.5 g/L FG gum + 0.05 M KCl	1.3467	5.1101	25.79	71.94	0.9438

Table III: Arrhenius parameters for the adsorption of halides, FG gum-halide mixtures and various concentrations of FG gum

On the other hand, data obtained for the entropy change were negative, which implies that the adsorption of the gum, halides and halide-gum mixtures occurs with increasing degree of orderliness.

The value of ΔS^0_{ads} is negative in the absence of inhibitors because the transition state of the rate-determining recombination step represents a more orderly arrangement relative to the initial state; hence, a negative value for ΔS^0_{ads} is expected. ΔS^0_{ads} values were still negative in the presence of inhibitors but the magnitude increases with increasing concentrations of the inhibitors. This was because these compounds inhibited acid dissolution of metal by simply blocking on the surface without changing the mechanism of the corrosion process.
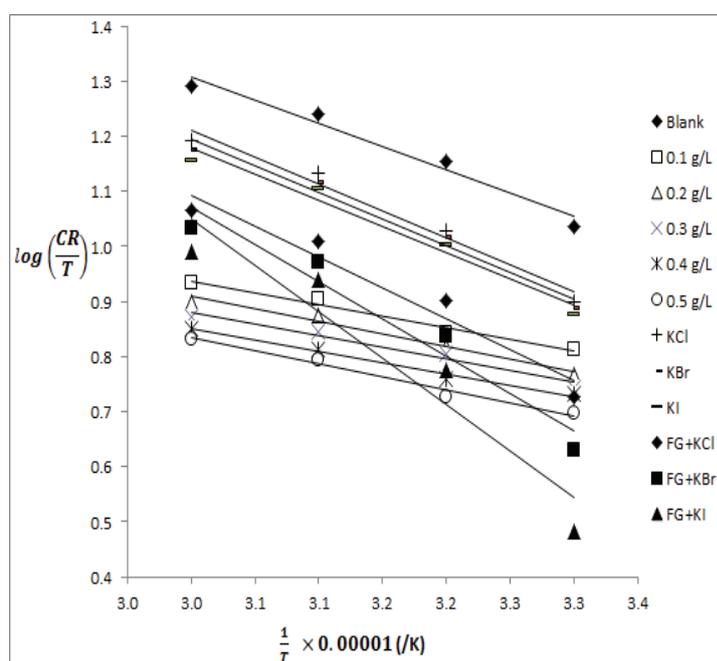

Fig. V: Variation of log(CR/T) with 1/T for the corrosion of mild steel in solutions of HCl containing 0.05 M halide, 0.5 g/L FG gum + 0.05 M and various concentrations of FG gum, halide

According to Khadom et al. (2012), the corrosion of metals in a neutral or acidic solution is cathodically controlled by the hydrogen evolution reaction, which occurs in two steps, as indicated below:

$$H^+ + e^- = H_{ads} \qquad\qquad IX$$

$$H_{ads} + H^+ = H_2 \qquad\qquad X$$

The rate-determining step for the hydrogen evolution reaction is the recombination of adsorbed hydrogen atoms to form hydrogen molecules (equation X).

In free acid solution, the transition state of the rate-determining recombination step represents a more orderly arrangement relative to the initial state; hence, a negative value for the entropy of activation is obtained. In the presence of inhibitors, the entropy of activation still has a negative value, but its magnitude increases with increasing inhibitor

System	Slope	Intercept	ΔH^0_{ads} (J/mol)	ΔS^0_{ads} (J/mol)	R^2
Blank	0.713	0.9253	13.65	-0.49	0.9597
0.1 g/L FG gum	0.2911	-0.7119	5.57	-0.58	0.958
0.2 g/L FG gum	0.3176	-0.6614	6.08	-0.57	0.9585
0.3 g/L FG gum	0.2877	-0.7791	5.51	-0.58	0.9246
0.4 g/L FG gum	0.2795	-0.8325	5.35	-0.58	0.9664
0.5 g/L FG gum	0.3369	-0.6786	6.45	-0.57	0.9604
0.05 M KCl	0.8458	1.2261	16.19	-0.47	0.9677
0.05 M KBr	0.8256	1.1483	15.81	-0.48	0.9664
0.05 M KI	0.8109	1.0889	15.53	-0.48	0.9574
0.5 g/L FG gum + 0.05 M KCl	0.9831	1.5201	18.82	-0.46	0.9319
0.5 g/L FG gum + 0.05 M KCl	1.21	2.1775	23.17	-0.43	0.9321
0.5 g/L FG gum + 0.05 M KCl	1.5494	3.1757	29.67	-0.37	0.8918

Table IV: Thermodynamic parameters for the adsorption of halides, FG gum-halide mixtures and various concentrations of FG gum

concentration, which indicates that the degree of orderliness increases with an increase in the inhibitors' concentrations.

In order to investigate the adsorption characteristics of FG gum as an inhibitor, data obtained for the degree of surface coverage at various concentrations of the gum were fitted into different adsorption isotherms and the best isotherms were chosen through values of R2 calculated from the plots. The results obtained indicated that Langmuir and Frumkin adsorption isotherms best fitted the adsorption of FG gum on a mild steel surface. The assumption establishing the Langmuir isotherm can be expressed as follows:

$$log \left(\frac{C}{\theta}\right) = log b_{ads} - log C \qquad XI$$

where C is the concentration of the inhibitor in the bulk electrolyte, θ is the degree of surface coverage of the inhibitor and bads is the adsorption equilibrium constant. From equation XI, a plots of $log\frac{(C)}{\theta}$ versus logC is expected to give a straight line with a unit slope, and the intercept should be equal to logbads. Figure VI shows the Langmuir isotherm for the adsorption of FG gum on a mild steel surface. The adsorption parameters deduced from the plots are shown in Table V. From the results obtained, values of R2 were very close to unity, indicating an excellent degree of fitness. However, the slopes of the plots were not equal to unity as expected from the ideal Langmuir equation. Deviation of the present data from ideality indicates that there are some interactions between the adsorbed species. In order to account for the interaction, the Frumkin adsorption equation (equation XII) was employed (Gojic, 2002),

$$log \left(\frac{\theta}{1-\theta}\right) * [C] = log b_{ads} + 2\alpha\theta \qquad XII$$

in the electrolyte, θ is the degree of surface coverage of the inhibitor and b_{ads} is the adsorption equilibrium constant.

Plots of $log \left(\frac{\theta}{(1-\theta)}\right) * [C]$ versus θ (Figure VII) were linear for all temperatures and from the slope and intercept of the plots, values of θ and b_{ads} were estimated and the results are presented in Table V. The results revealed that the interaction parameters are positive and tend to increase with increasing temperature.

	T (K)	slope	Inter-cept	b_{ads}	α or 1/y	R^2	ΔG^0_{ads} (kJ mol)
Langmuir	303	0.8269	0.2172	0.5396	-	0.9994	-11.35
	313	0.8791	0.1786	0.5191	-	0.9977	-11.50
	323	0.8911	0.1623	0.5107	-	0.9996	-11.40
	333	0.9055	0.1575	0.5083	-	1.0000	-11.37
Frumkin	303	7.0042	-3.9963	0.0080	3.50	0.9890	-50.73
	313	7.3715	-4.6342	0.0042	3.69	0.9259	-52.86
	323	8.3633	-5.3961	0.0020	4.18	0.9806	-58.62
	333	9.3781	-6.1371	0.0009	4.69	0.9963	-64.50
El Awardy	303	0.7530	0.3708	1.6363	1.33	0.9811	-19.59
	313	0.6404	0.6372	2.7047	1.56	0.8717	-26.64
	323	0.6123	0.7470	3.3872	1.65	0.9643	-31.71
	333	0.5530	0.7878	4.1562	1.82	0.9920	-37.59

Table V: Adsorption parameters deduced from Langmuir and Frumkin isotherms
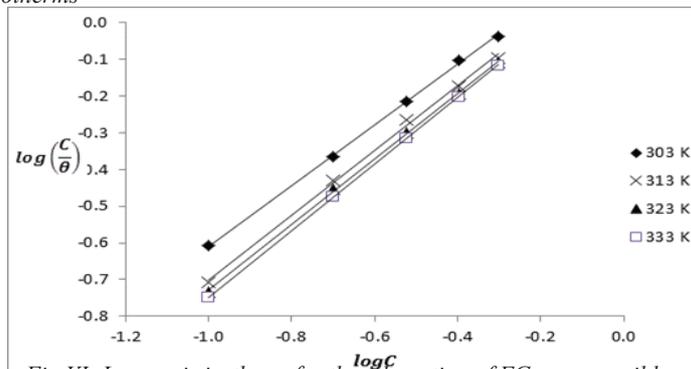

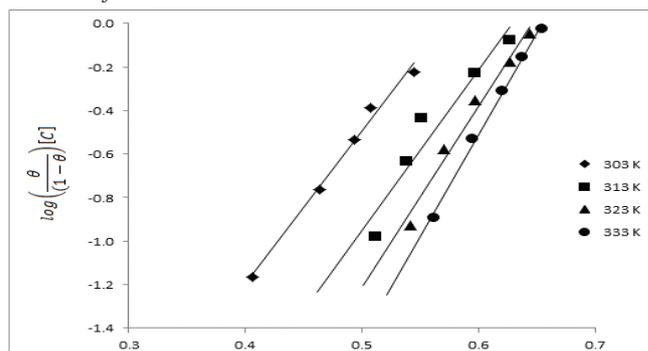*Fig.VI: Langmuir isotherm for the adsorption of FG gum on mild steel surface.*

Fig.VII: Frumkin isotherm for the adsorption of FG gum on mild steel surface

These observations suggest that there is attraction between the inhibitor's molecules and also revealed that the attractive behaviour of the inhibitor increases with an increase in temperature, a condition that favours the chemisorption mechanism. The results obtained also revealed that the binding constant increases with an increase in temperature, indicating that the strength of adsorption also increases with an increase in temperature.

The strength of adsorption of FG gum on a mild steel surface and the possible formation of a multi-molecular layer of adsorption were investigated using the El Awardy et al. kinetic isotherm, which can be written as equation XIII (Olusola et al., 2009),

$$\log\left(\frac{\theta}{1-\theta}\right) = \log b' + y \log C \qquad XIII$$

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_{ads} through $b_{ads} = b'^{\left(\frac{1}{y}\right)}$.

Figure VII shows the kinetic plots for the adsorption of FG gum, while the adsorption parameters deduced from the isotherm are also presented in Table V. The results obtained reveal that values of 1/y are greater than unity, indicating the formation of multiple layers of the inhibitor on the surface of the mild steel, as opposed to a situation where a given inhibitor's molecules will occupy more than one active site (i.e. 1/y < 1). Also, bads values tend to increase with temperature. Generally, larger a value of the binding constant (b_{ads}) implies better adsorption arising from stronger electrical interaction between the double layer existing at the phase boundary and the adsorption molecule. On the other hand, small values of the binding constant suggest with weaker interaction between the adsorbing molecules and the metal surface. Therefore, the extent of adsorption and hence inhibition efficiency of FG gum increases with increasing temperature, which is consistent with the mechanism of chemical adsorption.

Distinction between chemical and physical adsorption can be achieved through application of the Dubinin-Radushkevich isotherm model (D-RIM), which can be written as follows (Noor, 2009):

$$\log\theta = \log(\theta)_{max} - a\delta^2 \qquad XIV$$

where θ_{max} is the maximum surface coverage and δ (Polany potential) can be expressed as:

$$\delta = RT\left(1 - \frac{1}{C}\right) \qquad XV$$

where R is the universal gas constant, T is the absolute temperature and C is the concentration of the inhibitor. The constant 'a' gives the mean adsorption energy, E, which is the transfer energy of 1 mol of adsorbate from infinity(bulk solution) to the surface of the adsorbent, i.e.

$$E = \frac{1}{\sqrt{2a}} \qquad XVI$$

The magnitude of E gives information about the type of adsorption. Values of E less than 8 kJ/mol indicate physical adsorption, while those greater than 8 kJ/mol are consistent with the mechanism of chemical adsorption. Figure IX shows plots of ln θ versus δ for the adsorption of FG gum, while Table VI presents adsorption parameters deduced from the slope and intercept of the D-RIM isotherm. It is evident from the results that the numerical values of E are greater than unity, hence the adsorption of FG gum is confirmed to be consistent with the mechanism of chemical adsorption.
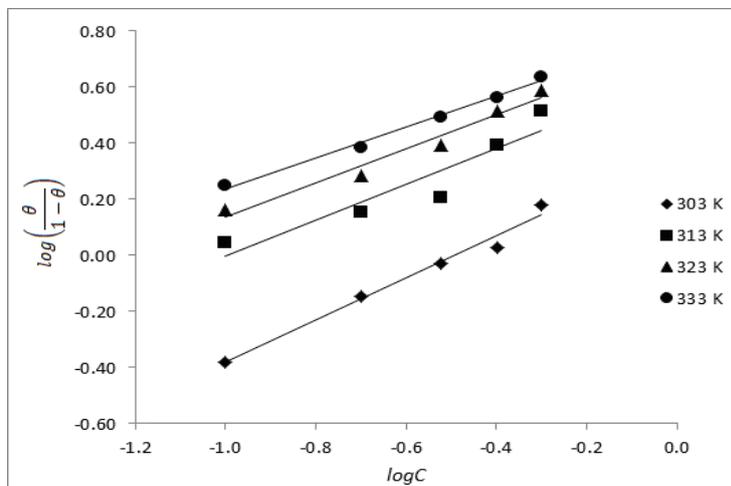

Fig.VIII : El Awardy et al isotherm for the adsorption of FG gum on mild steel surface
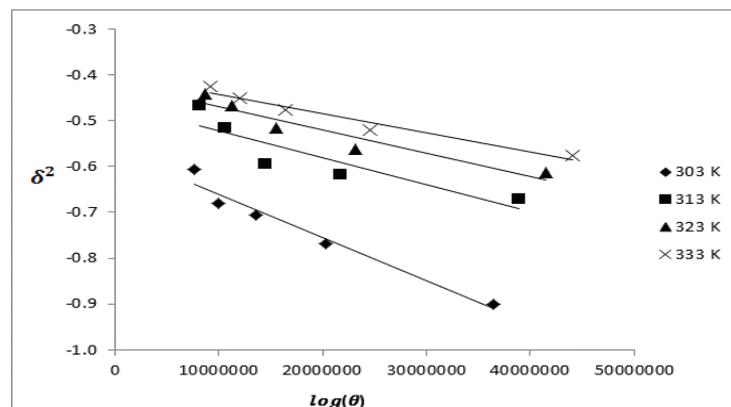

Fig. IX: Dubinin-Radushkevich isotherm for the adsorption of FG gum on mild steel surface

The standard free energy of adsorption of an FG inhibitor on a mild steel surface was calculated using the Gibb helmoltz equation, which relates the binding constant with the standard free energy of adsorption according to equation XVII

$$b_{ads} = \frac{1}{55.5}\exp\left(\frac{-\Delta G^0_{ads}}{RT}\right) \qquad XVII$$

From the results obtained for b_{ads}, values calculated from the Langmuir, Fumkin and El awardy et al. adsorption isotherms, ΔG^0_{ads} values were obtained and are presented in Table V. The results show at a glance that the free energies obtained from the Langmuir isotherm are less than the threshold value of – 20 kJ/mol expected for the mechanism of chemical adsorption but greater in the case of the Frumkin and El awardy et al adsorption

T (K)	$\log(\theta_{max})$	θ_{max}	a (mol²kJ⁻¹)	E (kJ/mol)	R²
303	-0.5674	0.2462	9.00×10^{-9}	10.50	0.9650
313	-0.4635	0.2732	6.00×10^{-9}	12.90	0.7945
323	-0.4185	0.2857	5.00×10^{-9}	14.10	0.9107
333	-0.4002	0.2910	4.00×10^{-9}	15.80	0.9594

Table VI :Dubinin-Radushkevich isotherm model (D-RIM) parameters for the adsorption of FG gum

isotherms. Therefore, the adsorption of FG gum on a mild steel surface is characterised by the mechanism of physical adsorption and was succeeded by the chemisorption mechanism.

Conclusion
FG gum is a good adsorption inhibitor for mild steel. However, it has low values of inhibition efficiency, which can be improved through synergistic combinations of chloride, iodide and bromide ions respectively. The adsorption of FG gum supported the mechanism of chemisorption and obeys the Frumkin adsorption isotherm. The strength of adsorption as examined through the El awardy et al. and D-RIM adsorption isotherms indicated that the adsorption of the inhibitor is enhanced at higher temperatures.

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