

Original Research Article**Electrochemical and Adsorption behaviour of *Diospyros mespiliformis* on annealed carbon steel corrosion in hydrochloric acid****Abstract**

The interfacial activities of *Diospyros mespiliformis* on annealed carbon steel in 2 M HCl solution was studied by electrochemical methods; polarization and impedance spectroscopy measurements, while weight loss at varying temperatures and gasometric method was studied. The corrosion rate results showed that *D. mespiliformis* mitigates carbon steel corrosion in HCl. the results of the study revealed that *D. mespiliformis* reduced the corrosion of FE164531 in HCl solution via adsorption. Tafel results suggest that DM behaves predominantly as a cathodic inhibitor and shows high inhibition efficiency (91%) at 1000 ppm. The Nyquist and Bode plots of the test solutions were similar in both inhibited and free medium and contained capacitive and inductive loops. The thermodynamical parameters suggest that *D. mespiliformis* is adsorbed on carbon steel mainly by physical adsorption. The values of enthalpy and entropy of adsorption suggests that DM adsorption on FE164531 surface was spontaneous. *D. mespiliformis* was found to reduce the volume of hydrogen gas evolved. A good correlation was obtained between the percentage inhibition efficiencies calculated from all the technique employed.

Key words: Annealed carbon steel, *D. mespiliformis*, corrosion inhibition, adsorption, HCl

1. Introduction

25 The significance of corrosion protection of carbon steel in acidic solutions is become necessary
26 due to its propensity to be attacked in acidic media when deployed in services like acid pickling,
27 chemical cleaning of scale in metallurgy, in electrochemical systems, oil recovery and also the
28 petrochemical industry. The protection of carbon steel against corrosion in acidic environments
29 can be achieved in various ways using corrosion inhibitors [1-3]. Researches on usage of
30 inhibitors have been carried out in the field of carbon steel corrosion in acid solutions [4-
31 7].Corrosion inhibitors are commonly added in small amounts to pickling acids, acid stimulation
32 fluids, cooling waters, oil and gas production streams, either continuously or intermittently to
33 control corrosion. These inhibitors generally control corrosion by forming various types of films
34 that modify the corrosivity at the metal surface in contact with its environment in several ways;
35 either by adsorption or the formation of bulky precipitates, and/or the formation of a passive
36 layer on the metal surface [8-10]. The mechanism of most corrosion inhibitor on metal
37 oxidization can be explained on the basis of molecular adsorption, which involves forming a
38 thin, invisible film that coat the metal thereby protecting it from attack or a combination of
39 adsorption films and corrosion product forms a passive layer on the metal surface [11]. In
40 aqueous acidic solutions, corrosion inhibitors subsist either as neutral molecules or protonated
41 molecules which adsorb on the metal/acid solution interface through electrostatic attraction
42 between charged molecules and charged metal or by the interaction of unshared π electrons in
43 the inhibitor molecule with the metal surface [12]. Apart from sea water, hydrochloric acid
44 remains the main source of the aggressive chloride ions in aqueous solutions and occurrence of
45 carbon steel corrosion in environments containing chloride ions, limits the metal usage [13].
46 Several reports claims the used of green inhibitor as cheap, effective, renewable and zero-toxic
47 inhibitor for metal corrosion [14-20]. The effectiveness of these bio-extracts as metal corrosion

inhibitor mainly depend on its phytochemical functional groups having; steric effects, π -orbital character of donating electrons via adsorption at active sites and electronic density of donor atoms among other variables. *Diospyros mespiliformis* commonly called African ebony is confined to tropical and sub-tropical regions notably in Central and West Africa [21]. Several ethnopharmacological applications have been reported for *D. mespiliformis* which include the use of leaf decoction as extraordinary remedy for fever, whooping cough and for wounds [22,23]. Chemical analyses of extracts from *Diospyros mespiliformis* yielded components such as triterpenes, sterols, carotenoids, saponosides, anthracenosides, anthocyanosides and tannins [24].

In this present work, corrosion study was made using annealed carbon steel immersed in aerated stagnant 2 M HCl solutions with and without addition of ethanolic extract of *D. mespiliformis* leaves, using weight loss, gasometry and electrochemical techniques. The corrosion rate (mpy) and inhibition efficiency was evaluated with the different methods employed while insight into the adsorption mechanism through electrochemical impedance spectroscopy (EIS) was assessed. The experimental data were also fitted into Langmuir adsorption isotherm while the effects of temperature gave thermodynamic parameters such as ΔG , ΔH and ΔS .

2. Experimental

2.1 Material preparation

Corrosive solutions were freshly prepared from analytical grade chemical reagents using doubly distilled water and were used without further purification for each test run. Annealed carbon steel (FE164531) sheets of 99.5% purity, used for this study has the following typical analysis ppm: C< 1200, Mn< 5000, S< 500, P< 500 which was procured commercially from Advent research

materials Ltd, Eynsham Oxford England OX29 4JA. The sheet was mechanically press-cut into 40 x 40 x 0.92 mm coupons with a hole of 1mm drilled at the middle of the upper edge of the coupons and then grinded successively with metallographic emery paper of increasing fineness of up to 1200 grits. These coupons were degreased in absolute ethanol, dried in acetone, further dried with hot air and stored in moisture-free desiccator prior usage. Dried leaves of *D. mespiliformis* were blended to powder form; 10 g of powdered leaves was refluxed in 100 ml ethanol for 3 h, allowed to cool for 6 h and filtered. The filtrate was concentrated using rotary evaporator and stored in an oven at 40 °C. From the concentrate, inhibitor test solutions were prepared in the concentration range of 10 – 1000 ppm.

2.2 Weight loss

In gravimetric measurements, FE164531 coupons were weighed before total immersion in a 250ml beaker containing 200 ml test solutions, being suspended by suitable hooks at 1 cm below the solution surface. The beakers were placed in a freely aerated thermostated water bath maintained at constant temperature at 303, 313, 323 and 333 ± 0.5K. The coupons were retrieved after 3 hours, scrubbed with brush under running bidistilled water, dried as before and weighed [13]. The difference in weight of the coupons before and after immersion in different test solutions was taken as the weight loss. The corrosion rate and inhibition efficiency ($E_W \%$) was calculated using the following equations 1 and 2 respectively [10]

$$CR \text{ (mpy)} = \frac{534 \Delta W}{\rho AT} \quad (1)$$

$$E_W \% = \frac{CR^0 - CR}{CR^0} \quad (2)$$

where ΔW is weight loss in mg, ρ is the density of carbon, A the area of the coupon in inches, T is the immersion time in hours, CR and CR^0 are the corrosion rate in the presence and absence of inhibitors respectively.

2.3 Gasometric

Fifty milliliters of test solutions poured into a reaction vessel was used in the gasometric method. Upon introduction of the metal coupon, the vessel was quickly corked and the initial volumes of air in the burette, taken against that of the paraffin oil were recorded. The decrease in volume of the paraffin oil in the burette due to hydrogen gas evolution was noted after every five minutes till the last volume of paraffin oil in the burette. The volume of hydrogen gas evolved was used to evaluate inhibition efficiency of the test inhibitors using equation 3 [25]

$$E_H \% = 1 - \frac{CR_H}{CR_H^0} \quad (3)$$

where CR_H and CR_H^0 are corrosion rates got from total volume of gas evolved in the presence and absence of test inhibitors respectively.

2.4 Polarization technique

The electrochemical experiments were carried out in a three-electrode electrochemical cylindrical Pyrex glass cell with a graphite rod counter electrode and saturated calomel electrode (SCE) as reference. Annealed carbon steel having an exposed area of 1cm^2 was used as working electrode. Before recording the polarization curves, the working electrode was kept at its open circuit value in aerated stagnant 2 M HCl solution without and with inhibitor for 30 min. All electrochemical experiments were performed at room temperature ($27 \pm 1^\circ\text{C}$) using a VersaSTAT 3 electrochemical System. The potentiodynamic polarization curves were obtained by scanning

the potential of working electrode from -0.25 V to 1.7 V vs. SCE at a scan rate of 1 mV/s [8], while impedance spectroscopy experiments (EIS) was scanned at the open-circuit potential at frequencies from 100 kHz to 0.1 Hz with AC signal amplitude of 5 mV peak-to-peak along phase shifts between AC voltage and current. The Nyquist and bode plots were acquired using ZSimpWin Version 3.20. The values of E_{corr} , i_{corr} , R_t and C_{dl} were obtained from the electrochemical measurements. The inhibition efficiencies were determined using equations below:

$$E_i \% = \frac{i_{corr}^0 - i_{corr}}{i_{corr}^0} \quad (4)$$

$$E_R \% = 1 - \frac{R_{ct}^0}{R_{ct}} \times 100 \quad (5)$$

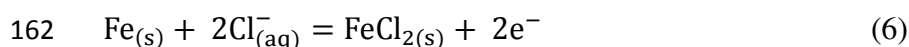
Where i_{corr} and i_{corr}^0 is corrosion current densities for inhibited and uninhibited solutions respectively, while R_t and R_t^0 is charge resistance in the presence and absence of inhibitor molecules respectively.

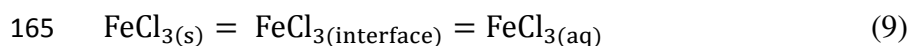
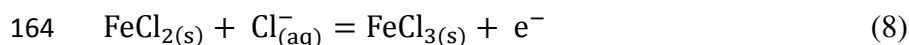
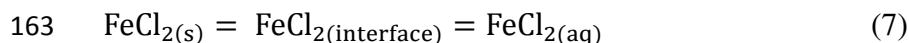
3. Results and Discussions

3.1 Polarization measurements

Figure 1 shows the anodic and cathodic polarization curves of FE164531 while calculated electrochemical parameters such as, corrosion potential (E_{corr}), corrosion current density (i_{corr}), degree of surface coverage (θ), the inhibition efficiency (E_i %) and linear polarization resistance (R_p) values are listed in Table 1. As can be seen from Fig. 1, the polarization curves showed features of spontaneous passivation in all test media and addition of inhibitor molecules at varying concentrations did not visibly alter the polarization behavior of the metal in the active, passive or transpassive region. This suggests that *D. mespiliformis* did not interfere with the

corrosion mechanism of FE164531, however the inhibitor additives caused a decrease in both cathodic and anodic currents proposing a reduction in anodic dissolution and retardation of hydrogen evolution reaction [5,8]. The cathodic polarization curves exhibit active behaviour with increasing inhibitor concentration with a shift towards lower current density region while the anodic polarization curves are almost identical irrespective of the concentration of inhibitor molecule. The lower values of corrosion current density facilitate slow electron transfer in the redox process, hence the rate of corrosion reaction becomes reduced. The decrease of current density indicate the fact that *D. mespiliformis* molecules gets adsorbed on pure carbon steel surface and hence retards the corrosion reaction of electrode with concurrent replacement of electrolyte solution at the metal/electrolyte interface [26]. Inspecting figure 1 reveals a decrease in both corrosion current and potential in the cathodic region with a cathodic shift was observed in the E_{corr} indicating that *D. mespiliformis* is a probable cathodic inhibitor. A spontaneous passivation in the anodic region was seen with a decrease in the corrosion potential as the inhibitor was introduced. This decrease is observed at the initial anodic – active dissolution of FE164531 which is an indication of the stability of the film formation comprising of γ - $\text{Fe}_2\text{O}_3/\text{Fe}_3\text{O}_4$ on FE164531 surface [3,27]. As the potential becomes more passive, the rates of anodic reactions increase while that of cathodic reactions decreases. This observation is an indication that the formation of γ - $\text{Fe}_2\text{O}_3/\text{Fe}_3\text{O}_4$ films gradually spreading over the surface of FE164531. Usually a low current density and long anodization time present a very good protection against corrosion due to the diminution of the porosity of the anodic films formed. The corrosion reaction of carbon steel in solutions containing chloride ions occur via these mechanisms as reported elsewhere;





The mechanism show that the film formed on the carbon steel surface is a mixed porous film of a precipitated ferrous chloride, FeCl_2 and ferric chloride, FeCl_3 compounds. Considering concentration gradients, the ferrous and ferric chloride specie at metal/electrolyte interface diffuse through the porous film and the diffusion boundary layer and then into the bulk solution through convection currents. This results in continuous uniform and pitting corrosion of FE164531 by attack of the chloride ions. The introduction of inhibitor molecules controlled the corrosion current with a maximum of 91% inhibition at 1000 ppm concentration. This can be explained on the bases that *D. mespiliformis* at this concentration strongly inhibit and block the corrosion sites on the carbon steel surface and retards uniform corrosion and prevents formation of pits. Table 1 shows the corrosion potential exhibiting a decrease with increasing concentration could be attributed to the passage of metal ions through the adsorbed film occuring slowly and the corrosion current due to metal ion transportation becomes reduced.

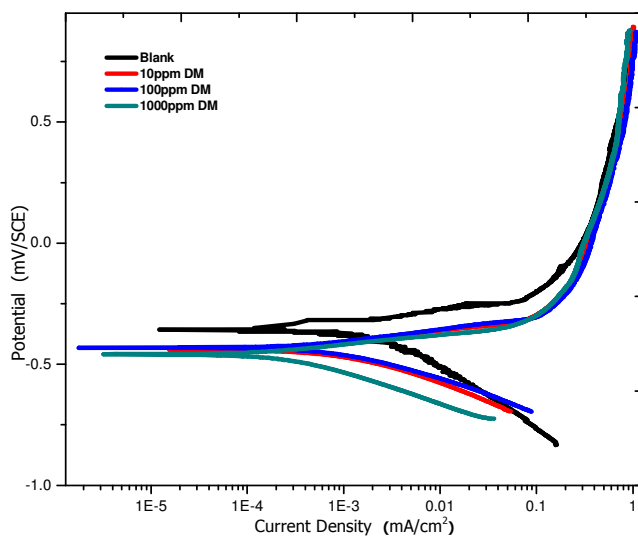


Fig. 1 Anodic and cathodic polarization curves for FE164531 electrode in aerated solution of 2 M HCl solution in the absence and presence of different concentrations of *D. mespiliformis* molecules.

The i_{corr} values were used to calculate the inhibition efficiencies from equation 4 and are presented in table 1. The linear polarization resistance (R_p) was found to increase from 0.496 to 1.497 Ω which results in an increase in corrosion current resistance on addition of *D. mespiliformis* to 2 M HCl. Further, on increasing the inhibitor concentration, E_{corr} values were shifted more negative. This proposes that *D. mespiliformis* behaves predominantly as a cathodic inhibitor. The increase of polarization resistance with increasing inhibitor concentration is mainly due to its adsorption on FE164531 surface. The value of R_p is a measure of electron transfer across the surface and it increases with an increase in corrosion rate. It was clear from table 1 that R_p values decreased with the addition of inhibitor molecules and further increased as inhibitor concentration increased, indicating a reduction in FE164531 corrosion rate through the formation of an adsorbed protective film on the metal/electrolyte interface [28,29].

Table 1 Corrosion parameters obtained from polarization curves for FE164531 in 2 M HCl solution in the absence and presence of *D. mespiliformis* molecules.

Solution	Parameters				
	i_{corr} ($\mu\text{A cm}^{-2}$)	$-E_{corr}$ (mV vs SCE)	θ	E_i %	R_p (Ω)
blank	5465.8	357.28	--	--	0.496
10 ppm	2715.03	427.01	0.5033	50	1.272
100 ppm	1342.04	436.27	0.7545	76	1.338
1000 ppm	517.01	443.08	0.9054	91	1.497

3.2 Impedance Spectroscopy Measurements

To determine kinetic parameters for electron transfer reactions at the carbon steel/electrolyte interface, electrochemical impedance spectroscopy experiment was carried out at open circuit potential in the absence and presence of *D. mespiliformis*. Typical Nyquist and Bode plots were obtained at the metal/electrolyte interface for all test solutions. Figure 2 shows the Nyquist plot of one capacitive loop exhibiting an extended semicircle in the complex impedance plane both in uninhibited and inhibited solutions, an indication that corrosion rate is controlled by charge transfer resistance. The impedance diagrams obtained were not perfect semicircles, and increases in diameter as inhibitor concentration increases indicating that the presence of inhibitor molecules strengthens the inhibitive film and/or the Faradic processes occurring through defects of this film with increase in *D. mespiliformis* concentration. The impedance data obtained are analyzed by simple equivalent Randles circuit which sufficiently explains EIS data for liquid and steam-treated samples [8,30]. Figure 3 shows typical Randles circuit consisting of solution resistance R_s in series with a component composed of transfer resistance R_t and parallel film capacitance C_{dl} . The obtained values for the charge transfer resistance and double layer

capacitance are listed in table 2. As seen from table 2 that the value of R_t increases in the concentrations of the inhibitor. Fig. 4 shows the Bode plots for FE164531 in 2 M HCl with and without different concentrations of *D. mespiliformis* inhibitor. The capacity of double layer (C_{dl}) was calculated from equation 7

$$C_{dl} = \frac{1}{2\pi f_{max} R_{ct}} \quad (10)$$

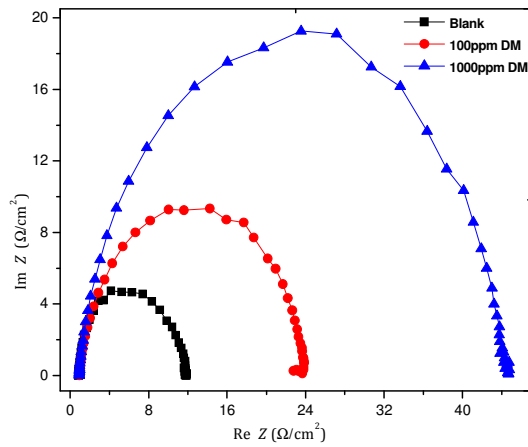


Fig. 2 Nyquist plots for FE164531 in 2 M HCl with and without different concentrations of *D. mespiliformis* inhibitor

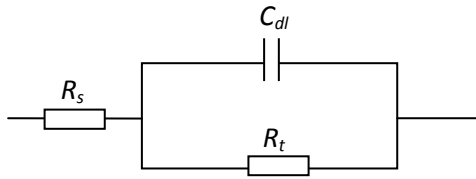


Fig. 3 Electrical equivalent circuit used to fit the impedance data

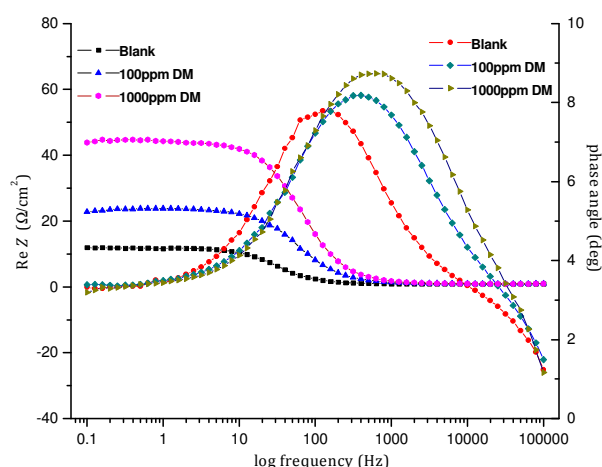


Fig. 4 Bode plots for FE164531 in 2 M HCl with and without different concentrations of *D. mespiliformis* inhibitor

Perusal of table 2 shows that C_{dl} values decreased when the concentration of the inhibitor molecules increased. The decrease in C_{dl} might arise from a decrease in local dielectric constant and/or an increase of the electrical double layer thickness which might arise from substitution of preadsorbed water molecules on the metal/electrolyte interface by adsorbed organics whose dielectric constant is lower, suggesting that inhibitor molecules function by adsorption at the metal/solution interface [30].

As the adsorption of the inhibitors at the metal/electrolyte interface increases, there was a gradual decrease in the double layer capacitance (C_{dl}) and corrosion current values indicating a decrease in local dielectric constant of the electrical double layer [8,31-33]. The inhibitor decreased the C_{dl} values by replacing water molecules present at the electrode surface [34].

The low frequency impedance in the Bode plot continues to increase as the frequency drops, indicating a strong resistance to the flow of ions and electrons through the adsorbed film, hence preventing corrosion. A capacitive behavior is indicated from medium to low frequencies by

phase angles approaching 9° , suggesting that a weak adsorbed film is formed on FE164531 in the 2 M HCl which is consistent with physical adsorption.

Table 2 EIS data and adsorption parameters for FE164531 in 2 M HCl solution in the absence and presence of *D. mespiliformis* molecules

Solution	Parameters					
	R_t ($\Omega \text{ cm}^{-2}$)	C_{dl} ($\mu \text{ cm}^{-2}$)	θ	$E_R \%$	$-\Delta S$ $\text{Jmol}^{-1}.\text{K}$	ΔH KJmol^{-1}
blank	34.2	294.8	--	--	52.632	44.0076
10 ppm	--	--	--	--	47.224	45.8647
100 ppm	185.4	104.1	0.8156	82	36.063	49.5686
1000 ppm	267.6	91.7	0.8718	87	16.04	56.3511

3.3 Gasometric technique

The gasometric measurement is based on the idea that the rate of hydrogen evolution in a corrosion reaction is directly proportional to the corrosion rate. This technique, apart from its experimental rapidity, ensures a more sensitive monitoring in situ of any perturbation by the inhibitor vis-a-vis hydrogen gas evolution on the metal-corrodent interphase [25]. The volume of H_2 evolved was observed to appreciably reduce in the presence of test inhibitors as compared to the free acid solution. Further reduction in the volume of H_2 evolved was observed as concentration of test inhibitor molecules increased. Figure 5 reveals that the most remarkable reduction in the volume of H_2 evolved was observed with *D. mespiliformis* molecules at 1000 ppm with inhibition of 83 %. The inhibition efficiency obtained from the hydrogen evolution measurements also increased with increase in inhibitor molecules concentration. The results obtained in the gasometric experiments are in agreement with the trend reported for weight loss

and electrochemical measurements. When the surface coverage of the metal by adsorbed inhibitor species increases, lateral reactions between inhibitor molecules may arise, thereby influencing inhibition efficiency. Attractive lateral interactions usually give rise to stronger adsorption hence higher efficiency [35]. This effect has been shown in cases of compounds containing long chain hydrocarbon because of attractive Van der Waals forces.

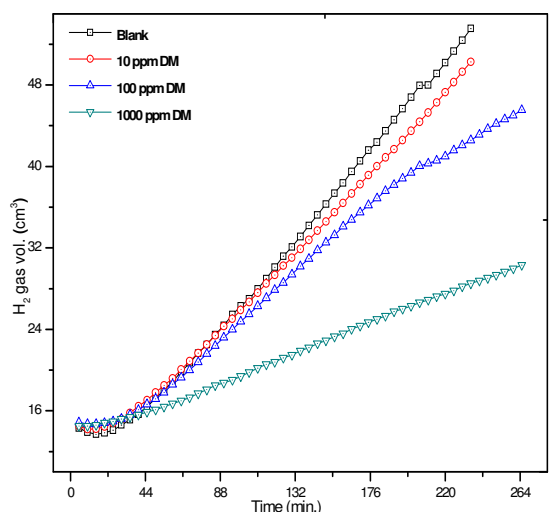


Figure 5 Variation of the volume of H_2 gas evolved with time for FE164531 corrosion in 2 M HCl with and without different concentrations of *D. mespiliformis* inhibitor

3.4 Weight loss

FE164531 was found to corrode at an appreciable rate in 2 M HCl solution. Results obtained clearly show that *D. mespiliformis* leaf ethanolic extract effectively retards corrosion rate of FE164531 in 2 M HCl, indicating inhibition of the corrosion reaction. The weight loss data reveal the dependence of inhibition efficiency of *D. mespiliformis* on concentration and temperature. Figure 6 shows variation of FE164531 corrosion rate with temperature in the absence and presence of *D. mespiliformis* molecules. Corrosion rate increased linearly with

278 increase in temperature but decreased with increasing *D. mespiliformis* concentration in the acid
 279 solution. Figure 7 shows inhibition efficiency ($E_w\%$) of *D. mespiliformis* extract on FE164531
 280 corrosion in 2 M HCl. It is clear from the figure that increase in concentration of *D.*
 281 *mespiliformis* molecules for all tests performed at varying temperatures result a decrease in
 282 corrosion reaction rate indicating geometric blocking effect of *D. mespiliformis* extract at active
 283 corrosion sites [36]. The extract inhibits corrosion by controlling the redox reactions. In most of
 284 the cases, the nitrogen/oxygen atom present in the inhibitor molecules is easily protonated in
 285 acidic solution and converted into quaternary/oxonium ions [37]. These protonated species get
 286 adsorbed on the cathodic sites of the metal surface and decrease the hydrogen evolution hence
 287 retard metal dissolution. Inhibition efficiency of *D. mespiliformis* leaf extract depends on
 288 various factors including but not limited to corrosive strength of the environment, concentration
 289 of inhibitor molecules, any synergetic effects with other molecules present in the environment
 290 and flow effects [14,38]. Inhibition efficiency trend observed for FE164531 in 2 M HCl using *D.*
 291 *mespiliformis* at varying temperature is an indication of physical adsorption. The evaluated
 292 inhibition efficiency had the optimum inhibition efficiency obtained at 68% for 303 K
 293 temperature with 1000 ppm inhibitor concentration. The fact that inhibition efficiency decreased
 294 with increasing temperature (303 – 313K) signifies that the inhibitors function effectively at
 295 lower temperatures. It also indicates that the time lag for the adsorption and desorption of the
 296 inhibitor molecules on FE164531 surfaces become shorter at higher temperature.

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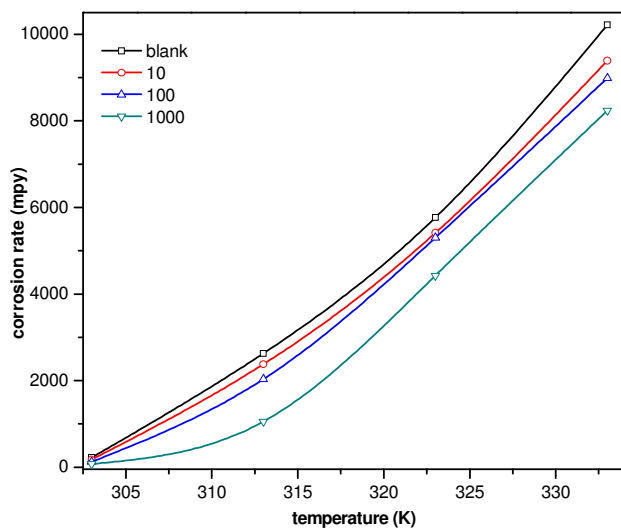


Fig. 6 Linear plot of FE164531 corrosion rate as a function of temperature in the absence and presence of *D. mespiliformis*

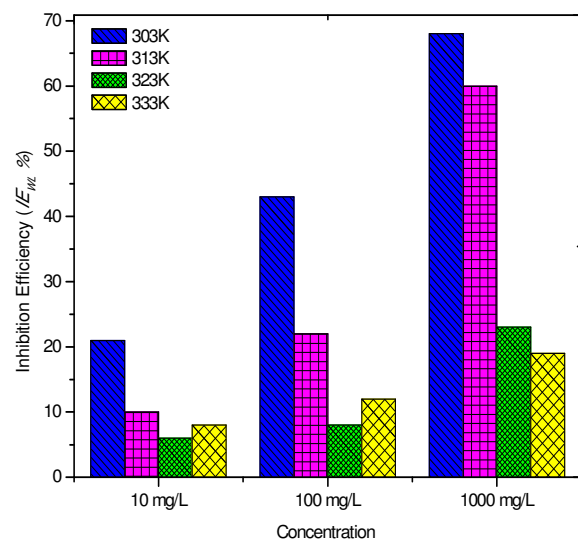


Fig. 7 Inhibition efficiency as a function of *D. mespiliformis* concentration for FE164531 in 2 M HCl at varying temperature obtained from weight loss results

3.5 Effect of temperature and adsorption consideration

Temperature investigation allows the determination of thermodynamic functions of annealed carbon steel in 2 M HCl with and without inhibitor. The obtained data were applied Langmuir adsorption isotherm which assumes that percentage area covered by the inhibitor is directly related to decrease in corrosion rate using equation 11 [14]

$$\log \left(\frac{\theta}{1-\theta} \right) = \log A + \log C - \left(\frac{\Delta H_{ads}}{2.303RT} \right) \quad (11)$$

herein, θ is the surface covered by inhibitor, A the temperature dependant constant, C is the bulk concentration of inhibitor, ΔH_{ads} the heat of adsorption. The heat of adsorption was calculated from slope of the plot of $\log \left(\frac{\theta}{1-\theta} \right)$ vs $1/T$. Fig. 8 shows heat of adsorption plot for *D. mespiliformis* on carbon steel in 2 M HCl while ΔH_{ads} values are listed in table 2. It can be observed from the table that inhibitor concentration at 1000 ppm has most positive value and 10 ppm has the least value of heat of adsorption supporting the fact that increase in concentration implies more stabilized adsorbed inhibitor molecule on the surface of FE164531. This is an indication of an increase the polarity and the adsorbability of inhibitors on the metal surface. It is clearly seen in Fig. 7 that increase in temperature undermined the integrity of the inhibitor which results to a decrease in inhibition efficiency. This decrease in $E_w\%$ with temperature rise is due to desorption of the inhibitor molecules from the surface of FE164531, thus we suggest that inhibitor molecules were physically adsorbed on the metal surface. The low positive value of ΔH_{ads} reveal that the process of adsorption of *D. mespiliformis* on carbon steel surface is an endothermic multilayer adsorption process.

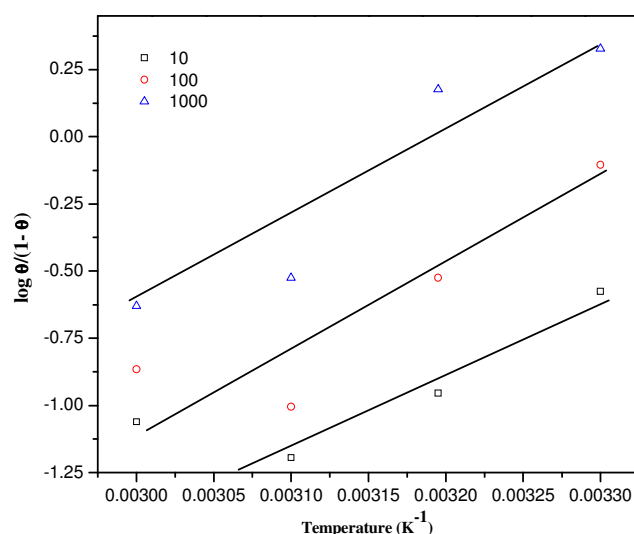


Fig. 8 Heat of adsorption plots as a function of temperature

The adsorption parameters are given in table 2. The values of ΔH increased with increasing inhibitor conc. indicating that the energy barrier of corrosion process increased and the activated complex is higher than that formed in the uninhibited solution. The positive sign of ΔH shows that the adsorption process of *D. mespiliformis* on FE164531 surface is endothermic in nature. The negative values of ΔS pointed to a greater order produced during the process of activation. This further decreased with increasing inhibitor concentration indicating a highering of the activation complex of the corrosion process. The values of $\Delta G_{\text{ads}}^{\circ}$ increased negatively with increase in temperature, a phenomenon implying that adsorption of inhibitor molecules onto the metal surface was unfavourable with increasing experimental temperature as a result of desorption of the inhibitor molecules in both acid solutions. ΔG values showed limited increase with rise in the concentration of organic additives revealing that weak dependence of ΔG on the composition of the organic additives can be attributed largely to the general linear composition

between ΔH and ΔS for the given temperature suggesting an adsorption type involving weak electrostatic forces.

Conclusion

The presence of *D. mespiliformis* in 2 M HCl for annealed carbon steel corrosion inhibition remarkably shifted the values of E_{corr} to the less negative directions and decreased the values of i_{corr} , while the values of R_p increased with increasing inhibitor molecule concentration. This effect is due to the fact that *D. mespiliformis* molecules decrease the severity of HCl solutions and increase the corrosion resistance of carbon steel surface by adsorption. The increasing values of $IE\%$ obtained with increasing inhibitor concentration of is attributed to greater adsorption of inhibitor molecules at active sites on FE164531 surface, hence prevention of carbon steel oxides and chlorides formation on FE164531 surface. This was also confirmed by the agreement between the results got from the various methods employed. It is worth noting that the change in the concentration of inhibitor did not alter the profile of the impedance behavior suggesting similar mechanism for the corrosion inhibition of pure carbon steel by inhibitor at various concentrations.

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