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Kinetic and Thermodynamic Studies of Corrosion Inhibition of Mild Steel using *Bridelia ferruginea* Extract in Acidic Environment

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ABSTRACT

The kinetic and thermodynamic studies of the corrosion of mild steel in acidic medium using methanolic extracts of *Bridelia ferruginea* (BF) was carried out using gravimetric and electrochemical linear polarization techniques. It was found that the BF extract retarded the corrosion of mild steel in 1.0 M HCl solution. The inhibition efficiency increased with increase in extract concentration but decreased with increase in temperature and immersion time. The values of activation energy (Ea) obtained is suggestive of physical adsorption mechanism while the values of Gibbs free energy (ΔG°) obtained indicated a spontaneous adsorption of the extract components on the metal surface. Kinetic treatment of the data followed a pseudo first order reaction. The electrochemical linear polarization result suggests that the BF extract functioned as mixed-type inhibitor. The adsorption of BF extract onto the mild steel surface followed Langmuir and Fruendlich adsorption isotherm models. The micrographs obtained from optical microscopy revealed the presence of a good protective film upon adsorption of inhibitor molecules onto the MS surface, which was responsible for the inhibition of corrosion. Thus, it can be concluded that BF inhibitor system acted as a good inhibitor in hydrochloric acid.

1. Introduction

Mild steel is an alloy that has found high range of mechanical and industrial application world-wide. It is one of the best preferred construction material for industries due to its availability and mechanical properties, however, it is highly vulnerable to corrosion and pose high economic burden to replace. Almost all of the environments in which metals are used serve as potential hostile and aggressive medium to them. Their successful application depends on the protective mechanisms against corrosion. Corrosion occurs when protective mechanisms have been overlooked, break down, or have been exhausted, leaving the metal vulnerable to attack [1].

There are several methods of corrosion control and prevention such as material selection, coating, cathodic protection and the use of corrosion inhibitors among others. Most of the chemical substances used to inhibit and control corrosion are not friendly to the ecosystem and has posed adverse effect to man and his environment, thus the motivation for the use of some natural products as corrosion inhibitors. Corrosion inhibitors are substances which when added in small concentrations to corrosive media decrease or prevent the reaction of the metal with the media [2, 3]. Plant extracts could therefore serve as sources of non-toxic and inexpensive corrosion inhibiting additives due to the presence of phytochemical compounds including alkaloids, tannins, flavonoids, saponins, amino acids, ascorbic acid, phenolic acids, pigments, resins and triterpenoids with molecular electronic structures similar to conventional corrosion inhibitors.

Bridelia ferruginea is usually dark grey and rough scaly shrub that can reach the size of a tree in a conducive environment. It is a common savannah Bridelia with wide range of medicinal values [4]. Preliminary phytochemical analysis of the plant extracts showed the presence of phenols and tannins. In contribution to the search for efficient corrosion inhibitors for metals in acidic corrodents, the authors undertake kinetic and thermodynamic studies of corrosion inhibition of mild steel using *Bridelia ferruginea* extract in acidic environment as an alternative cheap, eco-friendly and biodegradable methanol extract of the stem bark of *Bridelia ferruginea (*BF) in controlling corrosion of mild steel in acidic medium.

2. Experimental Methods

2.1 Materials

1.0 M analytical grade HCl solution was used as aggressive acid environment, methanol, acetone as drying agent, sodium hydroxide and distilled water, all obtained from Emole Scientific in Makurdi. Analytical digital balance (Acculab Startorius Group) was used for weighing. Linear polarization measurement was carried out using Potentiostat/Galvanostat (NOVA AUTOLAB – PGSTAT 302N VERSION – 1.10.1.9) at Ahmedu Bello University, Zaria, Nigeria. Fourier transform infrared spectrophotometer (FTIR) was done at National Research Institute, Zaria using FTIR-8400S fourier transforminfrared spectrophotometer. Optical micrograph was taken using Metallurgical microscope (Tsview Digital Metallurgical Microscope, Model: TUCSEN 0923502, at Mechanical Engineering Department, University of Agriculture, Makurdi.

2.2 Material Preparation

The mild steel specimens were polished successively with sand paper, washed in distilled water, degreased with acetone and finally dried in hot air blower. Weight loss experiments were conducted on mild steel specimens of dimension 3.0 cm × 2.0 cm × 0.14 cm and electrochemical measurements were conducted in 1.0 cm long stem (isolated with epoxy resin) to provide an exposed surface area 1.0 cm^2 of working electrode (WE).

2.3 Inhibitor

The stem bark of *Bridelia ferruginea* (BF*) was* collected from Ipinu Igede forest in Oyinyi-Iyeche, Oju Local Government Area of Benue State. The plant specimens were identified in the Department of Forestry and Wildlife, Federal University of Agriculture Makurdi. The fresh stem barks were air dried for six weeks, then pulverized with a pestle and mortar. The fine powdered samples were stored in a polyethylene bag for analysis. The pulverized stem barks were extracted exhaustively with methanol at room temperature (27±2 °C) using Soxhlet extraction. From the respective stock solutions, inhibitor test solutions was prepared in the desired concentration range (0.2 g/L, 0.6 g/L and 1.0 g/L) by diluting with the respective aggressive solutions.

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2.4 Test Solution

The aggressive solution 1.0 M HCl was used to carry out all weight loss and electrochemical experiments which was prepared by dilution of analytical grade 37% HCl with distilled water.

2.5 Weight Loss Measurements

The effect of immersion time and temperature were carried out using weight loss measurement.The effect of temperature was carried out at 303, 313, 323 and 333 K. Gravimetric experiments was conducted on test coupons of dimension 2 cm x 3 cm x 0.14 cm. The pre-cleaned and weighed coupons were suspended in beaker containing the test solutions using glass hooks and rods. Tests were conducted under total immersion conditions in 200 mL of the aerated and unstirred test solutions. To determine weight loss with respect to time, the coupons were retrieved at 24 hrs intervals and were repeated for 168 hrs, immersed in 20% NaOH solution, scrubbed with bristle brush, washed, dried and weighed. The weight loss was taken to be the difference between the weight of the coupons at a given time and its initial weight. All tests were run in duplicate to obtain good reproducible data. Average values for each experiment was obtained and used in subsequent calculations. A mild steel specimen was immersed in duplicate in 200 mL of the test solutions (1.0 M HCl) with and without addition of inhibitors of different concentrations at room temperature (27±2 °C). The cleaned specimens were weighed before and after 3 hours of immersion in the test solution for effect of temperature. The percentage inhibition efficiency (IE), the degree of surface coverage (θ) and the corrosion rate (CR) of mild steel was calculated using equations below [5]

$$IE_{\exp} = \left(1 - \frac{W_{(1)}}{W_{(0)}}\right) x100 \qquad (1)$$

where, $W_{(0)}$ is the weight loss of the mild steel without inhibitor and $W_{(1)}$ is the weight loss of mild steel with inhibitor.

$$\theta = \frac{IE_{\exp}}{100} \qquad (2)$$

$$CR\left(gh^{-1}cm^{-2}\right) = \frac{\Delta W}{At} \qquad (3)$$

2.6 Electrochemical Linear Polarization Measurements

The mild steel was sealed with epoxy resin in such a way that only one square surface area will be left uncovered. The exposed surface was degreased in acetone, rinsed with distilled water and dried in warm air. A conventional three-electrode system consisting of mild steel as working electrode, platinum (Pt) as an auxiliary electrode and saturated calomel electrode (SCE) as reference electrode was used for the measurements. The experiments was conducted at room temperature (27±2 °C) using 200 mL of test solution. The % IE was calculated from the charge transfer resistance (R_{ct}) values by using the equation,

$$\%IE = \frac{R_{ct(1)} - R_{ct(0)}}{R_{ct(1)}} \times 100 \qquad (4)$$

Where, $Rct_{(0)}$ is the charge transfer resistance of MS without inhibitor and $R_{ct(1)}$ is the charge transfer resistance of MS with inhibitor. The Tafel polarization curves was recorded by scanning the electrode potential from -300 mV to 300 mV (*vs* SCE) with a scanning rate of 1 mV/s. The corrosion current densities (Icorr) was extrapolated from the anodic and cathodic curves to corrosion potential. The %IE was obtained from the equation above.

2.7 Surface Characterization

Optical Microscope was used for monitoring the surface morphological changes. For this study, the micrograph finely polished MS plate was taken. Also, finely polished MS plate were immersed in 1.0 M HCl solution in the presence and absence of 1.0 g/L of green inhibitors for 24 h. Then the specimens were cleaned with distilled water and acetone, dried in air and used for the analysis.

3. Results and Discussion

3.1 Weight Loss Measurements

3.1.1 Effect of Time

The variation of weight loss, inhibition efficiency and corrosion rate, (CR) obtained from weight loss method of MS in 1.0 M HCl at room temperature (27±2 °C) as a function of concentration and time in the presence of BF is shown in Fig. 1a, b and c respectively. It is observed that the inhibition efficiency of MS increased with increasing concentrations of inhibitors but decreased with days. This behaviour could be attributed to the increase in adsorption of inhibitor on the metal or at the solution interface as the concentration increases, [6]. High inhibition efficiency observed after 24 h of immersion suggests that BF adsorption on the mild steel surface was completed within 24 h, afterwards the aggressive action of the acid medium was increasingly felt than the adsorbed inhibitor, leading to reduced inhibition efficiency with increased exposure time. This result is consistent with the pre-reports [6-12]. Inhibition efficiency and Corrosion rates (x 10^{-4} $gh^{-1}cm^{-2}$) of mild steel in various concentrations of BF are summarized in Table 1.

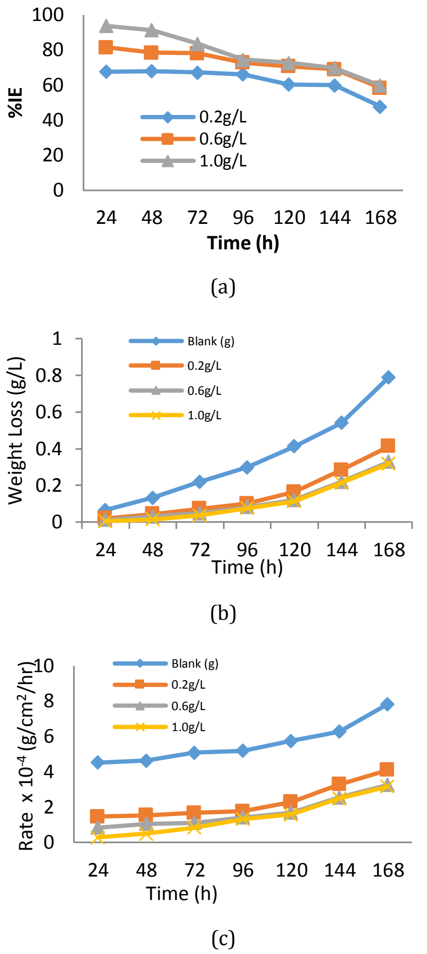

Fig. 1(a) Variation of weight loss with time for the corrosion of mildsteel in 1.0 M HClin the absence and presence various concentrations of methanol extract of BF(b) effect of immersion time (h) on corrosion inhibition efficiency (%ie) of mild steel in 1.0 m hcl in the presence ofvarious concentrations of methanol extract of bf(c) effect of immersion time on the corrosion rates of mild steel in 1.0 m hcl in the absence and presence of BF

Table 1 Inhibition efficiency and Corrosion rates (X 10^{-4} $gh^{-1}cm^{-2}$) of mild steel in various concentrations of BF at different time (h)

System	24	48	72	96	120	144	168
%IE							
0.2g/L	67.69	67.90	67.12	66.11	60.29	59.89	47.66
0.6g/L	81.54	78.40	78.08	72.82	70.70	69.07	58.43
1.0 g/L	93.85	91.36	83.56	74.50	72.64	69.77	59.70
CR							
Blank	4.514	4.618	5.069	5.174	5.736	6.262	7.827
0.2g/L	1.458	1.528	1.667	1.754	2.278	3.287	4.097
0.6g/L	0.833	1.042	1.111	1.406	1.681	2.535	3.254
1.0g/L	0.278	0.486	0.833	1.319	1.569	2.477	3.155

3.1.2 Effect of Temperature

Gravimetric measurements under these conditions were undertaken for 3 h immersion periods at 303, 313, 323 and 333 K, to assess the effect of temperature change on the inhibitive effect of BF. The inhibitor concentration for this study were 0.2 g/L, 0.6 g/L and 1.0 g/L. The results obtained are presented in Fig. 2(a) and (b). Inhibition efficiency increased

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with increase in concentration of the inhibitors but decreased with increase in temperature. This is again evidence that BF is effective corrosion inhibitor for mild steel in hydrochloric acid. The reduction in inhibition efficiency with increasing temperature has also been attributed to the nature of adsorption, in which the inhibitor is physically adsorbed at lower temperature while chemisorption is favoured at higher temperature, [7]. In this case, physicosorption was favoured. The inhibition efficiency at different temperature are summarized in Table 2 below.

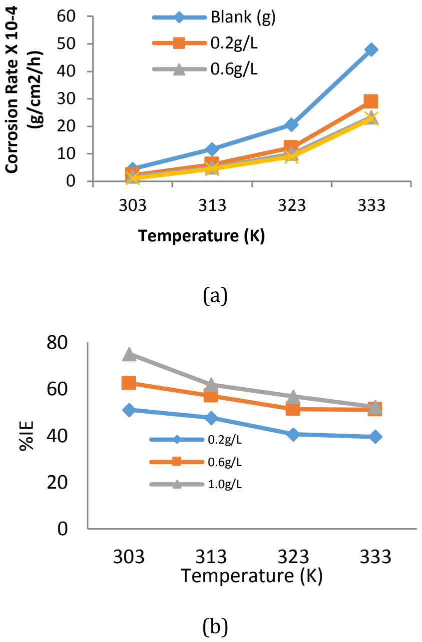


Fig. 2(a) Effect of temperature (K) on corrosion inhibition efficiency (%IE) of mild steel in 1.0 M HCl in the presence of BF (b) effect of immersion time (h) on corrosion inhibition efficiency (%IE) of mild steel in 1.0 M HCl in the presence of BF

Table 2 Inhibition Efficiency (%IE) of mild steel in 1.0 M HCl in the presence of BF at various temperatures (K)

System	303 K	313 K	323 K	333 K
Blank	-	-	-	-
0.2 g/L	51.00	47.62	40.54	39.54
0.6 g/L	62.50	57.14	51.35	51.16
1.0 g/L	75.00	61.91	56.76	52.33

3.1.3 Electrochemical Linear Polarization

In the linear polarization resistance (LPR) technique, the values of change in current as a result of applied potential obtained from electrochemical measurements were used. After measuring the currents and potentials, a plot of the parameters measured for mild steel as the working electrode immersed in 1.0 M HCl containing different concentrations of BF as inhibitor is presented in Fig. 3.

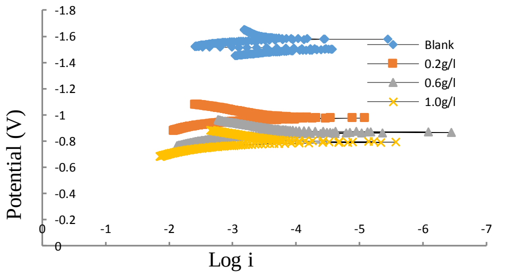


Fig. 3 Electrochemical Linear Polarisation plot for mild steel in 1.0 M HCl in the absence and presence of BF

The linear polarization parameters obtained from the measurement are presented in Table 3. The results in the table indicates that the introduction of the various concentrations of *BF* extracts remarkably shift E_{corr} /SCE. For instance, the difference between the Ecorr /SCE of the blank solution and that of the highest concentration of BF is 781.93 mV. It could be inferred that BF acted as a mixed-type inhibitor and the inhibition is due to simple geometric blocking mechanism [10]. Also, the corrosion current densities of the additives decreased very noticeably compared to the blank. It is clear also from the result (Table 3) that the βa and βc values for the various concentrations of the BF reduced remarkably compared to the blank indicating that the additive simultaneously modified both the anodic and cathodic reactions thus supporting that the extract is a mixed-type inhibitor [11]. The inhibition efficiencies were calculated from the linear polarization data using the relation in Eq. (5),

$$\%IE = \frac{R_{ct(1)} - R_{ct(0)}}{R_{ct(1)}} \times 100 \qquad (5)$$

where, $Rct_{(0)}$ is the charge transfer resistance of MS without inhibitor and $R_{ct(1)}$ is the charge transfer resistance of MS with the inhibitor. The values obtained are given in Table 3 with the highest inhibition efficiency of 96.44 %. The trend for the inhibition efficiencies were consistent with those obtained from gravimetric analysis. This result agreed with those reported by [13, 14].

Table 3 Electrochemical Linear Polarisation parameters for mild steel in 1.0 M HCl in the absence and presence of BF

System	Ecorr (mV)	jcorr ($\mu A/cm^2$)	βa (V/dec)	βc (V/dec)	CR (mm/year)	%IE
Blank	-1577.20	1404.80	-163.33	63.46	16.324	-
0.2 g/L	-974.01	167.02	60.15	36.90	1.941	88.11
0.6 g/L	-870.40	54.10	31.76	31.43	0.629	96.15
1.0 g/L	-795.27	49.90	19.69	25.45	0.580	96.44

3.1.4 Kinetics/Thermodynamics of the Corrosion

Rate constant and half-life

The half-life of this process was obtained from Eq. (6), [15]

Half-life expression: $t_{1/2} = \frac{0.693}{k_1}$ (6)

Fig. 4a shows the plot of –log (weight loss) against time (in days) in the absence and presence of BF. The rate constant parameters; rate constant and half-life are also recorded in Table 4. The plots showed a linear variation and slop, k, which confirms a pseudo-first order reaction kinetics with respect to the corrosion of mild steel in 1.0 M HCl solution in the absence and presence of BF. This result is in line with that reported by [16].

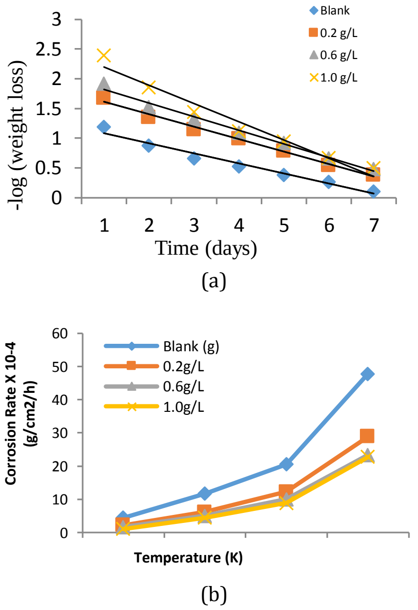


Fig. 4(a) Variation of –log (weight loss) with time (days) for mild steel in the absence and presence of BF at room temperature(b) effect of temperature on the corrosion rate of mild steel in 1.0 M HCl in the absence and presence of BF

Table 4 Half-life parameters at various concentrations of BF

System	Rate constant, k, (day^{-1})	Half-life (days)
Blank	0.389	1.782
0.2 g/L	0.481	1.441
0.6 g/L	0.527	1.315
1.0 g/L	0.702	0.987

The E_a, ΔH and ΔS were evaluated from the transition state values and plots shown in Fig. 5. The thermodynamic activation parameters obtained from the plots are shown in Table 5.

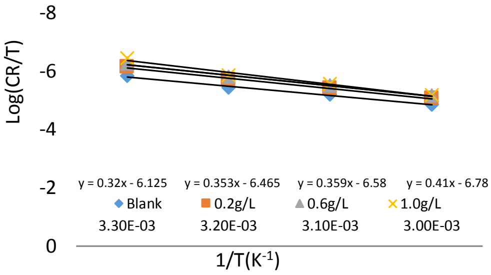


Fig. 5 Transition state plots for the corrosion of mild steel in the absence and presence of BF

In other to study the effect of temperature on the corrosion of metal in the presence of an inhibitor, then Eq. (8) and (9) below were used [17, 18].

$$\log\frac{CR_2}{CR_1}=\frac{Ea}{2.303R}\left(\frac{1}{T_1}-\frac{1}{T_2}\right) \tag{7}$$

$$CR=\frac{RT}{Nh}\exp^{\left(\frac{\Delta S_{ads}}{R}\right)}\exp^{\left(\frac{-\Delta H_{ads}}{RT}\right)} \tag{8}$$

where CR_1 and CR_2 are the corrosion rates of metal at the temperatures T_1 and T_2, Ea is the activation energy, R is the gas constant, N is the Avogadro's number, h is the Planck's constant, T is the temperature, ΔS_{ads} and ΔH_{ads} are the entropy and enthalpy of adsorption of the inhibitor on a metal, respectively.

The Ea was found to be 42.875 $KJmol^{-1}$ for 1.0 M HCl and increased with increasing concentration of the inhibitor, with the highest values of 58.201 $KJmol^{-1}$ in the presence of 1.0 g/L of the inhibitor. This showed that the adsorbed organic matter has provided a physical barrier to the change as well as mass transfer, leading to reduction in corrosion rate [19]. It has been reported earlier that the value of Ea greater than 80 $KJmol^{-1}$ indicates chemical adsorption, whereas, Ea less than 80 $KJmol^{-1}$ infers physical adsorption [9, 20]. On the basis of the experimentally determined Ea values that are all less than 80 $KJmol^{-1}$, it is evidenced that the additives were physically adsorbed on the coupons. Therefore, it is plausible that a multilayer protective coverage on the entire mild steel surface was obtained.

Table 5 Thermodynamic parameters

System	E_a (kJ mol^{-1})	ΔH (J mol^{-1})	ΔS (kJ mol^{-1})
Blank	42.875	6.127	0.315
0.2	47.711	6.759	0.321
0.6	50.066	6.874	0.324
1.0	58.201	7.850	0.327

The results showed that all the enthalpy of activation for the inhibitors are positive, reflecting the endothermic nature of the mild steel dissolution process. Also, the entropies of activation energy were positive for the extract, indicating that the activation complex represents association steps and that the reaction was spontaneous and feasible. These results were in excellent agreement with the reports of previous works [16].

3.1.5 Synergistic Effect

Synergism refers to combined total action of a compound greater than the sum of its individual effects. Synergistic inhibition is an effective means to improve the inhibitive force of inhibitor, to decrease the amount of usageof the inhibitor in acidic media. Synergism (S) of corrosion inhibitors is either due to interaction between components of the inhibitors or due to interaction between the inhibitor and one of the ions present in aqueous solution.

Table 6 Inhibition efficiency of mild steel in the presence of KI at 30 °C

System	%IE
5.0 mM KI	36.93
0.2 g/L BF + 5.0 mM KI	78.05
0.6 g/L BF + 5.0 mM KI	92.68
1.0 g/L BF + 5.0 mM KI	97.56

The greater influence of the iodide ion is often attributed to its large ionic radius, high hydrophobicity, and low electronegativity, compared to the other halide ions [21]. Table 6 shows the inhibition efficiency of 5.0 mM KI and extract-iodide mixtures at 30 °C.

The inhibition efficiency in the presence of the iodide is higher than those for only BF in 1.0 M HCl. This result is in agreement with the reported works [22]. Fig. 6 illustrates the relationship between the inhibition efficiency and the respective concentration of the inhibitor in the presence of 5.0 mM KI.

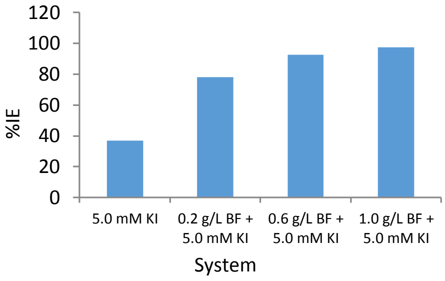


Fig. 6 Inhibition efficiency of mild steel in the presence of KI

3.1.6 Adsorption Isotherm

Different adsorption isotherms were tested in order to obtain more information about the interaction between the inhibitors and the mild steel surface. The various isotherms tested includes Temkin, Frumkin, Freundlich and Langmuir adsorption isotherms and linear regression coefficients (r^2) were used to determine the best fit. Langmuir and Freundlich adsorption isotherms were found to be best fit in which case all the linear regression coefficients (r^2) were close to unity. Langmuir adsorption isotherm assumes that the solid surface contains a fixed number of adsorption sites and each site holds one adsorbed species [23]. Langmuir isotherm gives a straight line between $C/\theta vsC$[24] as shown in Fig. 7(a), where C is the concentration of the inhibitors and θ the surface coverage. The results obtained for ΔG and K_{ads} are shown in Table 7. The values obtained for ΔG were negative indicating that the adsorption process proceeded spontaneously.

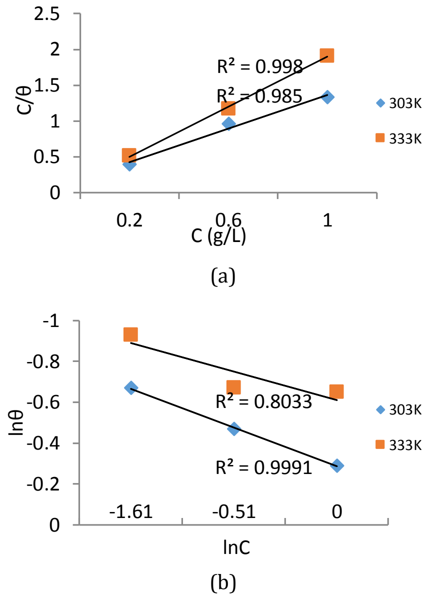


Fig. 7 (a)Langmuir isotherm for the adsorption of BF onto mild steel surface in 1.0 M HCl at 303K and 333K respectively(b)Freundlich isotherm for the adsorption of BF onto mild steel surface in 1.0 M HCl at 303K and 333K respectively

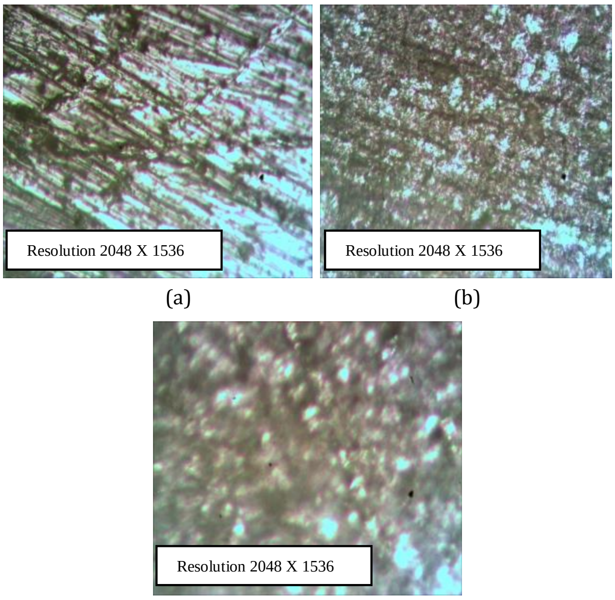
Table 7 Langmuir andFreundlich adsorption isotherm parameters obtained from the corrosion data for mild steel in 1.0 M HCl containing BF extract

Temperature (K)	Intercept	Slope	K_{ads}(M^{-1})	R^2	ΔG (kJ mol^{-1})
Langmuir adsorption isotherm parameters					
303	0.1883	1.175	5.311	0.998	-14.33
333	0.1467	1.750	6.817	0.986	-16.44
Freundlich adsorption isotherm parameters					
303	-0.316	0.227	4.405	0.996	-3.735
333	-0.620	0.184	5.435	0.803	-4.687

Generally, the value of ΔG° ads less than −20 kJ mol⁻¹ signify physisorption and values more negative than −40 kJ mol⁻¹ signify chemisorption [7, 25, 26]. The results are presented in Table 7. The values of ΔG_{ads} are negative and less than -40 kJmol^{-1}. This implies that the adsorption of the inhibitor on metal surface is spontaneous and confirms physical adsorption mechanism.

3.1.7 Surface Morphology

Surface morphology of MS was studied by optical microscopy after 24 h immersion in 1.0 M HCl. Fig. 8(a) represent the micrograph of polished MS without being exposed to the corrosive environment while Fig. 8(b) showed strongly damaged MS surface due to the formation of corrosion products after immersion in 1.0 M HCl solution. The micrograph of MS surface after immersion in 1.0 M HCl with 1.0 g/L BF is shown in Fig. 8(c). It could be seen that no pits and cracks are observed in the micrographs after immersion of MS in 1.0 M HCl in the presence of the inhibitor except polishing lines. Thus, it revealed the presence of a good protective film upon adsorption of inhibitor molecules onto the MS surface, which was responsible for the inhibition of corrosion.



(a) (b)

(c)

Fig. 8(a) Polished MS(b)MS in blank 1 M HCl(c)MS in the presence of 1.0 g/L BF

3.1.8 Fourier Transformed Infra-Red (FTIR) Analysis

Fig. 9(a) below is the FTIR spectrum of BF (Table 8). The peak at 3407 cm^{-1}could be due to a phenolic–OH while the peak at 2936 cm^{-1} correspond to an alkyl C-H. The peak at 1638.58 cm^{-1} and 1499.70 cm^{-1} is attributable to aromatic ring and aromatic C=C respectively, present in the molecule. The presence of C-O in the molecule is due to the peak at 1144.79-1043.52 cm^{-1} while aromatic substitution is attributed to the peak at 619.17-401.21 cm^{-1}.

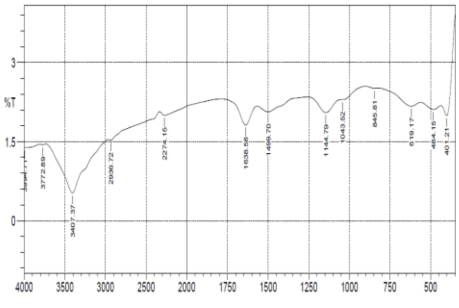


Fig. 9(a) FTIR spectra of pure BF extract

Fig. 9(b) shows the infrared spectra of BF adsorbed on the MS surface (Table 8). It is evident from the spectra that the peak at 3407.34 cm^{-1} has disappeared, indicating that the oxygen atoms are participating in the adsorption process through its lone pair. All the peaks corresponding to the presence of aromatic rings also disappeared, showing that the aromatic rings of the phenolic group are active in the adsorption process. BF as indicated from the spectra data, results in strong adsorption due to donation of lone pair of electrons on oxygen to the vacant d-orbitals of the metal which leads to the formation of the metal complexes.

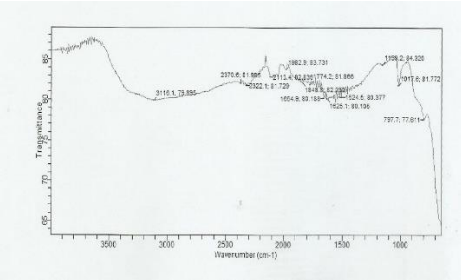


Fig. 9(b) FTIR spectra of adsorbed BF extract on MS

Table 8 Important peaks of BF and adsorbed inhibitor to MS surface

Functional group	BF	BF ON MS
Phenolic –OH	3407.34 cm^{-1}	-
Alkyl C-H	2936.72 cm^{-1}	2113.4 cm^{-1}
Aromatic ring	1638.58 cm^{-1}	-
Aromatic C=C	1499.70 cm^{-1}	-
C-O	1144.79 cm^{-1}	1017.6 cm^{-1}
Aromatic substitution	401.21 cm^{-1}	

4. Conclusion

The extracts of BF acted as good and efficient mixed inhibitor for mild steel corrosion in 1.0 M hydrochloric acid. The inhibition process which followed pseudo-first order rate kinetics was observed to be physicosorptively adsorbed to the metal surface. It is evidenced from the positive values obtained for enthalpy of activation that the reaction is endothermic. Also, the values of entropy of activation is positive, suggestive of association mechanism. The inhibitive ability of corrosion of MS by BF in 1.0 M HCl was found to be enhanced by halide ions. FTIR result showed that the effective adsorption of the inhibitor is due to the donation of lone pair of electrons on oxygen to the vacant d-orbitals of the metal which leads to the formation of the metal complexes.

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