Adsorption and corrosion inhibiting behavior of *Passiflora foetida* leaf extract on mild steel corrosion

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Abstract

Passiflora foetida leaf extract (PFLE) as a corrosion inhibitor in 1 M HCl was investigated by weight loss method and electrochemical techniques. Inhibition efficiency of PFLE was found to increase with increasing concentration. Polarization measurements revealed that the PFLE acted as a mixed type inhibitor. Nyquist plots showed that on increasing the PFLE concentration, the charge transfer resistance increased and double layer capacitance decreased. The adsorption of PFLE on mild steel obeyed the Langmuir adsorption isotherm. The maximum inhibition efficiency was found to be 94.61% at 313 K in the presence of 130 ppm of PFLE. SEM and AFM techniques confirmed the adsorption of PFLE on mild steel surface.

Keywords: PFLE, potentiodynamic polarization, EIS, SEM, AFM, XRD.

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1. Introduction

Low carbon material is most widely used as a constructional material in many industries due to its excellent mechanical properties and low maintenance. It is used in large tonnages in marine applications, chemical processing, petroleum production and refining process, construction, and metal processing equipment. Acid solutions are commonly used in industry, for example, chemical cleaning, descaling, pickling, oil-well acidizing, petrochemical processes, erecting boilers, drums, heat exchangers, tanks, etc., which lead to corrosive attack. Corrosion prevention employing inhibitors is one of the most common, effective, and economic methods to protect metals in acidic media [1-3]. Therefore the consumption of inhibitors to reduce corrosion has increased in recent years.

Due to increasing ecological awareness and strict environmental regulations, as well as the inevitable drive toward sustainable and environmentally friendly processes, attention has been now focused toward the development of non toxic alternatives to inorganic and organic inhibitors applied so far. Currently, research in corrosion is oriented to the development of "green corrosion inhibitors," compound with good inhibition efficiency but low risk of environmental pollution [4, 5]. Plant extracts are bio degradable and constitute incredibly rich sources of natural chemical compounds that can be extracted by simple procedures at low cost [6]. Thus since the 1990's, many investigations have been related to the evaluation of natural compound as corrosion inhibitors. For instance, some amino acids, vitamins, and plant extract have been tested [7–11]. The basic components of extracts are sugars, gallic acid, ellagic acid, and flavanoids [12]. Even the presence of tannins, cellulose and poly cyclic compounds normally enhances the film formation over the metal surface, thus decreasing corrosion [13].

Passiflora foetida (Passifloraceae) is an herbaceous vine with the auxiliary tendrils and yellowish white hairy stems [14-16]. This plant is native to the West Indies, North South America and naturalized weed in Taiwan and China [17]. It is also widely distributed in Thailand [18]. The leaves of this plant have been widely used as traditional therapeutics for insommia, hysteria, emmenagogue, biliousness, asthma and skin inflammation in some coutries such as India, Nigeria, Brazil and also in La Reunion [19]. The major phytochemical constituents of *P. foetida* leaves are C-glycosyl flavonoids such as chrysoeriol, apigenin, luteolin, kaempferol, isoschaftoside, 2"-xylosylvitexin, isovitexin and vitexin [20]. There are many reports indicating biological benefits of these flavonoids and crude extracts of P. foetida leaves. Vitexin exhibited potent hypotensive, antiinflammatory and anti-spasmodic properties [21]. Recently vitexin and isovitexin have been shown to effectively inhibit the formation of advanced glycation endproducts (AGEs) which are found to be implicated in diabetic complications [22]. Kaempferol, apigenin and luteolin were demonstrated to possess anti-allergic effect by inhibition of histamine release [23]. Regarding the crude extract of the leaf, the ethanolic extract of *P. foetida* displayed antiproliferative activity on human breast adenocarcinoma in potential range of IC50 [24]. It was shown that the ethanolic extract possesses remarkable antibacterial against Ps.putida, V.cholerae, S.flexneri and St pyogenes [25]. Chan et al. (2008) [26] reported the analgesic activity of the hydro-alcoholic extract in mice. Even though *P. foetida* is abundant in Thailand and it has been extensively used in the folklore medicine of some countries, there has been no report on the long-term toxicity of *P. foetida*.

The present work has investigated the corrosion of mild steel in 1 M HCl using the extract of *P.foetida* as corrosion inhibitor by the mass loss method, electrochemical method, SEM and AFM. Additionally, thermodynamic and kinetic parameters were calculated and discussed. To the best of our knowledge, it has never been reported so far on the use of leaf extract of *P.foetida* on the corrosion of mild steel in 1 M HCl.

2. Experimental

2.1. Preparation of the specimens

Composition of mild steel specimen was C: 0.13, Si: 0.18, P: 0.39, S: 0.04, Cu: 0.025 and balance Fe. The specimens were mechanically cut into sizes with 2.5 cm \times 2.5 cm \times 0.4 cm

dimensions and abraded with different emery papers up to 4/0 grades. Each specimen was degreased by washing with acetone, dried at room temperature and preserved in moisture-free desiccators. All chemicals and reagents are analar grade. The concentration of test solution (1 M HCl) was prepared by using triple-distilled water and AR grade hydrochloric acid.

2.2. Extraction of passiflora foetida leaf extract (PFLE)

P.foetida leaves were collected in and around Madurai, India. The leaves were dried, grain and soaked in bidistilled water for 6 h. After 6 h, the crude extracts were boiled, cooled and triple filtered. The amount of plant material extracted into solution was quantified by comparing the weight of dried residue with the initial weight of the dried plant material before extraction. From the respective stock solutions, inhibitor test solution was prepared in the concentration range from 50 ppm to 130 ppm.

2.3. Mass loss method

Mass loss method was conducted at different temperatures in the range 308–333 K for 2 h in 1 M HCl. The specimens were immersed in 100 ml of the respective inhibitor and the test solution in a thermostated bath. The specimens were weighed before and after immersion. The difference in weight was taken as the weight loss of mild steel. From the weight loss (ΔW), corrosion rate (Λ) and the percentage of inhibition efficiency (*IE* %) were calculated using the following equation:

$$\mathcal{K}(\mathrm{mpy}) = 534 \times \Delta W/DAT \tag{1}$$

$$IE \% = (W_0 - W_1) / W_0 \times 100$$
⁽²⁾

Here $\Delta W = (W_b - W_a)$, where W_b and W_a are the specimen weights before and after immersion in the tested solution, W_0 and W_1 are the weight loss of mild steel in the absence and presence of inhibitor respectively, *D* is the density of the iron (g/cm³), *A* is the area of the specimen in inch² and *T* is the period of immersion in hours.

2.4. Electrochemical Impedance Spectroscopy measurements (EIS)

Tafel polarization curves and Nyquist impedance curves were recorded using H and CH electrochemical workstation impedance analyzer model CHI 604D. A cell containing three compartments for electrode was used. The working polished mild steel electrode with exposed area of 0.5 cm² was immersed in a test solution. A platinum electrode and saturated calomel electrode were used as the counter and the reference electrode respectively. Before each potentiodynamic polarization (Tafel) and electrochemical impedance spectroscopy (EIS) experiment, the electrode was allowed to corrode freely and its open-circuit potential was recorded. Potentiodynamic polarization curves were recorded from -300 to +300 mVsce, (*versus* OCP) with a scan rate of 1 mV s⁻¹. Electrochemical impedance spectroscopy measurements were performed in the frequency range of 0.1 Hz to

100 KHz. All electrochemical measurements were studied at 308 K using 100 ml of electrolyte (1 M HCl) in stationary condition. Each experiment were repeated in triplicate to check the reproducibility of the data.

2.5 Surface analysis studies

2.5.1. UV-Visible spectroscopic studies

The phytochemical constituents of PFLE treated with 1 M HCl and after 2 h mild steel immersion were analyzed using JASCOW 32 spectrophotometer. The absorption spectra of these solutions were determined with test solution as a reference.

2.5.2. SEM and AFM characterizations

The mild steel specimens were immersed in acid solutions in the absence and presence of optimum concentration of inhibitor for a period of 2 h. After 2 h, the specimens were taken out and dried. The nature of the surface film formed on the surface of the mild steel specimen was examined by using a JEOL (JSM 6390) scanning electron microscope and scanning probe microscope (Akilan Technology UK 5500 series).

2.6. Phytochemical studies

Phytochemical analysis of alkaloids, flavonoids, glucosides, carbohydrates, phenols, aminoacids, steroids, triterpenoids, saponins and tannins was carried out by using the methods of Brindha *et al.* [27] and Harbone [28].

3. Results and discussion

3.1. Effect of PFLE on corrosion rate of mild steel

The corrosion rate of mild steel in 1 M HCl in the absence and presence of different concentrations of PFLE was determined at 308–333 K. Figure 1 shows the effect of concentration of PFLE on the corrosion rate and inhibition efficiency of mild steel in 1 M HCl with and without the PFLE. From the graph, it is clear that the corrosion rate of mild steel decreases in the presence of 130 ppm of PFLE as inhibitor. This indicates that the corrosion of mild steel is inhibited by PFLE in 1 M HCl.

We investigated the inhibition efficiency of PFLE on mild steel in 1 M HCl at various temperatures, 308, 313, 323, and 333 K. Maximum inhibition efficiency is found to be 94.61% at 313 K, which indicates that PFLE is a good inhibitor in 1 M HCl. Figure 2 shows the plot of inhibition efficiency against different temperatures with different concentrations of inhibitor. From the plots, it is very clear that the inhibition efficiency decreases above 313 K. Inhibition efficiency of PFLE is 93.73, 94.61, 89.32, 79.83 at temperatures 308, 313, 323, 333 K respectively.



Figure 1. Corrosion rate and inhibition efficiency of mild steel specimens immersed in 1 M HCl with and without PFLE at 308, 313, 323, 333 K. (-) corrosion rate; (---) inhibition efficiency.



Figure 2. Inhibition efficiency versus temperature in the presence of different concentrations of PFLE.

3.2. Electrochemical measurements

3.2.1. Potentiodynamic polarization measurements

The potentiodynamic polarization curves of mild steel immersed in the absence and presence of inhibitor are shown in Figure 3. The corrosion parameters namely corrosion potential (E_{corr}), corrosion current (I_{corr}), cathodic slope (b_c), anodic slope (b_a), Linear polarization resistance (LPR) and percentage of inhibition efficiency were calculated from Tafel plots, which are given in Table 1. The inhibition efficiency is defined as

$$IE\% = \left(i_{\rm corr}^0 - \frac{i_{\rm corr}}{i_{\rm corr}^0}\right) \times 100,\tag{3}$$

where i_{corr}^0 and i_{corr} are the corrosion current density values without and with inhibitor respectively, In the present study, the maximum shift E_{corr} values are in the range of 24 mV. Table 1 shows that the values of b_c change less than b_a values. This suggests that the anodic reaction is controlled predominantly than the cathodic one at all concentrations. Moreover in the presence of the inhibitor system, the corrosion current decreases from 529 to 20.64 μ A/cm² and LPR values increase from 7 to 111 Ohm cm². These observations confirm that the addition of PFLE to 1 M HCl solution reduces anodic dissolution of mild steel more than the cathodic hydrogen evolution reaction [29].



Figure 3. Tafel plots of mild steel immersed in 1 M HCl with and without PFLE.

C _{inh} (ppm)	E _{corr} (mV)	I _{corr} (μA cm ⁻²)	b _c (mV/decade)	b _a (mV/decade)	<i>R</i> _p (ohm cm ²)	% <i>IE</i>
0	-455	529.1	196.8	143.5	7	
50	-449	164	188.8	99	17	69
70	-449	45.84	173.6	74.4	49	91.33
90	-469	44.86	170.1	75.8	51	91.52
110	-460	43.87	172.8	77.6	53	91.70
130	-479	20.64	156.1	79.5	111	96.09

Table 1. Potentiodynamic polarization parameters for the corrosion of mild steel in 1 M HCl containing different concentrations of PFLE.

3.2.2. Electrochemical impedance measurements

Impedance diagrams obtained for mild steel in 1 M HCl in the presence and absence of the inhibitors are shown in Figure 4. The impedance parameters such as R_s , R_{ct} , C_{dl} and f_{max} derived from Nyquist plots are given in Table 2. The charge transfer resistance (R_{ct}) increases with an increase in the concentration of inhibitor in acid solution. From impedance studies, *IE* % is calculated as:

$$IE\% = \left(R_{\rm ct(inh)} - \frac{R_{\rm ct}}{R_{\rm ct(inh)}}\right) \times 100,\tag{4}$$

where R_{ct} and $R_{ct(inh)}$ are uninhibited and inhibited charge transfer resistance respectively. The diameter of Nyquist plots increase on increasing the concentration of PFLE which indicates the strengthening of inhibitor film [30]. As the concentration of the inhibitor increases, charge transfer resistance enhances and the double layer capacitance values decrease. This is due to the adsorption of PFLE on the metal surface leading to the formation of the protective layer on the electrode surface and decreasing the extent of dissolution reaction [31, 32]. These results are in very good agreement with both weight loss and polarization data and can be attributed to decreased local dielectric constant and increased thickness of electrical double layer [33].



Figure 4. Nyquist plots for mild steel immersed in 1 M HCl and different concentrations of PFLE at 308 K.

C _{inh} (ppm)	$R_{\rm s}(\Omega~{\rm cm}^{-2})$	$R_{\rm ct} (\Omega \ {\rm cm}^{-2})$	$C_{\rm dl}({\rm F~cm}^{-2})$	% IE	
			2		
0	2.563	4.96	1.6×10^{-5}	—	
50	2.096	14.83	1.9×10^{-4}	66.6	
70	2.900	39.05	2.5×10^{-4}	87.3	
90	1.345	40.14	2.6×10^{-4}	87.6	
110	1.192	40.86	2.7×10^{-4}	87.9	
130	0.907	85.64	6.4×10^{-5}	94.2	

Table 2. Electrochemical impedance parameters for mild steel in 1 M HCl in the absence and presence of PFLE.

3.3. Thermodynamic considerations

The thermodynamic parameters such as the apparent activation energy E_a , the enthalpy of activation ΔH^* and the entropy of activation ΔS^* for corrosion of mild steel in 1 M HCl solutions in the absence and presence of PFLE at 308–333 K were calculated from the Arrhenius equation:

$$CR = A \exp\left(-\frac{E_{a}}{RT}\right)$$
(5)

Taking the logarithm of both sides of the above equation can be obtained,

$$\log CR = \log A - \frac{E_{\rm a}}{2.303RT} \tag{6}$$

The change of enthalpy $\{\Delta H^*\}$ and entropy $\{\Delta S^*\}$ for the formation of activated complex in the transition state was obtained from the transition state equation.

$$\log CR/T = \{(\log R/hN + (\Delta S^*)/2.303R)\} - H^*/2.303RT,$$
(7)

where *CR* is the corrosion rate, *A* is the pre-exponential factor, *h* is the Planck constant, *N* is the Avogadro number, E_a is the apparent activation energy, *R* is the gas constant (*R* = 8.314 J mol⁻¹ K⁻¹) and *T* is the absolute temperature.

A plot of log *CR vs.* 1/*T* gives a straight line with slope of the line $(-E_a/2.303R)$ and intercept (log *A*) as shown in Figure 6. The values of E_a were determined in solutions containing PFLE which can be interpreted as physical adsorption [34]. A plot of log *CR/T vs.* 1/*T* (Figure 6) gives a straight line with slope of the line $(-\Delta H^*/2.303R)$ and an intercept (log *R/hN* + (ΔS^*)/2.303*R*) from which the values of ΔH^* and ΔS^* can be calculated and are summarized in Table 3. From these data, it is found that the thermodynamic parameters, ΔH^* and ΔS^* of dissolution reaction of mild steel in 1 M HCl in the presence of PFLE are higher than uninhibited solution. The positive signs of the enthalpies ΔH^* reflect the endothermic nature of the steel dissolution process [35]. The values of ΔS^* in the absence and presence of the tested inhibitor are negative, which indicates that the activated complex in the rate determining step represents an association rather than dissociation step, meaning that a decrease in disordering takes place on going from reactants to the activated complex [36–38].



Figure 5. Arrhenius plot of log CR versus 1/T at different concentrations of PFLE.



Figure 6. Transition state plots log CR/T versus 1/T at different concentrations of PFLE.

C _{inh} (ppm)	E _a (KJ/mol)	Δ <i>H</i> * (KJ/mol)	–Δ <i>S</i> * (J/mol/K)
0	30.65	15.18	197.57
50	34.17	118.63	197.55
70	52.61	182.05	197.54
90	44.01	151.43	197.55
110	61.30	95.73	197.56
130	66.65	223.63	196.94

Table 3. Corrosion kinetic parameters for mild steel in 1 M HCl in the absence and presence of different concentrations of PFLE.

3.4. Adsorption isotherm

In general the adsorption isotherm provides essential information on the adsorption of inhibitor on metal surface. The θ values of different concentrations of inhibitor were tested by fitting to various isotherms including Frumkin, Langmuir, Temkin, Freundlich, Bockris–Swinkles and Flory–Huggins isotherms. In the present study, the results fit best the Langmuir adsorption isotherm, which is given by

$$C/\theta = 1/K_{\rm ads} + C,\tag{8}$$

where K_{ads} is the equilibrium constant of the adsorption process, C is the inhibitor concentration and θ is the surface coverage. The best fitted straight line was obtained for the plot of C/θ vs. C (g/l) with slope of almost unity (Figure 7). This behavior indicated

that the adsorption of PFLE on mild steel surface obeyed the Langmuir adsorption isotherm meaning that there was no interaction between the adsorbed species [38].



Figure 7. Langmuir adsorption isotherm for mild steel in 1 M HCl containing different concentrations of PFLE at 308–333 K.

The free energy values of adsorption (ΔG_{ads}) of PFLE on mild steel surface were calculated using Eq. (9).

$$\Delta G_{\rm ads} = -RT \ln(55.5K_{\rm ads}) \tag{9}$$

Here *R* is the gas constant, *T* is the absolute temperature and 55.5 is the concentration of water in the solution. The values of K_{ads} are found to decrease with increasing temperature showing that the interactions between the adsorbed molecules and the metal surface are weakened and the inhibitor molecules become easily removable. Such data explain the decrease in the production efficiency with increasing temperature. In the present work, the negative value of ΔG_{ads} (Table 4) clearly indicates the spontaneous adsorption of PFLE on mild steel surface and strong interactions between inhibitor molecules and the metal surface [38, 39]. Generally the values of ΔG_{ads} up to -20 KJ/mol signify physisorption, which is consistent with electrostatic interaction between charged molecules and a charged metal. The values around -40 KJ/mol or higher involve charge sharing or transfer from the inhibitor molecules to the metal surface to form a co-ordinate type of bond [38-41]. In this study, the calculated values of ΔG_{ads} are around -30 KJ/mol, indicating that the adsorption of mechanism of PFLE on mild steel in 1 M hydrochloric acid solution at the studied temperatures is both physisorption and chemisorption [41-43].

The heat of adsorption and entropy of adsorption are important parameters for understanding adsorption of organic inhibitors at metal/solution interface. The heat of adsorption(ΔH_{ads}) is calculated using the Van't Hoff equation:

$$\ln K = -\Delta H_{\rm ads}/RT + \text{constant}$$
(10)

All the calculated thermodynamic parameters are listed in Table 4. It has been found that values of ΔH_{ads} are negative, suggesting that the adsorption of inhibitor is an exothermic process, which means lower inhibition efficiency at high temperature. This indicated the gradual desorption of inhibitors from the surface of mild steel [40]. All values of ΔS_{ads}^0 are negative. This behavior might be explained as follows: before the adsorption of inhibitor molecules onto the mild steel surface, inhibitor molecules might freely move in the bulk solution (inhibitor molecules were chaotic), but with the process of adsorption inhibitor molecules were orderly adsorbed onto the steel surface, as a result a decrease in entropy is observed [40, 44].

Table 4. Langmuir adsorption parameters and free energy of adsorption of PFLE as inhibitor on the surface of mild steel.

Temp (K)	Kads	$-\Delta G^{\circ}_{ads}$ (KJ/mol)	R^2
308	250	24.42	0.951
313	1000	28.42	0.999
323	500	27.47	0.984
333	500	28.32	0.991

3.5. UV-visible Spectra

In order to confirm the possibility of the formation of inhibitor–Fe complex, UV-Visible absorption spectra were obtained from the mid steel surface before and after immersion in 1 M HCl solution containing 130 ppm of PFLE which are shown in Figure 8. The electronic spectra of a PFLE before immersion have absorption maximum at 212 nm, 268 nm and 330 nm as shown in Figure 8*a*. After 2 hrs immersion of mild steel, the absorbance band at 268 nm disappeared and 212 nm the conjugation length increases to 217 nm, this indicates that the complex formation (Figure 8*b*) between two species in solution. However, there is change in the absorption. The electronic absorption spectra of PFLE after immersion have absorption maximum at 217 nm and 335 nm. These experimental findings provide the formation of complex between Fe²⁺ and PFLE confirm the inhibition of steel from corrosion [45].

3.6. Scanning electron microscopic studies

Figure 9 (a & b) shows the SEM images of mild steel surface after immersion in 1 M HCl in the presence of PFLE for 2 h. After 2 h, the specimens were taken out and dried. SEM images show that the surface of the inhibited sample of mild steel specimens are better than the uninhibited sample. This examination indicates that the corrosion rate is reduced in the

presence of inhibitors. This may be due to the adsorption of inhibitor molecules on the metal surface as a protective layer [46].



Figure 8. UV-visible spectra of the solution containing PFLE in 1 M HCl and the mild steel immersion in PFLE and HCl.



Figure 9. (*a*): SEM image of mild steel after immersed in 1 M HCl without PFLE; (*b*): SEM image of mild steel after immersed in 1 M HCl with PFLE.

3.7. Atomic force microscope (AFM) surface examination

Atomic force microscope is a powerful technique to investigate the surface morphology which is useful to study the influence of inhibitors on the metal/solution interface [47, 48]. The AFM images of mild steel surface in 1 M HCl in the absence and presence of 130 ppm PFLE is given in Figure 10 (a & b). As is shown in Figure 10a, the surface of mild steel electrode exposed to 1 M HCl solution has a considerable porous structure with large and deep pores. On the other hand, in the presence of PFLE inhibitor, Figure 10b shows that the mild steel surface appears more flat, homogeneous and uniform, which indicates that

PFLE shows an appreciable resistance to corrosion. Therefore, it can be concluded that the molecules of leaf extract are adsorbed on the mild steel surface and protects the metal against corrosion.



Figure 10. (*a*): AFM image of mild steel after immersed in 1 M HCl without PFLE. (*b*): AFM image of mild steel after immersed in 1 M HCl with PFLE.

3.8. Phytochemical screening of leaf extract

The phytochemical screening of the PFLE show the presence of alkaloids, phenols, carbohydrates, steroids, phenolic compounds, tannins, and flavonoids, wheres glucosides, terpenoids, aminoacids, saponins are absent in the PFLE. The information pertaining to phytochemical study is clearly shown in Table 5.

S.No	Phytochemical components	Ethanolic extract
1	Alkaloids	+
2	Flavonoids	+
3	Glucosides	_
4	Carbohydrates	+
5	Phenols	+
6	Aminoacids	_
7	Steroids	+
8	Terpenoids	_
9	Saponins	_
10	Tannins	+

Table 5. Qualitative analysis of phytochemical compounds of PFLE.

3.9. Mechanism of inhibition

The mechanism of inhibition can be understood by knowing the mode of interaction of the inhibitor molecules with a mild steel surface. Inhibitors function by adsorption and/or hydrogen bonding to the metal. This depends on the chemical composition and structure of the inhibitor, the nature of the metal surface, and the properties of the medium. Structural and electronic parameters like functional group and steric and electronic effects may also be responsible for the inhibition efficiency of any inhibitor, that is the adsorption mechanism. The compounds block the active corrosion sites on the metal surface and hence the adsorption occurs by the bonding of the free electrons of inhibitor with the metal. The extract may constitute organic compounds containing:

i. lone pair of electrons present on a heteroatom (*e.g.*, N, S, P, O)

- ii. π bond
- iii. triple bonds (e.g., cyano groups), and
- iv. heterocyclic compounds such as pyridine ring, pyrrole, imidazole, etc.

Phytochemical analysis of *P.foetida* extract shows the presence of alkaloids, flavanoids, carbohydrates, phenols, steroids, tannins. These compounds possess hetero atom such as -N, -O, which strengthen adsorptive property over a mild steel surface. The inhibitive influence of these molecules may be attributed to their adsorption through the -NH, C=O, OH, COOH, *etc.* groups and also may be because of the presence of π -electrons in the rings. These organic molecules gets adsorption on the metal surface forming a protective layer and hence the anti corrosive behaviour [49].

4. Conclusion

The results presented in this paper show that PFLE inhibits the corrosion of mild steel in 1 M HCl. The inhibition efficiency of mild steel in 1 M HCl increases with increasing the concentration of PFLE but decreases with increasing temperature. Potentiodynamic polarization measurements reveal that PFLE acts as a mixed type inhibitor but effect on the anodic reactions is more predominant. EIS measurement reveals that charge transfer increases with increase in concentration of PFLE, indicating that the inhibition increases with increase in concentrations. The adsorption of the inhibitor obeys the Langmuir adsorption isotherm at all investigated temperatures. The adsorption is spontaneous and the inhibition of corrosion by PFLE is due to the formation of both physical adsorption and chemisorption on the mild steel surface. Protective film formation against acid attack has been confirmed by SEM and AFM techniques. The results obtained from weight loss, polarization and impedance measurements are in good agreement.

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