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Corrosion resistance of mild steel in acidic environment; Effect of *Peltophorum ptetocarpum* extract

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Abstract :*Peltophorum ptetocarpum* is a tropically grown deciduous ornamental tree and have significant applications in medical filed mainly used for curing dysentery, muscular pain, sprain, eye lotions, sores and tooth powder. Mild steel is an alloy which has great revolution in structural and industrial applications due to the low carbon content (0.16-0.26) with low tensile, easier availability and cheaper cost material. These properties of mild steel are made to use them in constructing buildings and bridges etc. The main drawback of mild steel is easily undergoes corrosion during acid pickling, industrial cleaning, acid descaling, oil-well acid in oil recovery and petrochemical processes. The aim of present study is to investigate corrosion resistance of mild steel in *Peltophorum ptetocarpum* bark extract with acidic conditions. The bark of *Peltophorum ptetocarpum* has been used for corrosion studies because of its antimicrobial and antioxidant properties. The inhibitory effects of *Peltophorum pterocarpum* extract on mild steel in 1M HCl was investigated using weight loss studies, polarization resistance, open circuit potential and electro impedance spectroscopy. In this process we expected to develop better corrosion resistance of mild steel in acidic environment by using bark extract.
Keywords: *Peltophorum pterocarpum*, mild steel, Tafel, Impedance, surface morphology.

Introduction

Mild steel is an alloy which has great revolution in structural and industrial applications due to the low carbon content (0.16-0.26) with low tensile, high strength, easier availability and cheaper cost material. The main drawback of mild steel is easily undergoes corrosion[1, 2]. Corrosion is an electrochemical change that leads to the destruction or degradation of the materials. Degradation leads to the formation of oxides films on the materials in a gases or liquid environment. This result in economic lost during manufacturing, construction, and management[3]. Industrial applications of mild steel were suspected to different types of corrosion especially in equipment that contain acids. Acids solutions are extensively used in pickling, industrials cleaning, acid descaling, oil well acid in oil recovery and petrochemical process. It is also widely used to remove scales from material surface[4]. Corrosion inhibitors are used as an economical and theoretical concern against the corrosion to reduce the metal reaction.

Organic compounds were most commonly used as an corrosion inhibitors especially in acid solution that contain hetero atoms like nitrogen, oxygen, phosphorus, aromatic rings and π bonds allowing the adsorption of compounds on the metal surface. These organic compounds are highly expensive and found to be harmful to human and its environment[5]. Therefore, naturally synthesized plant extract which is non- toxic, inexpensive corrosion inhibitors has been developed to overcome the drawback of organic based inhibitors. These natural extract are considered as a rich source of chemical compound which can be extracted by simple procedure and environmentally accepted[6,7,8]. The use of plant extract as a corrosion inhibitor has been reported by several authors. Gunsekaran et.al has studied the corrosion inhibition effects of Zenthoxylum alatum plants extract on mild steel in phosphoric acid medium[9]. Maximahas studied the corrosion inhibition of mild steel in 1 M HCl using *Aniba rosaeodora* plant[10]. Fabienne Suedile has investigated the corrosion inhibition of zinc in sodium chloride by Mansoa alliacea plant extract[11].

Peltophorum pterocarpum with common name yellow Poinciana tropically grown deciduous ornamental tree which is widely found in India especially in Andaman island, Nigeria, Pakistan, Florida and Hawaii in united states and it is native to tropical southern Asia[12].*Peltophorum pterocarpum* is a source of chemical constituent like aliphatic alcohol, amino acid, terpenoid, fatty acid, phenolic, flavonoids, alkaloids, steroids[13, 14].The bark of the tree contain (±) leucocyanidin, leucocyanidin -3-O-α–D-galactopyranoside[15,16]. The bark of *Peltophorum pterocarpum* were collected from VIT University, Vellore and an attempt has been made to evaluate the corrosion inhibition of the bark extract.

The aim of the present study is to investigate corrosion inhibition of mild steel in *Peltophorum pterocarpum* extract with 1M HCl. The inhibitory effects of *Peltophorum pterocarpum* extract on mild steel in 1M HCl was investigated using weight loss studies, polarization study, open circuit potential and electrochemical impedance spectroscopy (EIS). The use of Optical microscope is to study the surface morphology of the specimens before and after weight loss measurements.

Experimental

Plant extraction

Peltophorum pterocarpum barks were soaked in 70% ethanol and refluxed for 24 hours. The obtained extract was evaporated at 100°C in a water bath until completely dried. The dried powder was finely grinded to obtain uniform particle size. The obtained powder was used for corrosion study.

Electrolyte preparation:

The analytical reagent grade of HCl was used for the current study. This acid was diluted with double distilled water to prepare 1M HCl. Freshly prepared 1M HCl solution was used for each set of experiments having different concentrations ranging from 0.1.0.5, 0.75, and 1.5 for corrosion studies to avoid contamination.

Specimen Preparation:

Mild steel of which contain C(0.18), Si(0.19), Mn(0.51), P(0,044), S(0.057), Cr(0.14), Ni(0.09), Mo(0.02), Cu(0.06), V(less than 0.01) and remaining Fe were used. Specimen surface was uniformly polished by 200, 400, 600, 800, 1000 grit silicon carbide abrasives. All the specimens were ultrasonically degreased by acetone for 15 mins and then washed and dried.

Weight loss method:

The polished and pre-weighted mild steel specimens with area of 2.5 x 2.5 cm^2 were hanged and suspended in 100ml of test solutions, with and without inhibitors at various concentrations for 1 hour at room temperature. After completion of 1 hour the specimen were taken out, washed, dried and weighed accurately. Triplicate of the experiments were conducted and average values were calculated.

The surface coverage (θ), inhibitor efficiency (IE) (%) of the bark extract were determined using following equation.

$$\theta = \frac{w_o - w_i}{w_o} \qquad (1)$$

Where; w_o = average weight loss without the inhibitor; w_i=average weight loss with the inhibitor at the said concentration.

$$IE(\%) = \frac{w_o - w_i}{w_o} \times 100 \quad (2)$$

Where W_o and W_i are the weight loss value in presence and absence of inhibitor respectively. The corrosion rate C_R(units – mils per year) of mild steel was calculated using the following relation.

$$C_R = \frac{87.6\Delta w}{AtD} \quad (3)$$

A=area of mild steel coupon in cm^2; t=exposure time(h)
D=density (g ml^{-1}) of mild steel;Δw = Weight loss of mild steel (mg)

Electrochemical Behavior

The specimens with area of 1 x 1 cm^2 were used for electrochemical studies. The electrochemical experiments were carried out using BIOLOGIC SA SP-150 electrochemical analyzer. The three electrode setup was used in which working electrode was mild steel, Platinum (Pt) act as counter electrode and Silver-silver chloride electrode (Ag/Agcl) used as reference electrode. The whole setup was immersed in 100ml of electrolyte for one hour before electrochemical analysis to attain steady potential.

Potentiodynamic Polarization Studies

The polarization experiments were carried out at the potential range from -300mv to +300mv with respective to open circuit potential at a sweep rate of 30 mV min^{-1}. The percentage of inhibition efficiency was obtained using the following equation.

$$\boldsymbol{IE}\ (\%) = \frac{\boldsymbol{i^0_{corr}} - \boldsymbol{i_{corr}}}{\boldsymbol{i^0_{corr}}} \times \mathbf{100} \quad (4)$$

Where, I^0corr =Corrosion current density of mild steel without the inhibitor
Icorr= Corrosion current density of mild steel with the inhibitor at a certain concentration

Electrochemical Impedance Spectroscopic studies

The electrochemical measurements were carried out at the frequency ranging from 10, 000 HZ to 0.1HZ at AC amplitude of 10mv.Using EC lab software various equivalent circuit models were fitted to the obtained impedance data. The percentage of inhibition efficiency was obtained using the following equation.

$$\boldsymbol{IE}\ (\%) = \frac{R_{ct'} - R_{ct}}{R_{ct'}} X\ 100 \quad (5)$$

$R_{ct'}$ =Charge transfer resistance of mild steel with inhibitor
R_{ct}= charge transfer resistance of mild steel without inhibitor

Optical Microscopy Analysis

Optical microscopy was used to study the surface morphology of the specimens using the instrument **Imager Aim (Carl Zesis)**. The polished mild steel specimens were immersed in 1M HCl(absence of inhibitor) and in inhibitor containing various concentrations for the duration of 1hourat room temperature. After this study, specimens were removed, washed, dried and analyzed for optical microscopy.

Result and Discussion

Weight loss method

The corrosion rate(CR),inhibition efficiency(IE), surface coverage(θ) of mild steel in *Peltophorum pterocarpum* bark extract are summarized in Table 1.From Fig. 1 (a) it is observed that the rate of corrosion decreases with increases in the inhibitor concentration. The inhibition efficiency was inversely proportional to the corrosion rate and directly proportional to concentration of the inhibitor. This shows that the *Peltophorum pterocarpum* extract shows a good inhibition property against mild steel in acidic environment.Fig.1 (b) shows increasing trends of surface coverage with respect to increase in inhibitor concentration. This shows that more number of inhibitor molecules is adsorbed on the surface of the mild steel and this was further evidenced by the optical microscopy image which was shown in Fig. 4. From the weight loss method, it was confirmed that the concentration having 1.5 % are shown a maximum inhibition efficiency of 85.32% than the other concentrations. Even though, all the concentration have exhibited an IE of more than 75% and this implies that the extract made by *peltophorum pterocarpum* have the tendency to decrease the corrosion of mild steel substrate in acidic environment.

Table 1: Inhibition efficiency of Mild steel in absence and presence of *Peltophorum pterocarpum* extract in 1M HCl by weight loss measurement

Concentration (%)	Corrosion rate (mg cm^{-2} h^{-1})	Surface Coverage (θ)	Inhibition EfficiencyIE (%)
Control	1.6336	-	-
0.1	0.4319	0.7495	74.95
0.5	0.3384	0.8038	80.38
0.75	0.332	0.8077	80.77
1.5	0.2531	0.8532	85.32

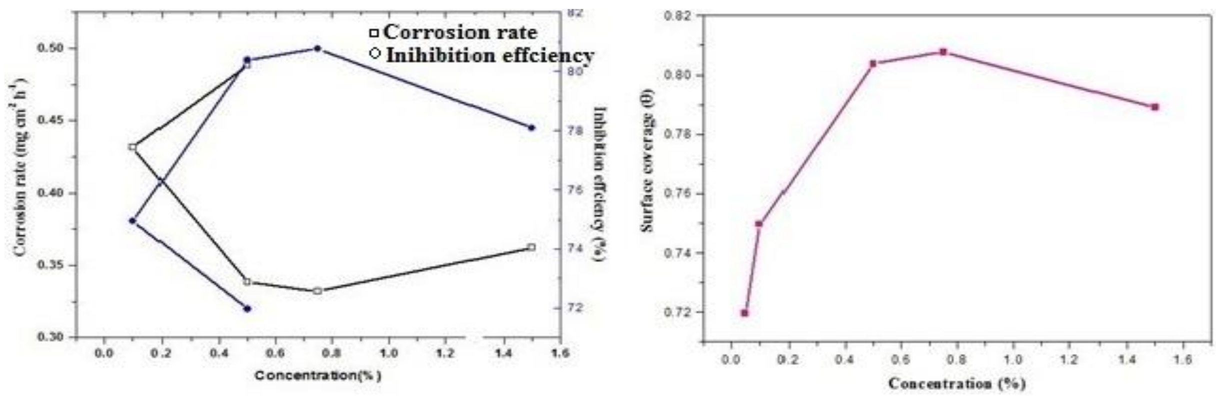

Fig: 1a inhibition efficiency IE (%) vs. corrosion rate(mg cm^{-2} h^{-1})b) Surfacecoverage (θ) obtained from weight loss measurement

Electrochemical Impedance Spectroscopy

Electrochemical impedance spectroscopy was used to investigate the corrosion resistance of mild steel in 1M HCl with *Peltophorum pterocarpum* bark extract. Fig 2 shows the result from the impedance measurements. From the figure 2a, it was observed that with increase in the concentration of inhibitor, the diameter of the circle was found to be increased which indicate the increased corrosion resistance behavior of *Peltophorum pterocarpum* bark extract. Bode plot and phase plot of mild steel in 1M HCl with and without inhibitor of various concentration (0.1, 0.5, 0.75, 1.5) are also confirms the inhibition effect and was shown in fig 2b and 2c. From the figure, the formation of film on the mild steel surface was confirmed at all the concentrations (0.1,0.5,0.75,and 1.5)and this was further evidenced by increase in the charge transfer resistance with decreased double layer capacitance behavior[17,18].

Table2 shows the parameter derived from tafel establishment which indicates more number of inhibitor molecule adsorbed on the surface of the mild steel. The good corrosion resistance of *Peltophorum pterocarpum* was found in the concentration of1.5%.Fig2a (Insert) shows equivalent circuit model used to investigate the electrochemical impedance behavior of the inhibitor. R_S is electrolyte resistance (Ωcm^{-2}),$R_{ct}$is charge transfer resistance (Ωcm^{-2}) and Cdl double layer capacitance (F) which used to fit the impedance data[19, 20]. With respect to weight loss method, the maximum inhibition efficiency was found to observe at the concentration of 1.5 %, this is due to the presence of sulfur and phenolic compound in the bark of *Peltophorum pterocarpum* tree.

Table: 2the electrochemical impedance parameter for mild steel in 1M HCl with and without inhibitor (*Peltophorum pterocarpum* bark extract.)

Concentration (%)	R_S (Ωcm^{-2})	R_{ct} (Ωcm^{-2})	C_{dl} (Faraday)	Inhibition efficiency IE (%)
Control	2.75	15.13	$0.409x10^{-3}$	-
0.1	1.008	171.2	0.103x10-3	91.16
0.5	1.259	228.5	$77.8x10^{-3}$	93.37
0.75	1.35	254.2	$5.84x10^{-3}$	94.04
1.5	2.046	251.3	$70.04x10^{-3}$	93.97

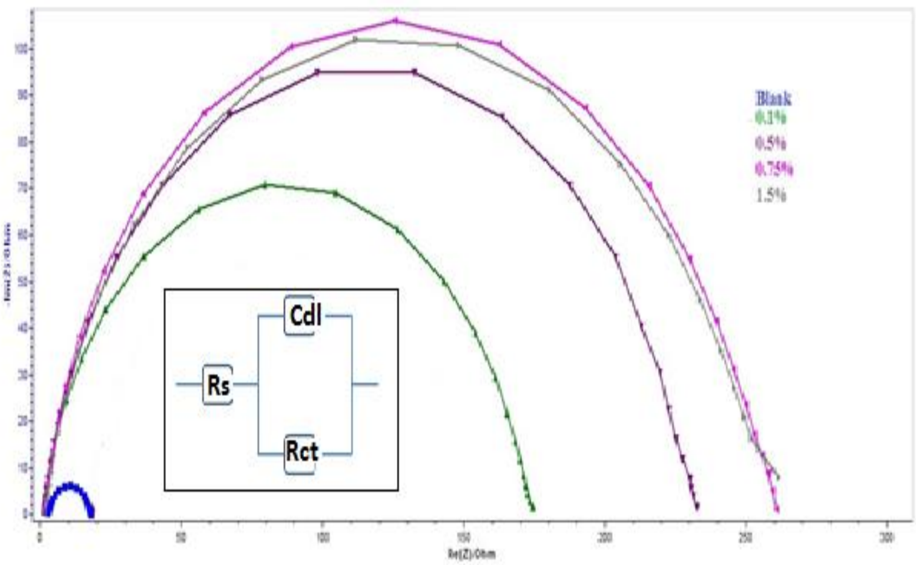

Fig: 2aNyquist plot of mild steel in 1M HCl with and without inhibitor of various concentrations (0.1, 0.5, 0.75, 1.5)

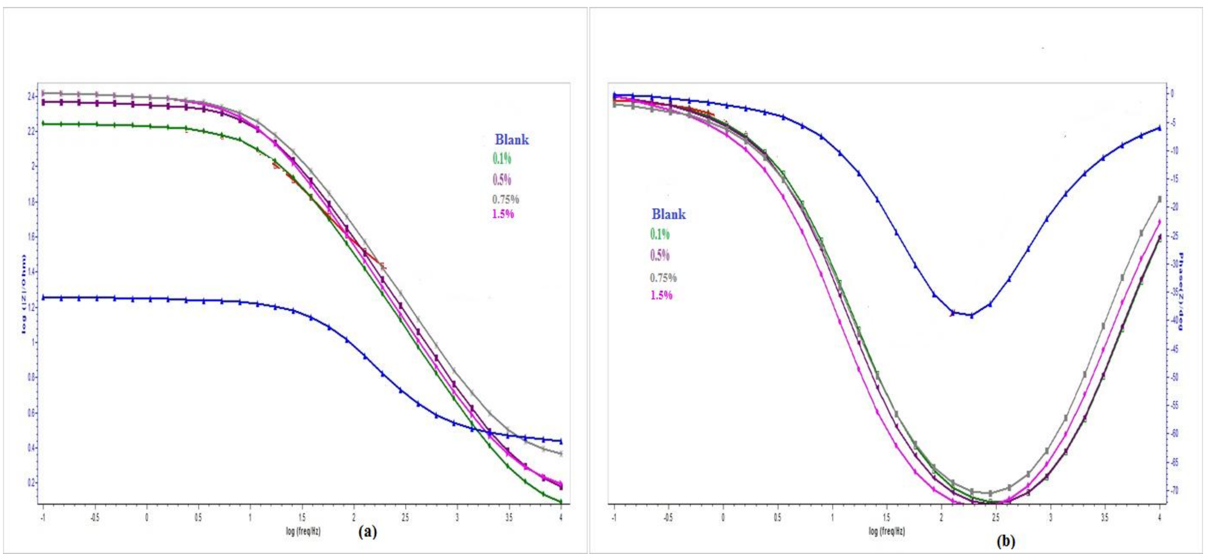

Fig: 2b Bode impedance and 2c phase plot for mild steel in 1M HCl with and without inhibitor of different concentration (0.1.0.5, 0.75, 1.75).

PotentiodynamicPolarization studies

Corrosion behavior of the mild steel in 1M HCl with *Peltophorum pterocarpum* bark extract is shown in Fig 3.Tafel data shows that decrease in the current density with increase in the inhibition efficiency of inhibitor. The corrosion parameters current density (I_{corr}), corrosion potential (E_{corr}),cathodic and anodic slope (β_{c} and β_{a}) was shown in Table 3. It shows that the inhibition of corrosion on mild steel increases with the concentration of inhibitor .The result indicates both cathodic and anodic slope reduce with addition of the inhibitor. Anodic polarization of mild steel in 1M HCl shows the drop in anodic slope due to passivation at -300mv. The anodic tafel slopes decreases with increase in the concentration of plant extract till concentration 1.5% which indicates decrease in anodic passivation in addition of the inhibitor. This indicates *Peltophorum pterocarpum* bark extract is a mixed type indicator because there is decrease in both anodic and cathodic current. Decrease in anodic current is due to adsorption of inhibitor on the surface of the mild steel whereas decrease in cathodic current is because of control of a cathodic reaction in 1M HCl[21, 22].

Table: 3 Tafelpolarization data for mild steel in 1M HCl with and without inhibitor at different concentrations

Concentration	I_{corr} (μA)	E_{corr} (mv)	β_a	β_c	Inhibition efficiency IE %
Blank	2159.015	-454	171	185	-
0.1%	99.373	-453	93	98	93.94%
0.5%	85.786	-454	99	108	95.65%
0.75%	92.619	-449	95	106	95.71%
1.5%	88.528	-489	91	92	95.89%

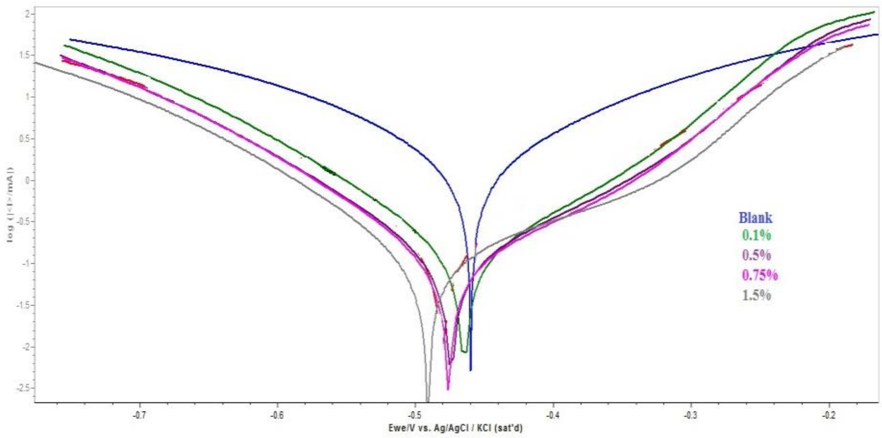

Fig:3Polarization curves of mild steel in 1M HClwith and without inhibitor of different concentration.

Surface morphology

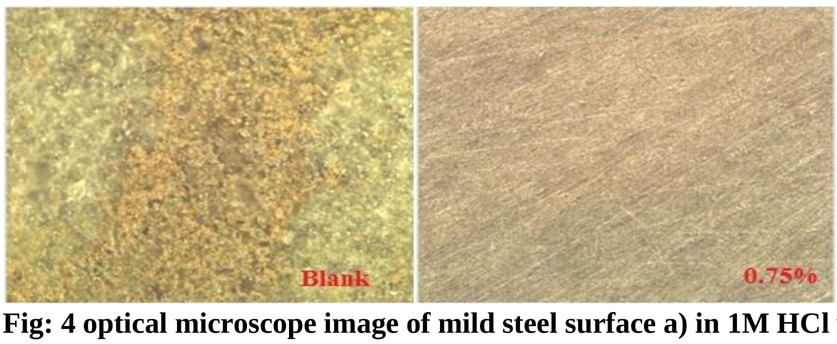

Fig: 4 optical microscope image of mild steel surface a) in 1M HCl without inhibitor b) With 0.75% of *Peltophorum pterocarpum* bark extracts.

The optical microscope images of the mild steel specimens with and without inhibitor are shown in fig 4 a, b.The fig 4a shows the presence of corrosion products on the metal surface which confirmed that the mild steel surface undergoes corrosion in acidic medium. Fig 4bshows that the absence of corrosion product on the metal surface .This states that *Peltophorum pterocarpum* ethanolic bark extract possess inhibition efficiency against mild steel in acidic medium.

Conclusion

1. Corrosion resistance of *Peltophorum pterocarpum* bark extract on mild steel in 1M HClsolution was found to be increases with increase in the concentration of the bark extract.
2. From weight loss method, the surface coverage of mild steel increases with increase in inhibitor concentration. This shows that more number of inhibitor molecules adsorbed on the surface of the mild steel.
3. Both polarization and electrochemical impedance data have shown increased inhibition efficiency with respect to increase in the concentration of inhibitor. All the concentration has exhibited the IE of more than 75%, and the better IE (95.89 %) has arrived at the concentration of 1.5 %.
4. Optical microscope image confirmed the absence of corrosion product on the metal surface in the presence of inhibitor. These studies reveal *Peltophorum pterocarpum* bark extract act as good inhibitor at different concentration.

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