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Tribulus terrestris .L water extract (TTWE) as eco-friendly inhibitor on mild steel corrosion in 1N Phosphoric acid

M.Sivaraju, K. Kannan *,

Department of Chemistry, Muthayammal Engineering College, Rasipuram.

*Department of Chemistry, Government College of Engineering, Salem–636 011.

Email: vstharanitharan@gmail.com; kannan_k2002@yahoo.co.in

The inhibition effect of Tribulus terrestris .L water extract (TTWE) on mild steel corrosion in 1N phosphoric acid has been studied by mass loss and polarization techniques between 303 K and 333K.The inhibition efficiency increased with increase in concentration of plant extract. The corrosion rate increased with increase in temperature and decreased with increase in concentration of inhibitor compared to blank. The adsorption of inhibitor on mild steel surface has been found to obey Temkin's adsorption isotherm. Potentiostatic polarization results revealed that Tribulus terrestris .L extract act as mixed type inhibitor. The values of activation energy (Ea), free energy of adsorption (ΔG_{ads}), heat of adsorption (Q_{ads}), enthalpy of adsorption (ΔH) and entropy of adsorption (ΔS) were calculated. Surface analysis (FT-IR and SEM) was also carried out to establish the mechanism of corrosion inhibitor on mild steel corrosion in phosphoric acid medium.

Keywords: Mild Steel; Phosphoric acid; Corrosion inhibition; Temkin's adsorption isotherm; Potentiostatic polarization; FT-IR; SEM; Tribulus terrestris .L water extract (TTWE).

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INTRODUCTION

Phosphoric acid is a major chemical product, which has many important uses, especially in the production of fertilizers. Most of the acid is produced from phosphate rock by wet process. Generally nickel–base alloys and stainless steel are frequently used in many parts of the wet process and a considerable quantity of data has been published about the resistance of these materials to corrosion by phosphoric acid solution [1-4]. Most of the previous studies were focused on the inhibition of stainless steel or chromium-nickel steel in hydrochloric acid or phosphoric acid solutions using organic compounds containing nitrogen, sulphur and oxygen atoms as corrosion inhibitors [5, 6]. The corrosion inhibiting property of these compounds is attributed to their molecular structure. These compounds contain π electrons and heteroatom, which induce greater adsorption of the inhibition molecules onto the mild steel surface.

Because of the toxic nature and high cost of some chemicals currently in use, it is necessary to develop environmentally acceptable and less expensive inhibitors. Natural products can be considered as a good source for this purpose. Extracts of naturally occurring products contain mixture of compounds and are biodegradable in nature, these compounds having nitrogen and sulphur as constituent atoms are studied as corrosion inhibitor in HCl medium [7]. G.Gunasekaran and L.R.Chaughan studied the inhibition effect of Zenthoxylum alatum on the corrosion of mild steel in Phosphoric acid medium [8]. A.M.Abdel–Gaber and co-workers studied inhibitive action of some plant extracts Nigella Sativa.L (Black cumin), Phaseolus vulgrais.L (Kidney bean) and Cymbopogon proximus (Halfabar) on the corrosion of mild steel in sulphuric acid medium [9]. Several works have been reported using such economical plant leaves extract of Azadirachta indica for mild steel in H_2SO_4 [10], leaves extract of Nypa fruticand wurmb [11] and occinium viridis [12], acid extract of Alllium sativum (Garllic) [13] Foenum Graecum [14], aqueous extract of Lawsonia inermis (Henna)[15] and Carboxymenthylchitoson [16] as inhibitors for mild steel in HCl medium. Literature survey revealed that not much work was done on the corrosion inhibition of mild steel in phosphoric acid solutions using naturally available plant extracts.

Tribulus terrestris L, is a member of the Zygophyllaceae family, is an annual plant native of Mediterranean region. It has pinnate leaves, yellow flowers and stellate shape carpel fruits. Extracts of this plant have been used traditionally in treating variety of diseases including hypertension, coronary heart diseases, ocular inflammation and infertility in both sexes.

The phytochemical components of TTWE has been extensively studied and it is known to have steroidal saponins compounds[17,18], Polysaccharides[19], tannins[20].These compounds have been known for their medicinal properties like antifungal, antibacterial, antioxidant and most likely responsible for inhibiting corrosion.

So, in this present investigation, the corrosion of mild steel in 1N phosphoric acid solution in the absence and presence of TTWE at 303 to 333K has been studied by mass loss and polarization techniques. It is aimed to predict the corrosion rate, inhibition efficiency on mild steel corrosion and the thermodynamic feasibility of inhibition via surface coverage on mild steel by adsorbed TTWE at various temperatures. The adsorption characteristic of TTWE was studied in order to access the mechanism of corrosion inhibition and the adsorption isotherm (s).

EXPERIMENTAL

1. Preparation of specimens:

Mild steel specimens were cut to size of 5 cm x 1.5 cm from the mild steel sheets having the following percentage composition as shown below. The surface of specimens were polished

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with emery papers ranging from 110 to 410 grades and degreased with trichloroethylene specimens were dried and stored in vacuum desiccators containing siligagel.

Composition of mild steel:

Element	Fe	Ni	Mo	Cr	S	P	Si	Mn	C
Composition (%)	99.686	0.013	0.015	0.043	0.014	0.009	0.007	0.196	0.017

2. Preparation of plant extract:

Water extract of Tribulus terrestris .L was prepared by the aerial part of plant collected and dried in air and then Grained. 50g of grained powder subjected to Soxhlet extraction using water. The solvent can be removed by boiled at constant temperature at 40'c in vacuum vaporator, finally the residue of TTWE was collected. From the TTWE residue the various concentration of inhibitor solution (1, 2, 3, 4, and, 5 mgs) was prepared. All the solutions were prepared with AR grade chemicals in double distilled water.

3. Weight loss measurement:

Polished specimens were initially weighed in an electronic balance. After that the specimens were suspended with the help of PTFE threads and glass rod in 100ml beaker containing acid in the presence and absence of TTWE. The specimens were removed after 4 hours exposure period, washed with water to remove any corrosion products and finally washed with acetone. After that they were dried and reweighed. Mass loss measurements were carried out in 1N phosphoric acid with TTWE in the concentration range of 1mgs to 5 mgs as inhibitors and the temperature between 303 K and 333 K for an immersion period of 4 hours. Mass loss measurements were performed as per ASTM method described previously [21, 22].

4. Potentiostatic Polarization measurements

Polarization measurements were carried out in a conventional three-electrode cell. Mild steel strips coated with lacquer except for an exposed area of 1 cm^2 were used as the working electrode. The saturated calomel electrode and the platinum foil were used as reference and counter electrodes respectively. The potentiostatic polarization measurement was carried out using BAS – 100, a model instrument. The potential of the test electrode was measured with respect to SCE, platinum electrode was used as auxiliary electrode and the experiment was carried out at 303K to333K.

5. Surface analysis:

The mild steel specimens were exposed in 100 ml of 1N Phosphoric acid solution having 5 mgs of plant extract for 3 hours at room temperature and washed with distilled water then dried. The nature of film formed on the surface of the metal specimens was analyzed by FT-IR and SEM. The dried specimens were scratched off and the resultant powder mixed with KBr (1:100 ratio) to prepare pellets, then the pellets was introduced into Fourier Transfer Infra-Red spectrophotometer FT-IR,8400's SHIMADZU, Japan to analyse the sample.

RESULTS AND DISCUSSION

Mass loss Studies

Table 1 shows the value of inhibition efficiency [IE%], surface coverage (θ) and corrosion rate obtained at different concentration of the inhibitors in 1N phosphoric acid solution for an immersion period of 3 hours. From the mass loss value, the inhibition efficiency [IE%] and surface coverage (θ) were calculated using the following equation [23].

$$IE(\%) = \frac{Wu - Wi}{Wu} \times 100 \qquad [1]$$

$$\theta = \frac{Wu - Wi}{Wu} \qquad [2]$$

Where Wu and Wi are the corrosion rates for mild steel in the absence and presence of inhibitor respectively at the same temperature.

It could be seen from the table that the addition of inhibitor to the acid had reduced the corrosion rate. The inhibition efficiency increased with increase in concentration of inhibitors and decreased with increase the temperature from 303 K to 333 K in 1N Phosphoric acid.

THERMODYNAMIC PARAMETERS

Energy of activation (Ea)**:**

Table 2 shows that the calculated values of activation energy (Ea) for mild steel corrosion in 1N phosphoric acid with and without inhibitor from 303K to 333K. Energy of activation (Ea) was calculated from the slopes of plots of log p versus 1/T in fig-1 and also calculated from Arrhenius equation [24].

$$\log \frac{P_2}{P_1} = \frac{Ea}{2.303R}\left[\frac{1}{T_1} - \frac{1}{T_2}\right] \qquad [3]$$

Where P_1 and P_2 are the corrosion rates at temperatures T_1 and T_2 respectively. The Ea values were found to be 36.98 KJ/mole and 14.95 KJ/mole in 1N phosphoric acid with and without TTWE respectively.

The addition of plant extract increases the activation energy as reported by G.Gunasekaran and L.R.Chaughan for metal dissolution reaction indicating that this plant extract hinders metal dissolution [25]. F.Bentiss et.al, explained that the Ea value increased in the presence of plant extract may be interpreted as physical adsorption (weakening) that occurs in the first stage , that is important because it is the proceeding stage of chemisorption of plant extract on mild steel [26]. But T.Szauer and A.Brand revealed that the increase in Ea can be attributed to an appreciable decrease in the adsorption of the inhibitor on mild steel surface with increase in temperature. A corresponding increase in the corrosion rate occurs because the greater area of the metal that is frequently exposed to acid environment [27].

Table -2 shows that the Ea values for 1N phosphoric acid containing TTWE are found to be higher than that of without inhibitor. These higher values of Ea indicate that the addition of plant extract hinders metal dissolution and also indicate that, decrease in the adsorption of inhibitor on mild steel surface with increase in temperature The Ea values are calculated from the slopes of Arrhenius plot and by using equation-3 are approximately almost similar.

Free energy of adsorption:

The free energy of adsorption (ΔG_{ads}) at different temperatures was calculated from the following equation [24].

$$\Delta G\ (_{ads}) = -RT\ In\ (55.5\ K) \qquad [4]$$

Where K is given by

$$K = \frac{\theta}{C\ (1-\theta)}$$

Where θ is surface coverage on the metal surface, C is concentration of inhibitor in mole/lit and K is equilibrium constant. 55.5 is concentration of water (mol. /lit)

M.Boukka et.al, explained generally the values of ΔG_{ads} upto -20 KJ/mole are consistent with characteristic interaction between charged molecules and charged metal surface (physisorption). While those around –40 KJ/mole or higher [26, 28] or smaller [17, 29] are associated with chemisorption [14] as a result of sharing or transferring of electrons from organic molecules to the metal surface.

The free energy of adsorption (ΔG_{ads}) in 1N phosphoric acid with TTWE on mild steel calculated from the equation (4) from 303K to 333K.. From table 2 the negative free energy values (ΔG_{ads}) ranging from -29.33 to -26.88 KJ/mole indicate that the adsorption of the inhibitor is spontaneous and also adsorption of plant extract (TTWE) on mild steel is chemically adsorbed in phosphoric acid medium attributed to the donation of π electron by aromatic rings or Non-bonding electron pair of compounds (hetero atoms) present in plant extract.

Heat of adsorption (Q_{ads}):

The values of heat of adsorption Q_{ads} were calculated using the following equation [30].

$$Q_{ads} = 2.303R\log\left[\frac{\theta_2}{1-\theta_2}\right] - \left[\frac{\theta_1}{1-\theta_1}\right] \times \frac{T_1 \times T_2}{T_2 - T_1} \qquad [5]$$

Where θ_1 and θ_2 are degrees of surface coverage at temperature T_1 and T_2 by the different additives.

E.E.Oguzie explained that the negative values of Q_{ads} also signify that the degree of surface coverage decreased with rise in temperature and positive values of Q_{ads} means the physical adsorption equilibrium is usually rapid and the process readily reversible whereas in chemisorption, the occurrence of chemical reaction at the metal surface makes the process relatively slow and not readily reversible [30]. From table 2 it is evident that in all the cases, the Q_{ads} values are ranging from -24.95 to 7.80 KJ/mole with TTWE. The higher negative values of heat of adsorption also show that the inhibition efficiency decreased with rise in temperature.

The enthalpy of adsorption (ΔH) and entropy of adsorption (ΔS)

The enthalpy of adsorption (ΔH) and entropy of adsorption (ΔS) were also calculated from the following equations [31, 32].

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$$\Delta H^0 = E_a - RT \text{ ------------------ [6]}$$

$$\Delta G^0 = \Delta H^0 - T\,\Delta S^0 \text{ ------------- [7]}$$

The thermodynamic data obtained in this study are shown in table –2. It could be seen from the table that the activation energy increased linearly with increasing the efficiency of inhibitor.

F.Bentiss et.al, revealed that the positive sign of enthalpies (ΔH) reflects the endothermic nature of the steel dissolution process, which means dissolution of mild steel in acid medium is difficult [26]. O.O. Adeyen and C.Montiealy et.al described that if the heat of adsorption (ΔH_{ads}) < 10 KJ/mole the adsorption is probably physisorption and if (ΔH_{ads}) > 10 KJ/mole the adsorption is probably chemisorption [33]. Therefore, the enthalpy of adsorption (ΔH_{ads}) values indicates that the plant extract strongly adsorbed on mild steel is chemisorption.

In authors view, the adsorption of inhibitor is not considered only physical or chemical adsorption phenomenon in this case. Physical adsorption that occurs in the first sage , then according to hard and soft acid base theory, inhibitors are chemisorbed on the surface of mild steel by sharing of an electron pair of hetero atoms present in plant extract with d-orbital of iron forming covalent bond, leading to the positive vale of ΔH_{ads}. [17].

It's also observed that ΔS values increased with increase the efficiency of inhibitors. This is opposite to the expectation, since the adsorption is an exothermic process and is always accompanied by decrease in entropy. Ateya et. al. [24, 34] has described this situation as the adsorption of the organic compound leads to desorption of water molecules from the surface. While the adsorption process is believed to be exothermic and associated with a decrease in entropy of the solute, the opposite is true for the solvent. Therefore, this gain in entropy that accompanied the substitutional adsorption process is attributed to the increase in solvent entropy.

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Adsorption isotherms

The electrochemical process on the metal surface are likely to be closely related to the adsorption of the inhibitors [35] and the adsorption is known to depend on the chemical structure of the inhibitors [36-37] .The adsorption of the inhibitors molecules from aqueous solutions can be regarded as quasi-substitution process [36] between the organic compound in the aqueous phase, org ($_{aq}$) and water molecules at the electrode surface, $H_2O_{(s)}$.

$$Org_{(aq)} + xH_2O_{(s)} = org_{(aq)} + x\,H_2O_{(s)}$$

Where x (the size ratio) is the number of water molecules displaced by one molecule of inhibitor.

Adsorption isotherms are very important in determining the mechanism of organo-electrochemical reactions. The most frequently used are those of Langmuir, Frumkin, Parsons, Temkin , Flory –huggins and Bockris –Swinkels [38-40]. All these isotherms are of the general form:

$$f(\theta,x)\exp(-a\,\theta) = K\,C$$

Where f (θ,x) is the configurational factor that depends essentially on the physical model and assumptions underlying the derivation of the isotherm [41]**.**

The mechanism of inhibition of corrosion is generally believed to be due to the formation and maintenance of a protective film on the metal surface. The plot of surface coverage (θ) obtained by mass loss method versus log C at different concentrations of the inhibitors shows a straight line indicating that the adsorption of the inhibitor from acid on mild steel surface follows the Temkin's adsorption isotherm. This also points out that the corrosion inhibition by these compounds is being a result of their adsorption on the metal surface. Fig.2 shows the Temkin's adsorption isotherm plots for TTWE with 1N phosphoric acid.

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SURFACE ANALYSIS:

FT-IR:

The peak values obtained from FT-IR analysis are shown in Table-3. The broad peaks between 3200cm^{-1} to 3500cm^{-1}assigned to the presence of a superficial absorbed water, stretching mode of an OH and /or NH [9]. The peaks at 2929 & 2858 corresponds to stretching vibration of aliphatic and aromatic C-H .The peaks at 1670, 1654, 1560, 1527,1122 & 1091cm^{-1} corresponds to stretching vibration of $R_2C=N$; C=O; Aromatic substituted C=N, C=C (Aromatic ring) , stretching vibration of ether linkage (C-O) and stretching vibration of C-O. This shows that the plant extract contains mixture of compounds. Almost all the peak observed for plant extract is also noticed on mild steel immersed in 1N phosphoric acid with 5mgs of plant extract as shown in Fig -4.

The stretching frequency of C-O shift from 1091cm^{-1}to 1018cm^{-1}due to electron cloud density shift from O atoms to co-ordinate with $Fe^{2+}$to form Iron plant extract complex [42-46]. The peaks at 1272 cm^{-1}(P=O) and 1018cm^{-1}(P-O-Fe) indicates Iron phosphate complex .Then the peaks between 400 and 700 cm^{-1} are mainly due to Fe_2O_3 [8].

Scanning Electron Microscope:

Surface of polished mild steel specimen immersed in 1N phosphoric acid in the presence of plant extract (5mgs) were examined using scanning electron microscope model JEOL6360, Japan. Fig 5a and 5b shows the surface photograph of mild steel specimens immersed in 1N phosphoric acid in the absence and presence of plant extract respectively. In the case of blank, the corroded metal surface with etched grain boundaries and corrosion products are clearly seen in fig 5a. But in the presence of plant extract there is formation of adsorbed layer of inhibitors on the metal surface as seen in fig 5b.

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Potentiostatic Polarization studies

The Polarization behavior of mild steel functioning as cathode as well as anode in the test solution is shown in fig.3 for 1N phosphoric acid with TTWE extract at room temperature (303K). The electrochemical data obtained are shown in Table 1. It is evident that TTWE bring about considerable polarization of cathode as well as anode. It was therefore inferred that the inhibitive action is of a mixed type. The non-constancy of Tafel slopes for different inhibitor concentration revealed that the inhibitor act through their interference in the mechanism of the corrosion processes at the cathode as well as anode. The i_{corr} values were decreased with increasing concentration of the inhibitors which indicate that the corrosion process is controlled by adding TTWE.

MECHANISM:

The composition and the structure of the films formed on iron remains subjects of continued interest from FTIR studies on the oxides of iron revealed the presence of Fe_2O_3 in solutions irrespective of the nature of the iron substrate.

At the interface of iron and electrolyte, the dissolution of iron can be written as,

$$Fe + H_2O \longleftrightarrow FeOH_{ads} + H^+ + e^-$$

$$FeOH_{ads} \longrightarrow FeOH^+ + e^-$$

$$FeOH^+ \longleftrightarrow Fe^{2+} + OH^-$$

At medium and high concentrations of phosphoric acid, precipitation of iron-phosphate occurs at interface.

$$6H_3PO_4 + 3Fe \longrightarrow 3\,Fe\,(H_2PO_4)_2 + 3H_2$$

$$3Fe\,(H_2PO_4)_2 \longrightarrow Fe_3\,(PO_4)_2 + 4H_3PO_4$$

However, this precipitation can be weakly observed when the mild steel is treated with phosphoric acid solutions with low concentration. The formation of insoluble phosphate depends on the metal ions present in solutions at interface, concentration of metal ion in the solution and the reactivity of metal surface. G.Gunasekaran and L.R.Chauhan explained that as soon as the plant extract interact with dissolving iron to form an organo-metel complex (Fe-PE) and forms a layer.

$$Fe^{2+} + PE \longrightarrow [Fe\text{-}PE]$$

This layer reacts with phosphate ions to form a layer of $FeHPO_4$/ FeH_2PO_4.This reaction takes place in series with the formation of Fe - PE, since it is mediated or catalyzed by this compound, as is observed by the increased rate of formation of iron phosphates. After certain period, the formation of iron phosphate results in a dense layer and formation of Fe-PE will less. This was reflected by FT-IR analysis of mild steel immersed in 1N phosphoric acid containing 5mgs of plant extract.

CONCLUSION

The following conclusions were made from the studies,

1. Corrosion rates of mild steel in 1N phosphoric acid decreased with increasing concentration of TTWE.
2. The inhibition efficiency increased with respect to the concentration of inhibitor and decreased with rise in temperature from 303K to 333K.
3. The maximum inhibition efficiency of TTWE was found to be 90.51 % and 84.62% in 1N phosphoric acid at 5mgs of inhibitor from mass loss studies and polarization measurement respectively at 303K.

4. The inhibition efficiency obtained from mass loss and polarization measurement showed fairly good agreement.
5. Energy of activation (Ea) values indicated that the addition of plant extract hinders metal dissolution and also indicated that, decrease in the adsorption of the inhibitor on mild steel surface with increase in temperature.
6. The negative value of ΔG_{ads} indicated that the TTWE is chemically adsorbed and spontaneous adsorption of inhibitors on the surface of mild steel.
7. The higher negative values of heat of adsorption also showed that the inhibition efficiency decreased with rise in temperature
8. The high positive enthalpy values of adsorption (ΔH_{ads}) evident that the plant extract strongly adsorbed on mild steel is probably chemisorption.
9. The gain in entropy that accompanied by the substitutional adsorption process was attributed to the increase in solvent entropy.
10. It is found that the TTWE acting as mixed type inhibitor.
11. The adsorption of TTWE on mild steel surface from the acid solution followed Temkin's adsorption isotherm.
12. FT-IR and SEM analysis showed the presence of compounds in the plant extract react with metal ion to form the layer of inhibitor on the metal surface.

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Table –1

The corrosion parameters for mild steel in 1N phosphoric acid with TTWE from Mass loss and polarization studies.

Temp (K)	Conc of (TTWE) (mgs)	Mass loss studies: Corrosion Rate (mmpy)	Mass loss studies: Surface coverage (θ)	Mass loss studies: Inhibition Efficiency (%)	Polarization measurement: E_{corr} Vs SCE (mv)	Polarization measurement: I_{corr} $\mu A/cm^2$	Polarization measurement: Tafel constant mv/decade b_a	Polarization measurement: Tafel constant mv/decade $-b_c$	Polarization measurement: IE (%)
303	Blank	159.2502			-460	260	55	110	------
	1	50.7718	0.6812	68.12	-440	60	45	95	76.92
	2	41.0633	0.7421	74.21	-455	54	45	90	79.23
	3	28.9276	0.8184	81.84	-450	51	50	95	80.38
	4	23.8751	0.8501	85.01	-450	46	55	90	82.31
	5	15.1077	0.9051	90.51	-455	40	35	85	84.62
313	Blank	182.7291			-465	610	50	120	-----
	1	96.8380	0.4700	47.00	-440	270	45	117	55.74
	2	80.5415	0.5592	55.92	-460	230	40	100	62.30
	3	59.9851	0.6717	67.17	-450	180	45	90	70.49
	4	45.7690	0.7495	74.95	-452	150	35	90	75.41
	5	31.1566	0.8295	82.95	-445	130	40	85	78.69
323	Blank	217.0558			-475	1050	65	135	------
	1	140.9228	0.3508	35.08	-450	620	60	110	40.95
	2	106.8933	0.5075	50.75	-450	480	60	98	54.29
	3	95.0548	0.5621	56.21	-440	390	60	105	62.86
	4	83.2163	0.6166	61.66	-470	280	55	100	73.33
	5	49.1868	0.7734	77.34	-450	240	52	95	77.14
333	Blank	271.7408			-480	1600	90	140	------
	1	190.5059	0.2989	29.89	-455	920	83	135	42.50
	2	161.0334	0.4074	40.74	-460	740	81	125	53.75
	3	131.3133	0.5168	51.68	-455	460	75	125	71.25
	4	114.5710	0.5784	57.84	-450	445	70	110	72.19
	5	109.3204	0.5977	59.77	-465	420	75	105	73.75

Table -2

Thermodynamic parameters for mild steel corrosion in 1N phosphoric acid with TTWE.

Conc. of TTWE (mgs)	Ea (from eqn,1) KJ/Mol	Ea (from plot) KJ/Mol	$-\Delta G_{ads}$ KJ/Mole				Q_{ads}	ΔH KJ /mol	ΔS KJ /mol / k
			302K	313K	323K	333K			
Blank	14.95	15.60	-------	------	-----	------	------	10.79	-------
1	36.98	34.52	29.33	28.12	27.68	27.88	-24.95	32.83	0.2004
2	38.22	38.86	28.34	27.24	27.56	27.29	-12.02	34.06	0.2040
3	42.31	41.23	28.45	27.43	27.06	27.39	-0.32	38.15	0.2159
4	43.86	45.65	28.30	27.67	26.89	27.28	6.30	39.71	0.2205
5	55.35	54.12	29.05	28.36	28.31	26.88	7.80	51.19	0.2633

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Table – 3

FT-IR peak values for plant extract, mild steel in H_3PO_4, and mild steel in H_3PO_4 with Plant extract (TTWE).

FT-IR peak values			Possible groups	Ref. No
Mild steel in H_3PO_4	Plant Extract (TTWE)	Mild steel in H_3PO_4 with Plant extract		
-	3608-3791	3608-3791	Non-bonded –OH stretching	42,45
3000-3500	-	-	Stretching mode of O-H (from adsorbed water)	42,8
-	3342	3344	O-H/N-H (Polymeric OH stret.)	8, 9,42
-	2929	2923	Aliphatic C-H	8, 9,42
-	2858	2852	Aromatic C-H	8, 9,42
-	1670	1670	$R_2C=N$	8, 9
-	1654	1654	C=O	8, 9,42
1610	-	-	Iron phosphate	8, 9
-	1560	1560	Aromatic substituted C=N	8, 9
-	1527	1527	C=C (Aromatic ring)	8, 9,42
-	1388	1373	Plane bending vibration of OH	40
1272	-	1272	Stret. P=O	8, 9
-	1122	-	Stret. vibration of ether linkage (C-O)	44,45
-	1091	-	C- O	41,42
1024	-	-	Iron phosphate	8, 9
-	-	1018	Fe-plant extract complex/ salt	8, 9
663		663	γ -Fe_2O_3	8, 9
The peaks between 400 -700 cm^{-1} mainly due to Fe_2O_3				8, 9

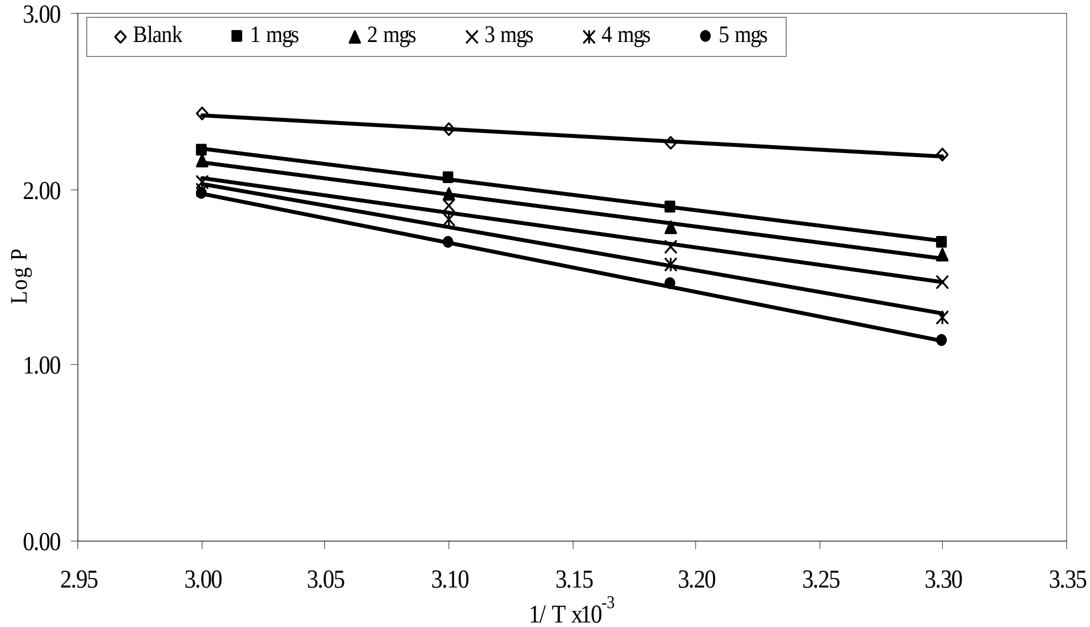

Fig: 1 Arrhenius Plot for Corrosion in 1N Phosphoric acid with TTWE

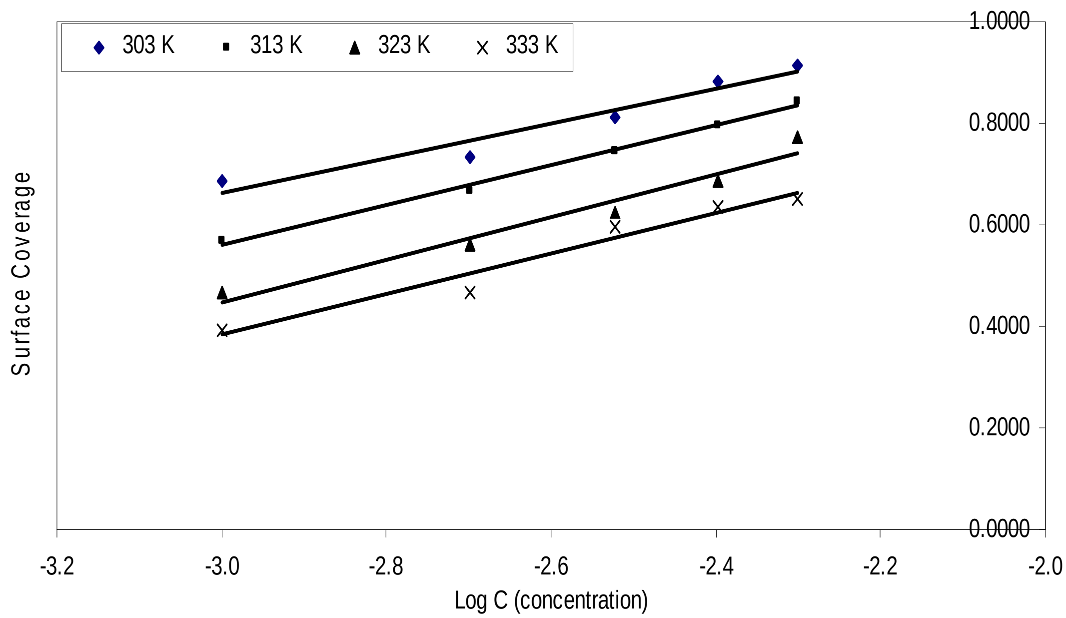

Fig: 2. Tempkin's adsorption isotherm for corrosion behaviour of mild steel in

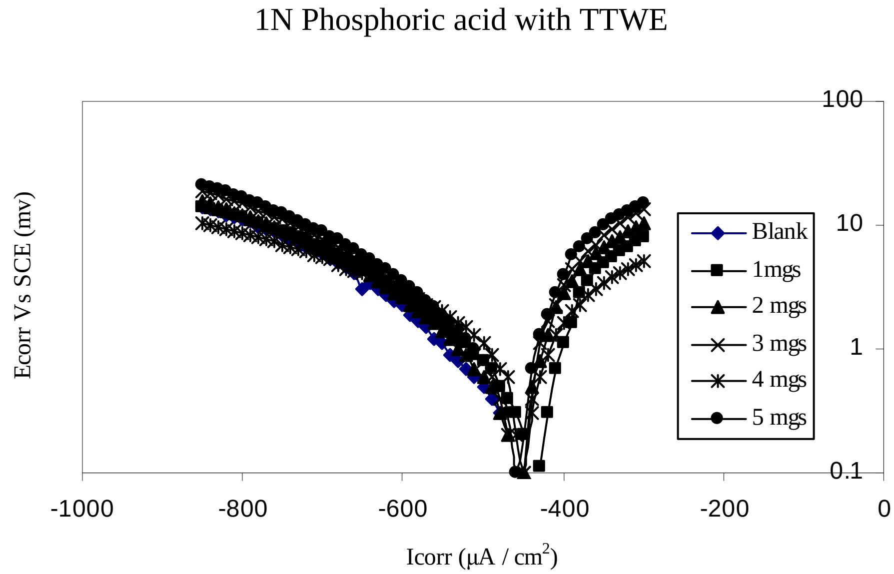

Fig: 3. Typical Potentiostatic curves for mild steel in 1N Phosphoric acid with TTWE

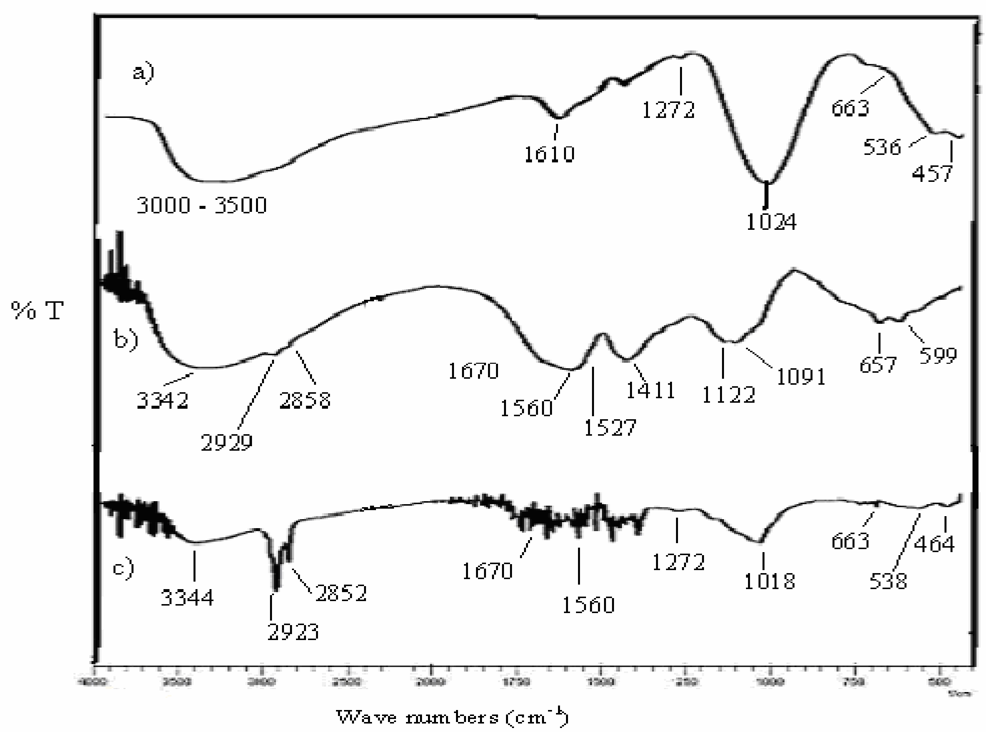

Fig: 4 FT-IR spectrum of a) Mild steel in 1N Phosphoric acid. b) Plant extract (TTWE)

c) Mild steel in 1N Phosphoric acid with TTWE

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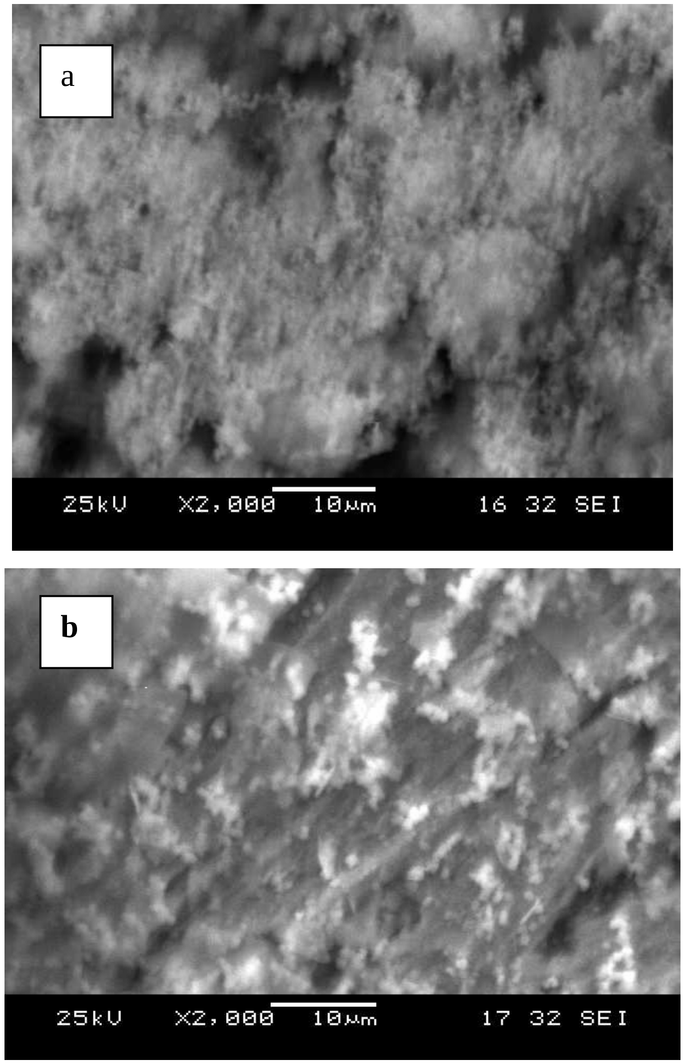

Fig: 5 SEM analysis of a) Mild steel in 1N Phosphoric acid

b) Mild steel in 1N Phosphoric acid with TTWE

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