

# Corrosion Behavior Of Mild Steel In Natural Sea Water With Tephrosia Purpurea– A Green Approach

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## ABSTRACT

*Corrosion Behaviour of "Tephrosia Purpurea" plant extract on mild steel corrosion in Natural Sea Water was carried out by Non-electrochemical using gravimetric and electro chemical techniques. Observed result indicates that the corrosion inhibition efficiency was increased with increase of inhibitor concentration and decreased gradually with rise in temperature. The maximum percentage of inhibition efficiency attained 89.35% by mass loss method. The corrosion current ( $I_{corr}$ ) decreased with increase of inhibitor concentration (from 67.34 to 8.05 mA cm<sup>2</sup>) studied by potentiodynamic polarisation. By using impedance spectroscopy the charge transfer Resistance ( $R_{ct}$ ) value increased from 2.509 to 73.3Ωcm<sup>2</sup>. This results very good agreement with the previous result. Thermodynamic parameters (viz;  $E_a$ ,  $Q_{ads}$ ,  $\Delta H_{ads}$ ,  $\Delta G_{ads}$ ,  $\Delta S_{ads}$ ) were evaluated for corrosion process, which is also suggested that the adsorption is exothermic, spontaneous and Physisorptions. The inhibitor follows Frumkin adsorption isotherm. The corrosion products formed on the metal surface was analyzed by using EDX techniques and the film formation also confirmed by SEM image.*

**Keywords:** Natural Sea water, Mild Steel, Corrosion inhibition, Mass loss, Adsorption, Spectral studies

## 1.Introduction:

Corrosion of materials is a natural phenomenon that is a cause of concern as it has incurred a total damage of billions of dollars to many industries in world wide. In order to overcome this corrosion problem various preventing measures such as inhibitors, anodic protections, Cathodic protections coatings and alloying were developed. Among all of these methods, corrosion inhibitors are most popular due to the ease in application and the advantage of in situ without disruption of the process. Corrosion inhibitors are substances which when added in small concentrations to the corrosive environment will reduce the rate of corrosion[1]. The heterocyclic organic compounds and their derivatives have been successful as corrosion inhibitors, although their toxicity is an important disadvantage, for it limits their application due to environmental impact reason [2,3]. The use of corrosion inhibitors as a means of protection is necessary in many industrial cases: surface preparation, transport and storage of metals, cooling circuits, rehabilitation of reinforced concrete, painting and Cathodic protection [4-6]. The adsorption characteristics mild steel of corrosion inhibitors depend upon the chemical moiety of the molecule, type of functional groups and the electron density at the donor atoms. Organic compounds, containing hetero atom's (N, O, S and P), electronegative functional groups,  $\pi$ -electrons and aromatic rings as electron density rich centres which are considered as good adsorptive centre [7-9]. These heterocyclic organic inhibitors get adsorb onto the steel surface or form protective insoluble layer and block corrosion sites, which reduces contact of corroding material with the corrosive medium/steel [10]. The plant extract are rich sources of molecules which have appreciably high inhibition efficiency and hence termed as "Green Inhibitors". These inhibitors do not contain heavy metals or other toxic compounds. Recent studies using plants containing heteroatom such as oxygen, nitrogen and sulphur like *Ocimum viridis*, *Phyllanthus amarus*, *Annona squamosa*, *Argan*, *Psidium guajava*, *black pepper*, *Punica granatum*, *Mentha pulegium*, *Cnidioscolus chayamans*, *Solanum Torvum*, *Pisonia Grandis*, *mimusops elengi*, *Sauropus Androgynus*, *Kingiodendron pinnatum*, *Wrightia Tinctoria*, *Aloe- Vera gel*, *Hibiscus Rosa Sinensis* and *Azadirachita Indica* leaves, *Aihagi Maurerum* and *Merusnigra* and *Apricot Leaves*, *Adansonia digitata* (Baobab) fruit pulp and seeds, *Cupressus sempervirens*, *Feungreak* leaves, essential oils of *Alpinia Galanga*, *Chrysophyllum Albidum* leaves, *poupartibirrea* back, *Acacia Tortilis*, *Arabinogalactan*, *keto sulphone drug*, *Artemisia Mesatlantica* essential oil, *spirogyraalgae*, *Tragacanth gum*, *Prunus Persic*, *Lemon Gross*, *Secang heartwood extract* (*Caesalpinia sappan I*), *Dried marjoram leaves*, *Lagenaria Siceraria Peel* [11-45] have also been used for inhibition of corrosion. In the present study, *Tephrosia purpurea* plant

extracts was investigated for its corrosion inhibition potential by using weight loss, adsorption studies, potentiodynamic measurement, electrochemical impedance spectroscopy and spectral studies.

## 2. MATERIALS AND METHODS

### (i). TEPHROSIA PURPUREA PLANT IS USED AS CORROSION INHIBITOR.

#### (ii). SPECIMEN PREPARATION

Rectangular specimen of Mild steel was mechanically pressed cut to form different coupons, each of dimension exactly 20cm<sup>2</sup> (5x2x2cm) with emery wheel of 80 and 120 and degreased with trichloroethylene, washed with distilled water, cleaned and dried, then stored in desiccators for our present study.

#### (iii). MASS LOSS METHOD

In the mass loss measurements on Mild steel in triplicate were completely immersed in 50ml of the test solution in the presence and absence of the inhibitor. The metal specimens were withdrawn from the test solutions after 24 to 360 hrs at room temperature and also measured 303K to 333K.

### 2.1 Adsorption studies:

#### 2.1.1. Activation energy:

The activation energy ( $E_a$ ) for the corrosion of metals in the presence and absence of inhibitors in 1.0N Hydrochloric acid, natural sea water environment was calculated using Arrhenius theory. Assumptions of Arrhenius theory is expressed by equation (4).

$$CR = A \exp(-E_a/RT) \quad \text{----- (4)}$$

$$\log(CR_2/CR_1) = E_a/2.303 R (1/T_1 - 1/T_2) \quad \text{----- (5)}$$

Where  $CR_1$  and  $CR_2$  are the corrosion rate at the temperature  $T_1$  (313K) and  $T_2$  (333K) respectively.

#### 2.1.2. Heat of adsorption:

The heat of adsorption on the surface of various metals in the presence of plant extract in 1.0N Hydrochloric acid, Natural sea water environment is calculated by the following equation (6).

$$Q_{ads} = 2.303 R [\log(\theta_2/1 - \theta_2) - \log(\theta_1/1 - \theta_1)] \times (T_2 T_1 / T_2 - T_1) \quad \text{----- (6)}$$

Where  $R$  is the gas constant,  $\theta_1$  and  $\theta_2$  are the degree of surface coverage at temperatures  $T_1$  and  $T_2$  respectively.

#### 2.1.3. Langmuir Adsorption Isotherm:

The Langmuir adsorption isotherm can be expressed by the following Equation-4.10 is given below [38-40].

$$\log C/\theta = \log C - \log K \quad \text{----- (7)}$$

Where  $\theta$  is the degree of surface coverage,  $C$  is the concentration of the inhibitor solution and  $K$  is the equilibrium constant of adsorption of inhibitor on the metal surface.

#### 2.1.4. Frumkin adsorption isotherm:

Frumkin adsorption isotherm is given by equation (8)

$$\log \{ [C] * (\theta/1 - \theta) \} = 2.303 \log K + 2\alpha\theta \quad \text{----- (8)}$$

Where  $k$  is the adsorption-desorption constant and  $\alpha$  is the lateral interaction term describing the interaction in adsorbed layer.

#### 2.1.5. Temkin adsorption isotherm:

For Temkin adsorption isotherm, the degree of surface coverage ( $\theta$ ) is related to inhibitor concentration ( $C$ ) according to equation (9)

$$\exp(-2a\theta) = KC \quad \text{----- (9)}$$

$k \rightarrow$  adsorption of equilibrium constant &  $a$  is the attractive parameter, Rearranging and taking logarithm of both sides of eqn(9) gives eqn (10)

$$\theta = -2.303 \log k / 2a - 2.303 \log c / 2a \quad \text{----- (10)}$$

### (iv). Electrochemical measurements

Electrochemical measurements were carried out using CH Instruments **reference 640** with three electrode system, Mild steel specimen with an exposure area 1cm<sup>2</sup> was used as working electrode, platinum electrode (pt) as the auxiliary electrode while the saturated calomel electrode (SCE) was used as the reference electrode. All the electrochemical studies were carried out at room temperature (27±3°C). The open circuit potential (OCP) was recorded as a function of time up to 30 minutes.

### (v). POLARISATION METHOD

The corrosion rates in the presence [ $I_{corr}(I)$ ] and in the absence [ $I_{corr}$ ] of the inhibitors were determined by Tafel (extrapolation) method. The inhibition efficiency (I.E) was determined by the following relationship.

$$I.E (\%) = \frac{[I_{corr} - I_{corr}(I)]}{I_{corr}} \times 100 \quad \dots\dots (4.4)$$

**(VI). IMPEDANCE MEASUREMENTS**

Inhibition efficiencies were also determined from R<sub>ct</sub> values with and without inhibitors by using the following relationships.

$$I.E (\%) = \frac{[R_{ct \text{ with } (I)} - R_{ct}]}{R_{ct \text{ with } (I)}} \times 100 \quad \dots\dots (4.5)$$

where, R<sub>ct with(I)</sub> = charge transfer resistance with inhibitor

R<sub>ct</sub> = charge transfer resistance without inhibitor

**(vii). EDX ANALYSIS**

By compositions of all elements present on the surface of the specimen, before and after immersion were identified by Energy Dispersive X- ray spectroscopy (EDX) using the Oxford Instrument Model - INCA Penta xFET. The energy of an acceleration beam employed was 20 kV.

**(VII). SCANNING ELECTRON MICROSCOPE (SEM)**

Model: Jeol - JSM 6390, Scanning Electron Microscope was used to study the nature of the corroded surface. The dissolution of metal and the protective film formed by the inhibitor on the metal surface was also studied.

**3.0 Results and Discussion**

**3.1 Effect of time variation**

Anti-Corrosion behavior of mild steel in Natural Sea Water containing the presence and absence of TPP extract with various exposure times (24hrs to 360 hrs) are shown in Table-1. Observed values are clearly indicates that the in presence of TPP extract, the corrosion rate moderately decreased from 0.0929 to 0.0232 mmpy for 24 hrs and 0.0573 to 0.0061 mmpy after 360 hrs respectively with increase of inhibitor concentration (0 to 1000 ppm). The maximum of 89.35 % of inhibition efficiency is achieved even after 360 hrs exposure time, suggests that the adsorption process occurs mainly due to the film formation on the metal surface.

**Table-1: Corrosion parameters of Mild Steel in Natural Sea Water containing different concentration of TPP extract with various exposure time**

Conc. of inhibitors (ppm)	24 hrs		72 hrs		120 hrs		240 hrs		360 hrs	
	C.R (mmpy)	% I.E								
0	0.0929	-	0.0542	-	0.0557	-	0.0813	-	0.0573	-
10	0.0697	24.97	0.0464	14.39	0.0511	8.18	0.0743	8.61	0.0511	10.82
50	0.0697	24.97	0.0387	28.52	0.0325	41.65	0.0674	17.09	0.0495	13.61
100	0.0464	50.05	0.0309	42.98	0.0278	50.08	0.0627	22.87	0.0433	24.43
250	0.0232	75.02	0.0309	42.98	0.0232	58.27	0.0604	25.70	0.0418	27.05
500	0.0232	75.02	0.0232	57.19	0.0232	58.27	0.0488	37.74	0.0418	27.05
1000	0.0232	75.02	0.0232	57.19	0.0139	74.97	0.0441	45.75	0.0061	89.35

**3.2. Effect of Temperature**

Dissolution behavior of Mild steel in Natural Sea Water containing various concentration of TPP extract at temperature ranges from 303to 333K and the observed the values are listed out in Table-2. It reveals that the corrosion rate decreased with increase of inhibitor concentrations and gradually increased with rise in temperature. Maximum of 83.33% inhibition efficiency is achieved upto 313K. Beyond that the value of inhibition efficiency is decreased with rise in Temperature may suggests and support the facts that the process of adsorption follows **Physisorption** with multilayer film formation.

**Table-2: Corrosion parameters of Mild steel in Natural Sea Water containing different concentration of TPP extract at 303 to 333 K after one hour exposure time.**

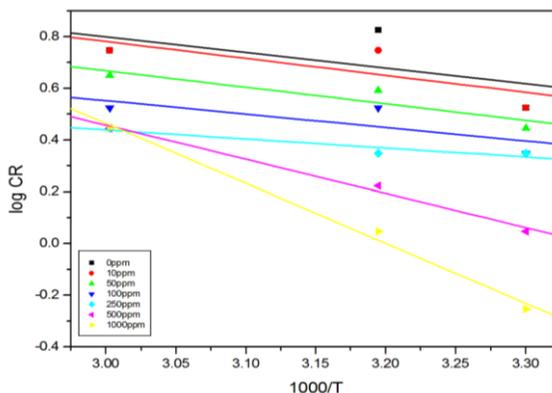
Conc. of inhibitor (ppm)	303 K		313 K		333 K	
	C.R (mppy)	% I.E	C.R (mppy)	% I.E	C.R (mppy)	% I.E
0	3.3477	-	6.6955	-	5.5796	-
10	3.3477	0	5.5796	16.66	5.5796	0
50	2.7898	16.66	3.9057	41.66	4.4636	20
100	2.2318	33.33	3.3477	50.00	3.3477	40
250	2.2318	33.33	2.2318	66.66	3.3477	40
500	1.1159	66.66	1.6738	75.00	2.7898	50
1000	0.5579	83.33	1.1159	83.33	2.7898	50

**3.3 ACTIVATION PARAMETERS ON THE INHIBITION PROCESS:**

Usually, the temperature plays an important role to understanding the inhibitive mechanism of the corrosion process. To assess the temperature effect, experiments were performed at the range of 303K- 333K in uninhibited and inhibited solutions containing different concentrations of TPP and the corrosion rate was evaluated and the values are presented in Table-3. The relationship b/w the corrosion rate (CR) of mild steel in acidic media and temperature (T) is expressed by the Arrhenius equation,

$$\text{Log CR} = -E_a/2.303RT + \log \lambda \text{ -----} \rightarrow (1)$$

Where  $E_a$  is the apparent effective activation energy, R molar gas constant and  $\lambda$  is the Arrhenius pre-exponential factor.



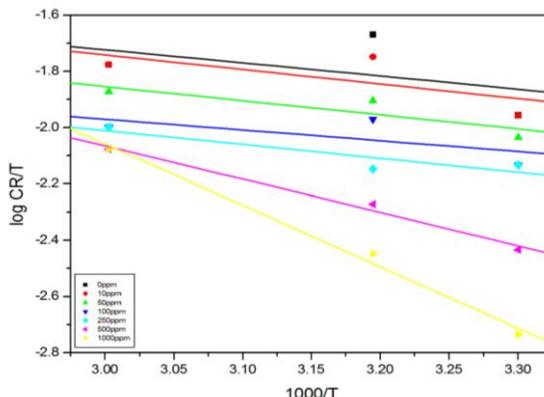
**Fig-1. Arrhenius plot for mild steel corrosion Natural Sea Water in the absence and presence of different concentration of TPP.**

A plot of log (CR) obtained by weight loss measurement versus 1/T gave straight line with regression co-efficient ( $R^2$ ) almost close to unity as shown in fig (1). The values of apparent activation energy ( $E_a$ ) obtained from the slope ( $-E_a/2.303R$ ) of the lines and the pre-exponential factor ( $\lambda$ ) obtained from the intercept ( $\log \lambda$ ) are given in Table -3. It is evident from the fact that the apparent energy of activation increased on addition of (TPP) in comparison to the uninhibited solution. These values ranged from 11.5955 to 44.3677 kJ/mol and are lower than the threshold value of 80kJ/mol required for chemical adsorption. This shows that the adsorption of ethanol extract of TPP on Mild Steel surface is Physisorption process.

**Table:3 Activation parameters of TPP in Natural sea water on mild steel.**

Inhibitor conc. (ppm)	$E_a$ (kJ/mol)	$\Lambda$ (mg/cm)	$\Delta H$ (kJ/mol)	$\Delta S$ (J/mol/k)	$Q_{ads}$ (KJmol <sup>-1</sup> )
Blank	11.5955	413.5233	8.9436	179.2067	--
10	12.5547	560.6605	9.9029	181.7417	-
50	12.2503	387.2576	9.6042	178.6840	6.3747

100	9.9641	129.8972	7.3180	169.6005	8.0489
250	6.6574	30.3179	9.4529	175.2356	8.0489
500	25.2014	25.4859	22.5629	213.5183	-19.3754
1000	44.3677	260.8555	41.7292	271.1532	-45.0012



**Figure-2 Transition state plot for mild steel corrosion in Natural Sea Water in the absence & presence of different concentration of TPP.**

The value of  $\lambda$  is also lower for inhibited solution than uninhibited soln. It is clear from equation (1) that corrosion rate is influenced by both  $E_a$  &  $\lambda$ . Moreover increase in the concentration of (TPP) in leads to an increase in the value of  $E_a$ , and ensure that the strong adsorption of the inhibitor molecules film layer on the metal surface.

Experimental corrosion rate values evaluated from the weight loss data for mild steel in Natural Sea Water in the presence and absence of TPP was used to determine the enthalpy of activation ( $\Delta H$ ) and apparent entropy of activation ( $\Delta S$ ) for the formation of the activation complex in the transition state equation (2). An alternative formula for the Arrhenius equation is the transition state.

$$CR = RT/Nh \exp(\Delta S/R) \exp(-\Delta H/RT) \text{ -----(2)}$$

A plot of  $\log (CR/T)$  versus  $1/T$  is shown in fig (2), a straight lines were obtained with slope  $(-\Delta H/2.303R)$  and the intercept of  $[\log (R/Nh)+(\Delta S/2.303R)]$ , from which  $\Delta H$  and  $\Delta S$  were calculated and listed out in Table -2. Positive value of enthalpy of activation ( $\Delta H$ ) in the presence and absence of various concentration of inhibitor reflects that the endothermic natures of mild steel dissolution process mean that the dissolution of mild steel is very difficult. It is evident that the value of  $\Delta H$  increased in the presence of the inhibitor than the uninhibited solution (Table-3) indicating that the higher protection efficiency. This may be attributed to the presence of energy barrier for the reaction; hence the process of adsorption of inhibitor leads to raise in enthalpy of the corrosion process on comparing with the values of entropy of activation ( $\Delta S$ ) listed in Table-3. It is clear that the entropy of activation increased in the presence of the using inhibitor compared to un-using inhibitor. The increase in the entropy of activation ( $\Delta S$ ) in the presence of inhibitor may disordering on going from reactant to activated complex is difficult.

**3.4 HEAT OF ADSORPTION:**

**THERMODYNAMIC/ ADSORPTION PARAMETERS:**

Heat of adsorption on the surface of various metals in the presence of plant extract in Natural sea water environment is calculated by the following equation (3).

$$Q_{ads} = 2.303 R [\log (\theta_2/1 - \theta_2) - \log (\theta_1 /1 - \theta_1 )] s \times (T_2 T_1 / T_2 - T_1) \text{ -----(3)}$$

The calculated  $Q_{ads}$  values (Table-3) are ranged from 6.3747 to -45.0012 kJ/mol indicating that the adsorption of ethanol extract of TPP on mild steel surface is exothermic.

**3.5 Adsorption studies:**

Process of adsorption are very important phenomenon to determine the corrosion rate of reaction mechanism. The most frequently use of isotherms are viz: Langmuir, Temkin, Frumkin, Flory- Huggins, Freundlich, Bockris-Swinkles, Hill-de Boer, Parson’s and the El-Awady, thermodynamic-kinetic model.

**3.5.1. Frumkin and Temkin Adsorption Isotherm**

The Figs 3(a-b) shows Frumkin and Temkin isotherm model respectively. The values of parameters K,  $R^2$  and slope are derived from these adsorption isotherm at different temperature ranges from 303 to 333K are given in Table -3. Frumkin adsorption isotherm model fit the corrosion rate data of TPP inhibitor

on mild steel strongly and clearly indicates that the average value of Regression co-efficient ( $R^2=0.9892$ ) is almost close to unity. Another adsorption isotherm values ie, Temkin the regression value ( $R^2=0.9686$ ) are move to near unity. we also attempts the others viz. Freundlich ( $R^2=0.9279$ ), Langmuir ( $R^2=0.9277$ ), Florry-Huggins ( $R^2=0.7267$ ), and El- Awady (0.7449) adsorption isotherm models of TPP extract. However observed the values relatively far from unity as compared with the values obtained with Frumkin adsorption isotherm, which is clearly indicates that the weak correlation between the two variables (i.e surface coverage, inhibitor concentration). It is concluded that the inhibitor obeys Frumkin adsorption isotherm.

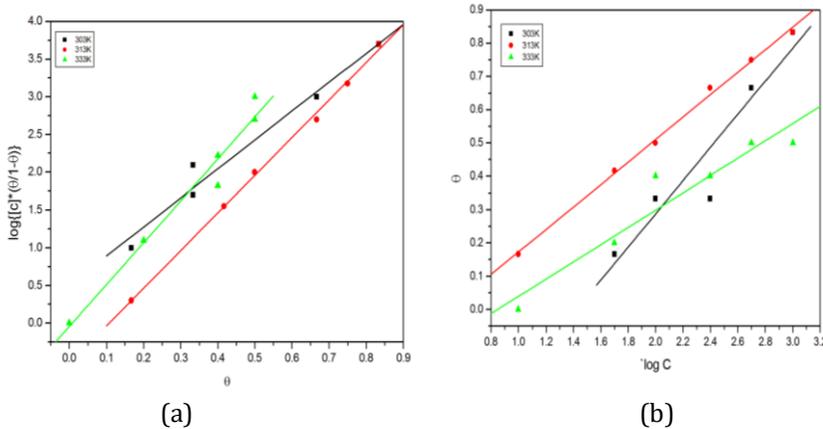


Fig.3 (a) Frumkin, (b) Temkin isotherm for the adsorption of TPP inhibitor on mild steel in Natural Sea Water.

**3.5.2. Free energy of adsorption:**

Equilibrium constant of adsorption for various plant extract on the surface of Mild steel is related to the free energy of adsorption ( $\Delta G_{ads}$ ) by the equation (5).

$$\Delta G_{ads} = -2.303 RT \log (55.5 K) \text{ ----- (5)}$$

(Where R is the gas constant, T is the temperature, K is the equilibrium constant of adsorption).

Values of intercept (K) obtained from Frumkin and Temkin adsorption isotherm is substituted in equation (5) and the calculated values of  $\Delta G_{ads}$  are placed in Table-4. In Frumkin adsorption isotherm, the adsorption parameter ' $\alpha$ ' are positive suggesting that the attractive behavior of the inhibitor on the metal surface. In Frumkin adsorption, the negative values of  $\Delta G_{ads}$  suggested that the adsorption of TPP extract onto Mild steel surface is a spontaneous process and the adsorbed layer is more stable one.

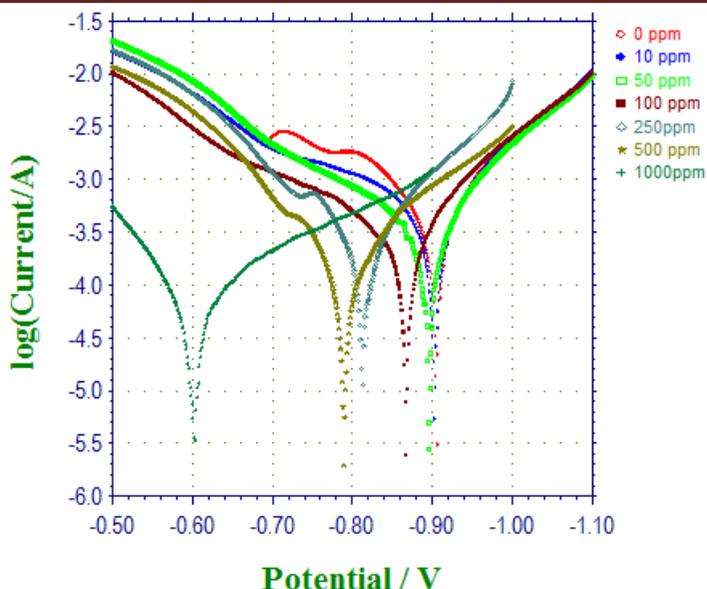
**Table- 4 Frumkin and Temkin adsorption parameters for the adsorption of TPP inhibitor on mild steel in Natural sea water.**

Temperature	Adsorption Isotherm							
	Frumkin				Temkin			
	K	R <sup>2</sup>	Slope( $\alpha$ )	$\Delta G$	K	R <sup>2</sup>	Slope(a)	$\Delta G$
<b>303K</b>	1.6648	0.9855	1.9169	-11.4039	0.0007	0.9497	-2.3141	2.3464
<b>313K</b>	0.5868	0.9988	2.4940	-9.0661	0.0024	0.9984	-3.4108	5.2081
<b>333K</b>	0.9574	0.9834	2.7757	-11.0010	0.0042	0.9577	-4.4373	4.0049

**3.6. ELECTROCHEMICAL STUDIES**

**3.6.1. Polarisation studies**

Fig.4 shows that the potentiodynamic polarisation behaviour of mild steel in Natural Sea Water containing different concentration of TPP inhibitor and the observed data were placed in Table- 5. It is clear that the corrosion current density ( $I_{corr}$ ) decreased from **67.34** to **8.05** mA/cm<sup>2</sup> with increase of inhibitor concentration (from 0 to 1000ppm) and the corrosion potential ( $E_{corr}$ ) was shifted to noble positive direction (from **-907** to **-603**mV). It clearly revealed that the TPP extract inhibit the corrosion of mild steel in Natural Sea Water which predominantly control cathodic protection and thus inhibitor behaved as cathodic type. Inhibition efficiency calculated from the extrapolation of the anodic ( $b_a$ ) and cathodic ( $b_c$ ) Tafel slopes were in good agreement with those observed from the previous datas.



**Fig. 4. Polarisation curves for mild steel in Natural Sea Water containing various concentration of TPP inhibitor.**

**3.6.2. Electrochemical impedance (EIS) studies**

Fig.5 (a-b) shows that typical set of complex planes plot of mild steel in Natural Sea Water in the absence and presence of various concentration of TPA inhibitor at room temperature. It was obvious that the addition of inhibitor results in an increase of the diameter of the semicircle capacitive loop (Fig.5(a)), the maximum phase angle (Fig.5(b)). Careful inspection of this data revealed that the value of charge transfer resistance ( $R_{ct}$ ) increased from 2.509 to 73.33  $\Omega$  cm<sup>2</sup> of mild steel in Natural Sea Water with increase of inhibitor concentrations. The inhibition efficiency increased from 24.69 to 96.57% with increase of inhibitor concentration. It ensures that the formation of protective film on the metal surface. Double layer capacitance ( $C_{dl}$ ) decreased as the increase of inhibitor concentration may be due to the adsorption of the active compounds on the metal surface to a film formation. It can be noticed that a perfect semi-circle clearly indicates that the charge transfer process may controlling the dissolution of the specimen. This data was also fitted with the values obtained from the previous data as described earlier.

**Table- 5 Parameters derived from electrochemical measurements of mild steel in Natural Sea Water containing various concentration of TPP inhibitor.**

Conc. (ppm)	Polarisation studies					Impedance studies		
	$-E_{corr}$ V/dec	$b_a$ (mV/decade)	$b_c$ (mV/decade)	$I_{corr}$ mA cm <sup>-2</sup>	I.E (%)	$R_{ct}$ ( $\Omega$ cm <sup>2</sup> )	$C_{dl} \times 10^{-4}$ Fcm <sup>2</sup>	I.E (%)
Blank	907	233.26	141.14	67.34	---	2.509	0.0249	---
10	904	307.78	134.66	59.65	11.41	3.332	0.0163	24.69
50	895	250.31	131.56	45.78	32.01	3.347	0.0163	25.03
100	868	221.48	136.10	35.48	47.31	3.514	0.0141	28.59
250	812	202.42	140.27	43.25	35.77	4.676	0.0094	46.34
500	789	109.24	158.95	17.85	73.49	7.308	0.0053	65.66
1000	603	109.12	220.99	8.05	88.04	73.33	0.00006	96.57

In phase plots (Fig.5(b)) the phase angle at higher frequencies attributed to anticorrosion performance. The depression of phase angle at relaxation frequency with the decrease in the inhibitor concentration indicates that the decrease of capacitive response with the decrease of inhibitor concentration. Such phenomenon reflected that the higher corrosion activity at low concentration of the inhibitor.

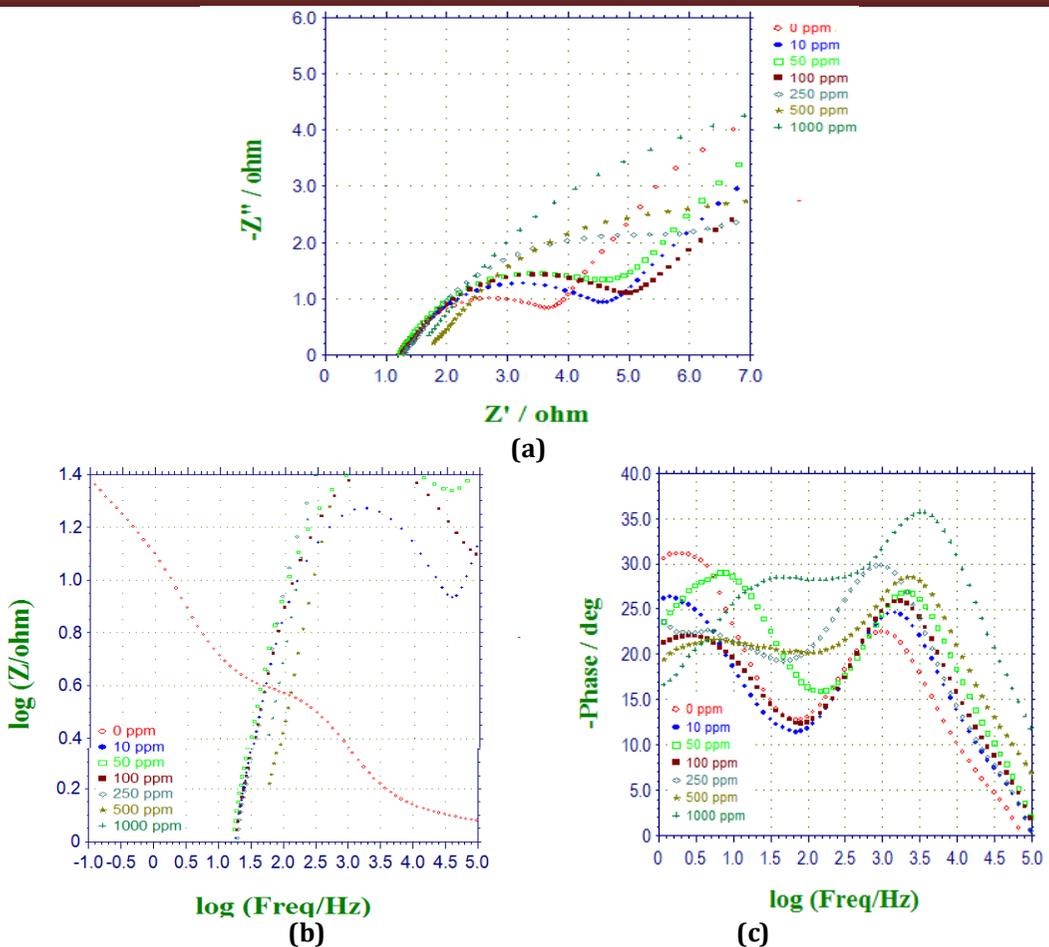


Fig.5 (a-c). Electrochemical impedance plots, (a) Nyquist, (b) Bode plot, (c) phase angle plot for mild steel in Natural Sea Water containing various concentration of TPP inhibitor.

3.7. Spectral studies:

3.7.1. EDX Spectrum:

EDX spectroscopy was used to determine the elements present on the Mild Steel surface in the presence and absence of inhibitor. Figs. 6 and 7 represents that the EDX spectra of the corrosion products on metal surface in the presence and absence of optimum concentrations of TPP extract in Natural Sea Water. In the absence of inhibitor molecules, the spectrum may concluded that the existence of its alloys present in the metal. However, in the presence of the concentrations of the inhibitors, the hetero oxygen atom is found to be present in the corrosion product on the metal surface. It clearly indicates that this hetero atoms present in the inhibitor molecules may involve the complex formation with the metal ion during the adsorption process and prevent the further dissolution of metal against corrosion.

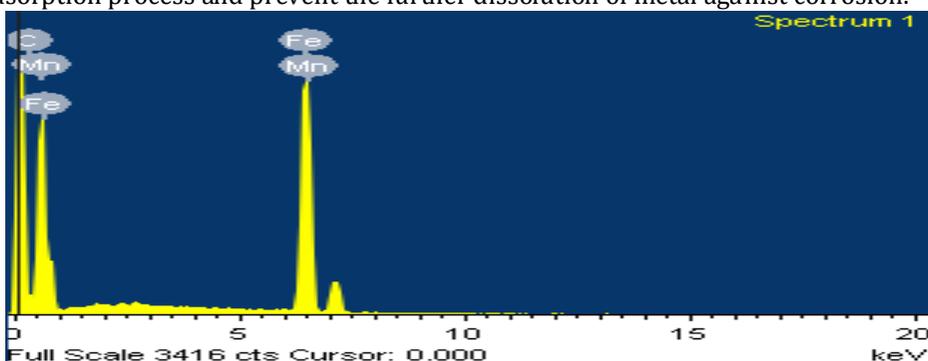
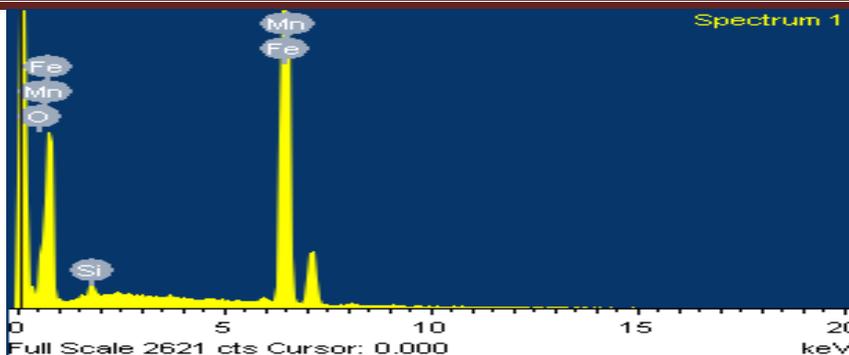


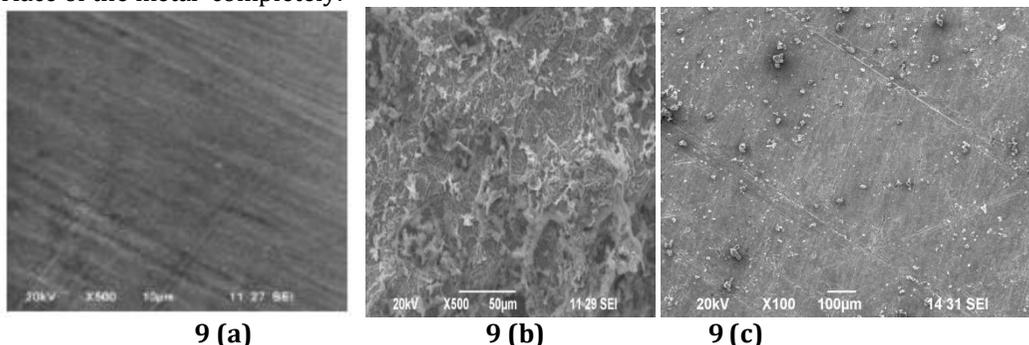
Fig 6: EDX spectrum of the corrosion product on Mild Steel surface in Natural Sea Water



**Fig 7: EDX spectrum of the corrosion product on Mild Steel in the presence of TPP extract in Natural Sea Water**

### 7. SEM Analysis

Damage of Surface morphology of the mild steel surface was studied by scanning electron microscopy (SEM). Figures 8(a-c) shows that the SEM micrographs of mild steel surface before and after immersion in Natural Sea Water respectively. SEM photographs (fig-8b) showed that the surface of metal has number of pits and cracks are visible in the surface may be belong to the plug type of corrosion. But in presence of inhibitor fig(8-c) the dissolution process significantly reduced by the formation of thin film covered on the entire surface of the metal completely.



**Figures 8 (a) to (c) SEM image of the Polished Mild Steel surface, SEM image of immersed in natural sea water and SEM image of immersed in Natural Sea Water with TPP extract respectively.**

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