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# Inhibitive effect of fruit extract from *Terminalia chebula* on the corrosive of mild steel in 0.5M hydrochloric acid medium

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## Abstract

Corrosion inhibition effect of *Terminalia chebula fruit extract* on mild steel in 0.5M HCl medium has been investigated by weight loss and electrochemical techniques. Inhibition efficiency of 91.15 % was achieved with 700 ppm Terminalia chebula fruit extract. The polarization studies showed that inhibitor acts as predominantly cathodic inhibitor. The Nyquist plots showed that on increasing inhibitor concentration, increases charge transfer resistance and decreases double layer capacitance. The adsorption of the extract molecules on the steel surface obeys Langmuir adsorption isotherm and occurs spontaneously. The activation energy as well as other thermodynamic parameters for the inhibition process was calculated. These thermodynamic parameters show strong interaction between inhibitor and mild steel surface. Scanning electron microscope and FTIR studies provided the confirmatory evidence of an improved surface condition, due to the adsorption, for the corrosion protection.

Keywords
Terminalia chebula Fruit, Polarisation , Impedance, FTIR

## Introduction

Mild steel is the most widely used material particularly in industry. Corrosion problem occurs in these industries and can cause disastrous damage to metal and alloy structures causing economic consequences. Use of inhibitors is one of the most practical methods for protection against corrosion especially in acid solutions to prevent unexpected metal dissolution and acid consumption [1]. Most of the efficient inhibitors used in industries are organic compounds having multiple bonds in their molecules which contain N and S atoms [2–3]. Plant extracts have become important as an environmentally acceptable, readily available and renewable source for a wide range of corrosion inhibitors.

. Terminalia chebula is a member of the combretaceae family and its fruit were shown to have anti-cancer, antimicrobial, anti-inflammatory, antimutagenic, antifungal, antiviral, antidiabetic and antianaphylactic activities [4–6]. However, not much has been reported on the use of the extract of Terminalia chebula fruit as inhibitor against corrosion Therefore, the present work is aimed at investigating the potential of methanol extract of Terminalia chebula fruit as corrosion inhibitor of mild steel in hydrochloric acid medium.

**Materials and methods**

Preparation of the mild steel specimens

The mild steel coupons with a chemical composition of (0.026% S,0.03 % Si, 0.06% P,0.016 % Cu, 0.018 % Ni, 0.029 % Cr, 0.4% Mn and 0.1% C and rest Fe) was utilized for the present study. The mild steel samples, with an active surface 0f 1.0× 4.0× 0.2 cm were used for Mass loss measurements and 1cm × 1cm specimen for electrochemical measurements. The mild steel samples were mechanically polished, washed in double distilled water and degreased with acetone and used for the weight-loss method and surface examination studies.

Preparation of fruit Extract

Fresh samples of *Terminalia Chebula* Fruit were collected from salem. The fruit were authenticated by Department of Botany, Holy Cross College (Autonomous), Tiruchirappalli. The fruits were washed thoroughly 2–3 times with running tap water and the leaves are air dried under shade. After complete shade drying, the fruit were grinded in the mixer, the powder was kept in small plastic bags with proper labeling. About 50 g of the powder was soaked in a 250 ml of methanol under cold percolation method. At regular intervals of time the extract was filtered and distillation was carried out to collect the crude extract. The extract was stored in an amper bottle and refrigerated .

Weight Loss Measurements

Weight loss measurements were carried out using Shimadzu ATP-224 model Electronic top loading balance, with readability/sensitivity of 0.1 mg in 210 g range. The specimens were immersed in beaker containing 100 ml acid solution without and with different concentrations of T. *Chebula* Fruit extract using hooks. At the end of exposure period, specimens were cleaned according to ASTM G-81 and the weight recorded. The specimens were removed and then washed with de-ionized water, dried and reweighed

The parameters used for the present study are given below:

1. Time (h): 1, 3, 7, 9, 24.
2. Concentration of the T.chebula : 100 to 900 ppm
3. Temperatures: (303 K, 313 K, 323 K, 333 K) ± 2 K

Electrochemical Impedance Spectroscopy

Electrochemical measurements were run using a potentiostate/galvanostat (Electrochemical System Model Vertex.100mA.D) and a personal computer was used. IVIUM software was used

Firstly, the EIS measurements were carried out using AC signals of amplitude 10 mV peak-to-peaks at the open circuit potential in the frequency range of 10 MHz to 1Hz. The charge transfer Resistance ($R_{ct}$) values have been calculated from the difference in the impedance at low and high frequencies. The capacitances of the double layer ($C_{dl}$) values are estimated from the frequency (f) at which the imaginary component of the impedance (–Z") is maximum and the double layer capacitance ($C_{dl}$) was calculated by using following equation [7]:

Obtained from the equation:

$C_{dl} = 1/2 \times 3.14 \times R_{ct} \times f_{max}$

Potentiodynamic Polarization

After impedance spectrum was obtained, the potentiodynamic current potential curves was recorded immediately by changing the electrode potential automatically taken from OCP value with scan rate of 5 mV $s^{-1}$. Tafel lines extrapolation method was used for detecting $I_{corr}$ and $E_{corr}$ values for the studied systems. Because of the presence of a degree of nonlinearity in the part of the obtained polarization curves, the corresponding anodic and cathodic Tafel slopes ($b_a$ and $b_c$) were calculated as a slope of the points after corrosion potential (i) by ±50 mV using a computer least square analysis [8]. All the electrochemical measurements were performed in stagnant, aerated solutions adjusted at 30°C.

$I_{corr} = b_a \times b_c / 2.303(b_a + b_c)R_p$

where, Rp is polarization resistance.

Linear Polarization Measurement

The linear polarization behavior of mild steel in 0.5M HCl in absence and presence of different concentration of inhibitor was studied at ±20 mV versus OCP at a scan rate of 0.125 mV $s^{-1}$ t. The polarization resistance ($R_p$) was calculated from the slope of curve in vicinity of corrosion potential.

Surface Analysis by FTIR Spectroscopic Study

After the immersion period of 3 h in the best system, the specimens were taken out of the test solutions and dried. The film formed on the surface was scratched carefully and it was thoroughly mixed so as to make it uniform throughout. FTIR spectrum of the powder (KBr) pellet was recorded using Perkin-Elmer 1600 FTIR spectrophotometer with a resolving power of 4 $cm^{-1}$.

Scanning Electron Microscopy

The mild steel specimens immersed in presence and absence of inhibitor for 3 hours were taken out, rinsed with double distilled water, dried and subjected to the surface examination. The surface morphology measurements of the carbon steel surface were carried out by SEM using "F E I Quanta FEG 200 - High Resolution Scanning Electron Microscope, SRM University, Kattankulathur."

## Results and Discussion

### Preliminary phytochemical screening

The results of the screening of methanol extract of the fruit of *Terminalia chebula* for the phytochemical constituents

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are shown in Table 1. The results obtained shows the presence of tannins, flavonoids, steroids, saponin, protein, carbohydrates, poly phenols, glycosides, terpenoids and triterpenoids. These active constituents are responsible for the inhibition efficiency of the extract.The qualitative phytochemical screening of T.C fruit was done and the results are shown in Table 1.

**Table 1 Qualitative phytochemical screening of Terminalia chebula fruit**

| Name of the phytochemicals | Presence/absence |
|---|---|
| Alkaloid | - |
| Saponin | + |
| Tannin | + |
| Flavonoids | + |
| Protein | + |
| Steroids | + |
| Carbohydrates | + |
| Poly phenol | + |
| Glycoside | + |
| Phlobatannins | - |
| Anthroquinone | - |
| Terpenoids | + |
| Triterpenoids | + |

(+) = presence; (–) = absence

### Mass Loss Measurements

### Effect of Concentration

The mass loss method of monitoring corrosion rate is useful because of its simple application and reliability [9]. Inhibition efficiencies of mild steel with different concentrations of *T.C fruit* extract is 0.5M HCl at room temperature are presented in Table 2. From the table, corrosion rate decreases noticeably with an increase in inhibitor concentration, i.e. the corrosion inhibition enhances with the inhibitor concentration. This behaviour is due to the fact that the adsorption and coverage of the inhibitor on the mild steel surface increase with the inhibitor concentration [10]. Maximum inhibition efficiency of *T.C fruit* at 700 ppm concentration was found to be 91.50% in 0.5M HCl at 3h immersion. The high inhibitive performance of T.C fruit suggests a higher bonding ability of inhibitor on to mild steel surface and decrease in the corrosion rate are shown in the (Fig.4).

**Table 2 Corrosion rates of carbon steel in 0.5M HCl in the presence and absence of the inhibitor and the inhibition efficiencies obtained by the mass-loss method**

| S.NO. | T.Chebula Concentration (ppm) | Corrosion rate (mpy) | Surface coverage (θ) | Percentage inhibition |
|---|---|---|---|---|
| 1 | Blank | - | - | - |
| 2 | 100 | 7.0063 | 0.5096 | 50.96 |
| 3 | 200 | 6.2542 | 0.5623 | 56.23 |
| 4 | 300 | 4.3146 | 0.6912 | 69.12 |
| 5 | 400 | 4.0771 | 0.7082 | 70.82 |
| 6 | 500 | 3.1271 | 0.7762 | 77.62 |
| 7 | 600 | 2.0979 | 0.8498 | 84.98 |
| 8 | 700 | 1.1875 | 0.9150 | 91.50 |
| 9 | 800 | 1.3458 | 0.9073 | 90.73 |

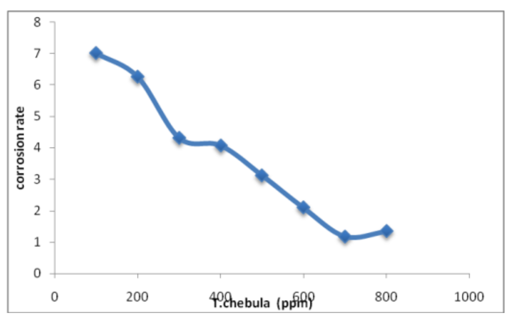


**Fig. 4 Corrosion rate of T.C fruit at different concentration.**

### Effect of immersion time

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**Table: 3 Corrosion rates of carbon steel in 0.5M HCl in the presence and absence of the inhibitor system and the inhibition efficiencies obtained by the mass-loss method**

| S.NO. | Immersion period(h) | T.chebula Concentration (ppm) | Percentage inhibition Efficiency | Corrosion rate (mpy) |
|---|---|---|---|---|
| 1 | 1 | 700 | 78.94 | 0.9500 |
| 2 | 3 | 700 | 91.50 | 1.1875 |
| 3 | 5 | 700 | 78.37 | 1.5700 |
| 4 | 7 | 700 | 77.62 | 2.4259 |
| 5 | 24 | 700 | 70.97 | 6.7638 |

Table 3 gives the values of corrosion rate and percentage inhibition efficiency obtained in 0.5M HCl in absence and presence of T.C fruit extract at 303 K for immersion period from 1 to 24h. The inhibition efficiency increases with increase in concentration of the inhibitor irrespective of the time of immersion. Maximum IE of 91.50% was observed for 700 ppm concentration at 3h of immersion period. Immersion studies reveal that as the time of immersion increased from 1to 3h the inhibition efficiency also increased from 78.94 to 91.50%. After 3h there is a slight decline in the inhibition efficiency at 5h yielding 78.37 and 70.97% for 24h. This may be explained due to increase of adsorbed of inhibitor molecules on MS surface with time. Prolonged immersion may result in desorption of the extract from mild steel surface [11]. It is clear that fruit extract of T.C fruit acts as a good corrosion inhibitor for mild steel in 0.5M HCl solution (Fig.5).

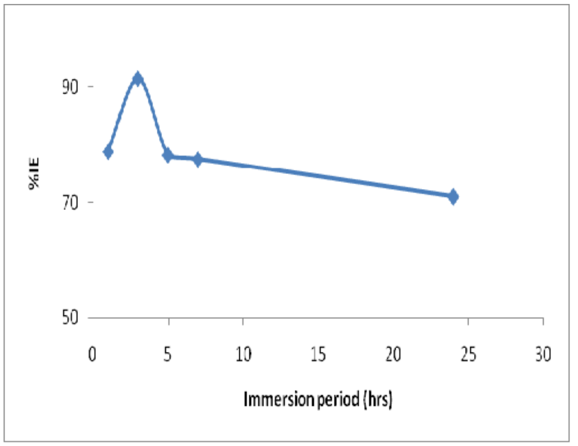


**Fig. 5 Inhibition efficiency of T.C fruit at different time periods**

### Effect of Temperature

To show the effect of temperature on inhibition efficiency of T.C fruit, weight loss experiment was performed in the temperature range of 305-335 K at optimum concentration of *T.Chebula* fruit. The variation of inhibition efficiency with temperature at optimum concentration of *T.Chebula* fruit is shown in Fig. 6. From Fig.6, it is clear that corrosion rate is temperature dependent and increases with increasing the temperature. This decrease in inhibition is due to desorption of inhibitors from metal surface [12]. Thus, at higher temperature more desorption of inhibitor molecules takes place and larger surface area of metal come in contact with acid, resulting in an increase in corrosion rate [13]. The values of percentage inhibition efficiency (η%), corrosion rate (CR), Surface coverage (θ) and corresponding efficiency obtained from weight loss method at different temperatures are summarized in Table 3.

**Table 4: Effect of temperature on the CR of carbon steel in 0.5M HCl by *T.Chebula* fruit extract (TCFE) at different temperatures**

| S. No. | Temperature (K) | Corrosion rate (Blank) | Corrosion rate (T.chebula ) | Surface coverage (θ) | % IE |
|---|---|---|---|---|---|
| 1 | 303 | 12.0730 | 1.9396 | 0.9150 | 91.50 |
| 2 | 313 | 16.3085 | 6.2938 | 0.6140 | 61.40 |
| 3 | 323 | 31.7857 | 18.9606 | 0.4034 | 40.34 |
| 4 | 333 | 77.5841 | 57.5152 | 0.2586 | 25.86 |

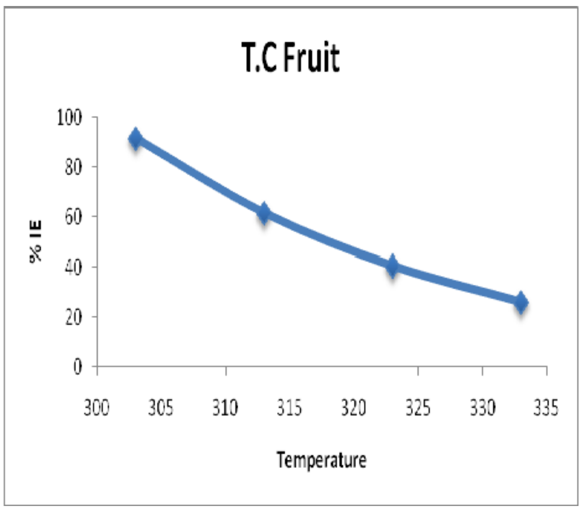


**Fig.6: Inhibition efficiency of T.C Fruit at different temperature**

**Kinetic and Thermodynamic Parameter**

The corrosion rate (CR) depends upon temperature and this temperature dependence corrosion rate of a chemical reaction can be expressed by following Arrhenius and transition state equation [14].

$$\text{Log}\,(C_R) = -\frac{-Ea}{2.303RT} + \log \lambda$$

$$C_R = \frac{RT}{Nh} \exp\left(\frac{\Delta S*}{R}\right) \exp\left(-\frac{\Delta H*}{RT}\right)$$

where Ea is activation energy for the corrosion of Mild Steel in 0.5M HCl, λ pre-exponential factor, R is the gas constant, A the Arrhenius pre-exponential factor and T is the absolute, h is Plank's constant, N is Avogadro's number, ΔS* is the entropy of activation and ΔH* is the enthalpy of activation temperature.

**Table 5: Effect of temperature on the CR of carbon steel in 0.5M HCl by *T.C* fruit extract (TCFE) at different temperatures**

| S.No | $1/T \times 10^{-3}$ | Log CR (Blank) | Log CR (Inhibitor) | % IE |
|---|---|---|---|---|
| 1 | 3.3 | 1.0817 | 0.2855 | 91.50 |
| 2 | 3.19 | 1.0916 | 0.7986 | 61.40 |
| 3 | 3.09 | 1.5022 | 1.2778 | 40.34 |
| 4 | 3.0 | 1.8897 | 1.7597 | 25.86 |

The Arrhenius plot for mild steel immersed in 0.5M HCl in inhibitor-free and with inhibitor solution is depicted in Fig. 7. The plot obtained was straight lines and apparent activation energies ($E_a$) at optimum concentration of inhibitors were determined by linear regression between log CR versus 1/T and listed in Table 4. All the linear regression coefficients are close to unity. Inspection of Table 4 reveals that $E_a$ values are higher in presence of *T.C* Fruit than in absence of *T.C* Fruit. The addition of inhibitor modified the values of $E_a$; this modification may be attributed to the change in the mechanism of the corrosion process in the presence of adsorbed inhibitor molecules [15]. A decrease in inhibition efficiency with rise in temperature with analogous increase in corrosion activation energy in the presence of inhibitor compared to its absence is frequently interpreted as being suggestive of formation of an adsorption film of a physical nature [16, 17].

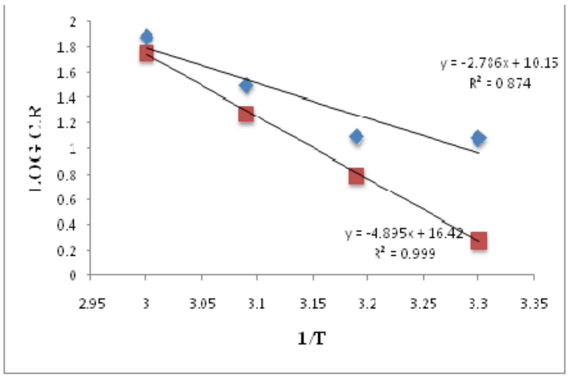


**Fig.7 Arrhenius plots of log CR versus 1/T**

Figure 8 represents the plot between log CR/T versus 1/T which give a straight lines from their gradient ((ΔH* = –slope/2.303R) and intercept (log(R/Nh) + (ΔS*/2.303R)]) of which values of the ΔH* and ΔS* were calculated and given in Table 5. Study of Table 5 reveals that the value of ΔH* for dissolution of mild steel in 0.5M HCl in presence of *T*.C Fruit is higher (107.15 kJ $mol^{-1}$) than that in absence of *T.C* Fruit (46.21kJ $mol^{-1}$). The positive sign and higher value of ΔH* reflected the endothermic nature of mild steel dissolution process, which mean that dissolution of mild steel is in presence of *T.C* Fruit is difficult [18]. The shift towards positive value of entropies (ΔS*) shows that the activated complex in the rate determining step represents dissociation rather than association, meaning that disordering increases on going from reactants to the activated complex [19]. This result permits to verify the known thermodynamic relation between Ea and ΔH°a as shown [20]:

$$E^a - \triangle H^* = RT \quad (4)$$

The change of ΔH* and ΔS* with concentration of the inhibitor suggests that the process is enthalpic and entropic controlled [21].

**Table 6 Thermodynamic parameters for mild steel in 0.5M HCl in absence and presence of optimum concentration of *T.C* fruit**

| | $E_a$ (kJ $mol^{-1}$) | $\triangle H^*$ (kJ $mol^{-1}$) | $\triangle S^*$(kJ $mol^{-1}$) | $\triangle G$ (kJ $mol^{-1}$) |
|---|---|---|---|---|
| Blank | 14.002 | 46.21 | -58.9674 | – |
| Inhibitor | 32.46 | 107.15 | -8.9857 | –10.247 |

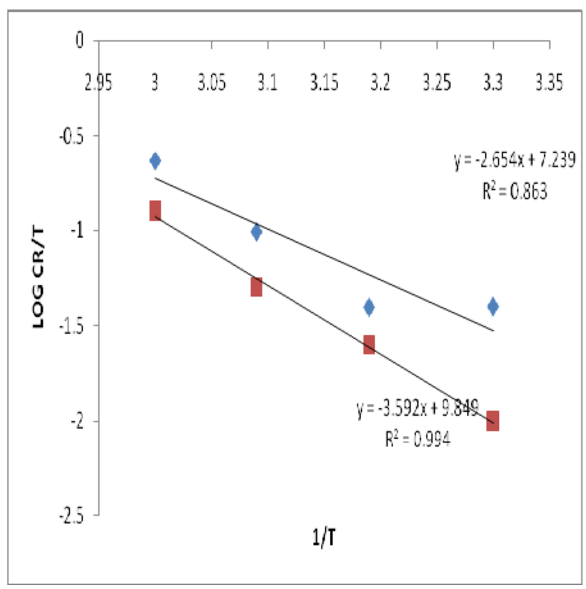


**Fig. 8 Transition state plots log CR/T versus 1/T**

## Adsorption Isotherm

Different adsorption isotherms were tested in order to obtain more information about the interaction between the *T.C* fruit and the mild steel surface. Langmuir adsorption isotherm was found to be best fit which assumes that the solid surface contains a fixed number of adsorption sites and each site holds one adsorbed species [22]. Langmuir isotherm gives a straight line between C/θ and C as shown below in Fig. 6.

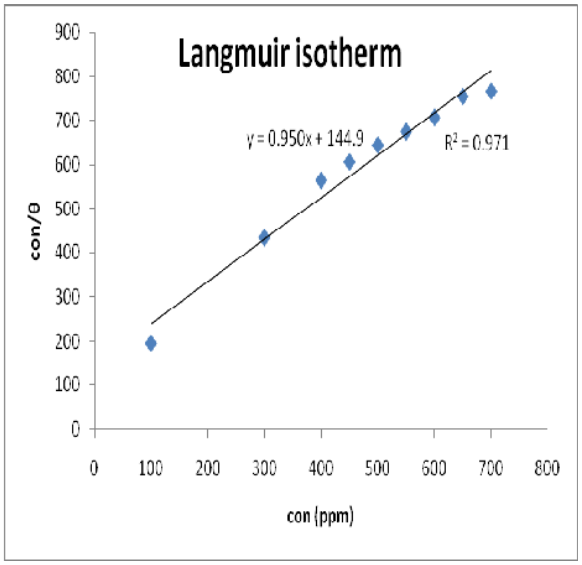


**Fig. 9: Langmuir adsorption isotherm plots for carbon steel in 0.5 M HCl with different concentrations of T.C fruit extract**

The standard free energy of adsorption, ΔG°ads and the values of equilibrium constant, $K_{ads}$ at different temperatures is calculated from the equation [23].

$$\frac{C\ (inh)}{\theta} = \frac{1}{Kads} + C_{(inh)} \qquad (6)$$

$$\triangle G^{o}_{ads} = -RT \ln (55.5K_{ads}) \qquad (7)$$

The negative values of free energy of adsorption ensure the spontaneity of the adsorption process and stability of the adsorbed layer on the metal surface [24]. Generally the values of △G up to –20 kJ $mol^{-1}$ are consistent with electrostatic interaction between charged molecules and a charged metal and the process indicates physical adsorption, while those more negative than –40 kJ $mol^{-1}$ involves charge sharing or transfer from the inhibitor molecules to the metal surface to from a co-ordinate type of bond that indicates chemical adsorption [25]. In the present study, the values of △G vary from –10.274 in 0.5M HCl which indicate that *T.C* fruit functions by physically adsorbing onto the surface of the metal. Physisorption is a result of electrostatic attraction between charged metal surface and charged species in the bulk of the solution. Adsorption of negatively charged species is facilitated if the metal surface is positively charged. Positively charged species can also protect the positively charged metal surface acting with a negatively charged intermediate, such as acid anions adsorbed on the metal surface [26]. It also shows the strong interaction between inhibitor and mild steel.

**Electrochemical Impedance Spectroscopy**

In general, as impedance diagrams for solutions examined have almost a semicircular appearance, it indicates that the corrosion of mild steel is mainly controlled by a charge transfer process. The impedance data such as $R_S$, $R_p$ and $C_{dl}$ were estimated by assuming Randles circuit. The values of charge transfer resistance ($R_t$) and double layer capacitance ($C_{dl}$) were evaluated from Nyquist and Bode plots as described elsewhere [27]. The values of $R_t$, $C_{dl}$ and

%IE derived from these investigations are given in Table 7. The existence of single semicircle showed that single charge transfer process occurred during dissolution of mild steel which is unaffected by the presence of extract. It was found that addition of extract increases the values of $R_t$ and reduces the $C_{dl}$ values. The decrease in $C_{dl}$ value is attributed to increase in thickness of electronic double layer [28]. The increase in $R_t$ value is attributed to the formation of protective film on the metal-solution interface [29].

The impedance behavior of mild steel in 0.5M HCl in absence and presence of different concentration of *T.C* fruit is shown as Nyquist plot in Fig. 7a & 7b and EIS parameter such as $R_s$, $R_{ct}$ ,and $C_{dl}$ were derived from the Nyquist plot are given in Table 6. Equivalent circuit was used analyze the impedance data. The $\omega_{max}$ represents the frequency at which the imaginary component reaches a maximum. It is the frequency at which the real part ($Z_r$) is midway between the low and high frequency x-axis intercepts It is clear from the result that value of $R_{ct}$ increases from 111.7 Ω $cm^2$ (Blank) to 361.3Ω $cm^2$ on addition of 700 ppm of inhibitor. The value of $C_{dl}$ decreases from $1.455 \times 10^{-4}$ F $cm^{-2}$ (Blank) to $2.805 \times 10^{-5}$ F $cm^{-2}$). The decrease in capacitance ($C_{dl}$) on addition of inhibitor may be due to increase in local dielectric constant and/or may be due to increase in the thickness of the double layer, showing that *T.C* fruit inhibited Iron metal corrosion in by adsorbing at metal/acid interfaces [30].

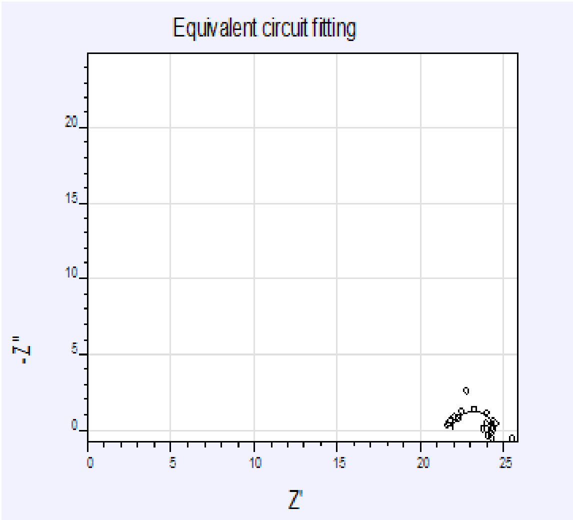


**Fig. 10a Nyquist plot in absence of optimum concentrations of *T.C* fruit**

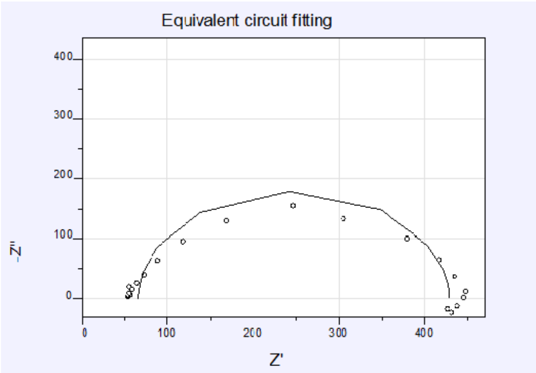


**Fig. 10b Nyquist plot in presence of optimum concentrations of *T.C* fruit**

**Table 7 The electrochemical impedance parameters of *T.C* fruit in 0.5M HCl at700 ppm concentration**

| **System** | **$R_s$ (Ω)** | **$R_{ct}$ (Ω $cm^2$)** | **$C_{dl}$ (F $cm^{-2}$)** |
|---|---|---|---|
| Blank | 23 | 111.7 | $1.455 \times 10^{-4}$ |
| Inhibitor | 66.35 | 361.3 | $2.805 \times 10^{-5}$ |

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**Linear Polarization Measurement**

The inhibition behavior of *T.C* fruit in 0.5M HCl in presence and absence of different concentration of inhibitor were also calculated linear polarization parameters given in Table 7. The efficiency found by linear polarization shows good agreement to efficiency obtained from Tafel and EIS that data.

**Potentiodynamic Polarization Measurements**

The potentiodynamic polarization behavior of mild steel in 0.5M HCl in absence and in presence of *T.C* fruit is shown as Tafel plot in Fig. 8a & 8b. The various electrochemical potentiodynamic parameters such as corrosion potential ($E_{corr}$), corrosion current density ($I_{corr}$), anodic and cathodic slope (βa and βc) were calculated from Tafel plots are given in Table 8. It is seen that addition *T.C* fruit decreases the corrosion current ($I_{corr}$) density from 369 (Blank) to 81.33 μA $cm^{-2}$ thereby giving the efficiency of 63.95% at the 700 ppm concentration. The addition of inhibitor $E_{corr}$ shift from –416.4 to –443 mV SCE did not cause significant shift of $E_{corr}$. This suggests that the reaction is predominantly cathodic controlled. The cathodic slope was practically unaffected by the addition of the *T.C* fruit which indicates that hydrogen evolution reaction is diminished exclusively by the surface blocking effect of adsorbed inhibitor [31]. Regarding the anodic region of the potentiodynamic polarization curves, there is clearly an active–passive behavior either in presence or in absence of the inhibitor. The maximum shift was 27 mV towards noble direction thus investigated compound behaves a cathodic type of inhibitor. Table 7 shows that inhibition efficiency increases with increasing the concentration of inhibitor.

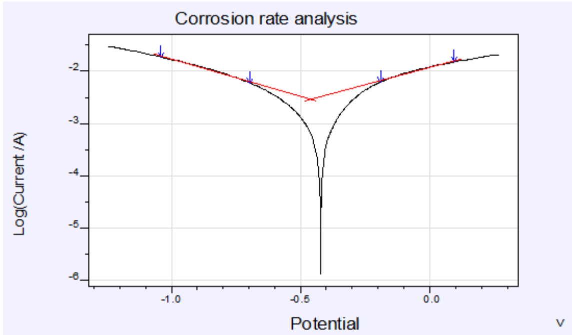



**Fig. 11a Tafel polarization curves for corrosion of mild steel in 0.5M HCl in the absence of *T.C* fruit**

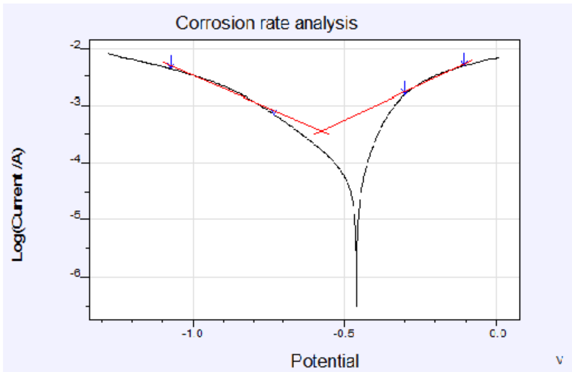



**Fig. 11b Tafel polarization curves for corrosion of mild steel in 0.5M HCl in the presence of *T.C* fruit**

**Table 8 The potentiodynamic polarization and linear polarization parameters of *T.C* fruit**

| System | $E_{corr}$ (mV/SCE) | $I_{corr}$ (μA $cm^{-2}$) | $β_a$ (mV/dec) | $β_c$ (mV/dec) | $R_p$ |
|---|---|---|---|---|---|
| Blank | -461 | 2916 | 759 | 702 | 61 |
| Inhibitor | -574 | 367.3 | 403 | 442 | 551 |

**Analysis of FTIR spectra**

FTIR gives a useful information about the protective film formed on the metal surface. The FTIR spectrum of T.chebula fruit extract shown in the figure 12a shows the presence of active phyto constituents present in the extract. The FTIR spectrum of the thin layer formed on the metal immersed in 0.5 M HCl with 700 ppmof T.chebula fruit extract shown in the figure 12b. From the spectrum it is clear that shift in the bands and appearance of new bands indicates the active constituents present in the extract form complex with the metal as shown in the table: 9.

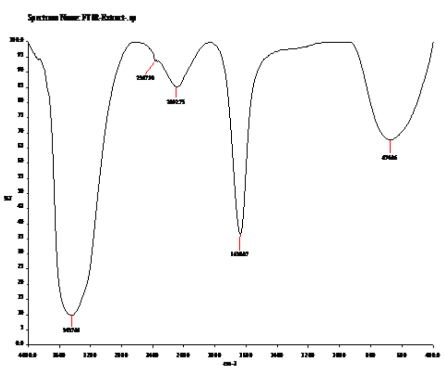


**Fig.12a FTIR spectrum of pure TCFE**

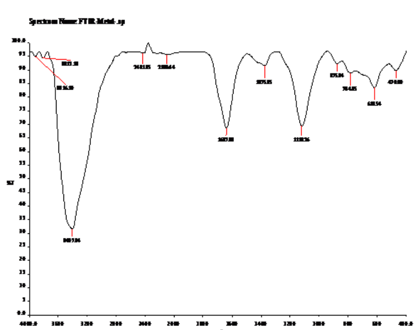


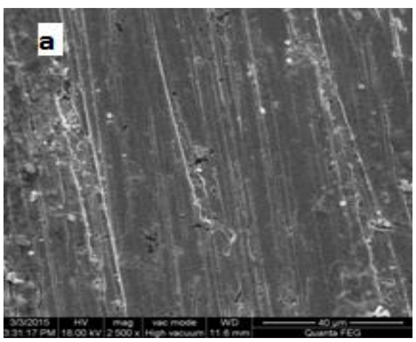
**Fig.12b FTIR spectrum of thin film formed on the surface of the carbon steel immersed in 0.5M HCl containing TCFE**

**Table: 9 FTIR band**

| Frequency (cm$^{-1}$) | Assignment | Frequency(cm$^{-1}$) | Assignment |
|---|---|---|---|
| 3437 | -OH stretching | 3916, 3812 | -NH stretching |
| 2367 | -CH stretching | 3407 | -OH stretching |
| 2092 | -CN stretching | 1637 | C=O stretching |
| 1638 | C=o bending | 1375 | -CH bending |
| 674 | -CH bending | 1118 | C-O sterching |
| | | 619 | -CH bending |
| | | 470 | Metal oxide |

**SEM Analysis**

The SEM images were recorded to establish the interaction of inhibitor molecules with metal surface. Figure 13 represents the SEM images of plain mild steel, mild steel immersed in 0.5M HCl, mild steel immersed in the presence of TCFE in 0.5M HCl The SEM images revealed that the mild steel specimen immersed in inhibited solution is in better condition having a smooth surface while the metal surface immersed in blank acid solutions is rough covered with corrosion products and appeared like full of pits and cavities [32]. Result shows that the phytochemical constituents present in the TCFE form a protective layer of the mild steel specimen and thereby reduce the corrosion rate.



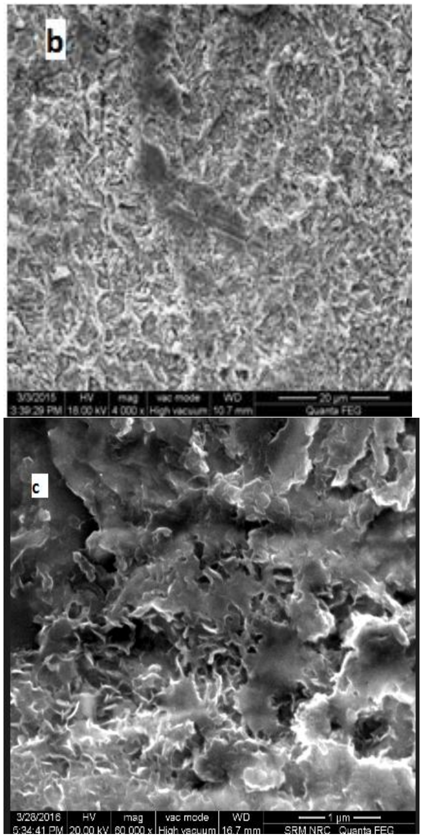



**Fig. 13 SEM micrograph of (a) Plain mild steel, (b) Mild steel immersed in acid,**

**(c) Mild steel immersed in the presence of TCFE in 0.5M HCl**

**CONCULSION**

From above study it is concluded that:

1. *T. chebula* fruit is good corrosion inhibitors for corrosion of mild steel in 0.5M HCl solution. The maximum efficiency was found to be 92 % at 700 ppm concentration.

2. The adsorption of *T. chebula* fruit on mild steel surface obeyed the Langmuir isotherm.

3. The potentiodynamic studies reveal that *T. chebula* fruit predominantly behaves as cathodic inhibitor.

4. EIS measurement results indicated that the resistance of the mild steel electrode increased greatly and its capacitance decreases by increasing the inhibitor concentration.

5. The negative values of $\Delta G$ shows that adsorption of *T. chebula* fruit on mild steel is a spontaneous process.

6. The increase in Ea is proportional to the inhibitor concentration, indicating that the energy barrier for the corrosion interaction is also increased.

7. FTIR spectra studies clearly reveal that the phytochemical constituents adsorbed on the mild steel surface.

8. The surface morphology of the thin layer on the mild steel is studied by SEM analysis.

9. The results obtained from weight loss and electrochemical methods show that *T.chebula extract* act as a good inhibitor.

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