

## Research Article

# An Ecofriendly Initiative for the Corrosion Inhibition of Mild Steel in 1 M HCl Using *Tecoma capensis* Flower Extract

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Corrosion inhibition of mild steel in 1 M HCl in the presence of *Tecoma capensis* flower extract was carried out by means of mass loss, potentiodynamic polarisation, and electrochemical impedance techniques. The inhibition efficiency varied with concentration of the inhibitor, immersion time, and temperature. The adsorption of the inhibitor on mild steel surface obeys Langmuir's adsorption isotherm. Thermodynamic parameters reveal that the adsorption process is spontaneous. Electrochemical studies reflect that the inhibitor acts as a mixed-type inhibitor. Surface analytical techniques ascertain the inhibitive nature of the studied inhibitor.

## 1. Introduction

The environmental consequences of corrosion on metals are enormous and the global stature of the problem has prompted an innumerable number of investigations in this area. Corrosion is a major problem that must be confronted for safety, environmental, and economic reasons. The general aggressive nature of industrial acids (HCl, H<sub>2</sub>SO<sub>4</sub>) mandates the usage of inhibitors for corrosion mitigation of metals. Prominent among them are synthetic organic compounds that afford a reasonable degree of inhibition but are carcinogenic and nonbiodegradable in nature. Sustainability and environmental issues have forced our investigators to look for an ecofriendly alternative, that is, natural products [1]. Numerous naturally occurring substances have been documented as inhibitors. Sprouted seeds of *Phaseolus aureus* [2], *Cyamopsis tetragonoloba* [3], *Ervatamia coronaria* [4], and *Cocos nucifera* [5] are some of the investigated inhibitors of our research team. Green inhibitors displaying improved environmental properties will be the inhibitors most widely used in the future. This motivated us to assess the effectiveness of *Tecoma capensis* flower extract in minimizing the corrosion of mild steel in 1 M HCl.

## 2. Methods

**2.1. Material Selection and Solution.** Mild steel (MS) specimens of the following chemical composition in wt%: carbon 0.13%, manganese 0.23%, silicon 0.03%, phosphorus 0.03%, sulphur 0.016%, chromium 0.022%, nickel 0.012%, and iron 99.95% were used for the entire study. Mass loss and electrochemical studies were carried out for assessing the efficacy of the inhibitor. For mass loss study, MS specimens of size 1 × 5 cm<sup>2</sup> were used. MS specimens with an exposed area of 1 cm<sup>2</sup> were used for electrochemical study. The specimens were mechanically polished, degreased, dried, and stored in a desiccator. The corrodent solution was obtained by diluting analytical grade 37% HCl with distilled water to get 1 M HCl.

**2.2. Preparation of Plant Extract.** *Tecoma capensis* flowers (TCF) were collected from the nearby locality and shade-dried. The selected plant was authenticated by Botanical Survey of India, Coimbatore, Tamil Nadu. 25 g of the dried flowers was refluxed with 500 mL of 1 M HCl for 3 hours and kept overnight. The cooled extract was filtered and diluted up to 500 mL (5% extract) to obtain the stock solution. Further dilutions were done from stock solution to obtain the desired concentration.

*Characterisation of the Extract.* Phytochemical examinations were carried out for the extracts as per the standard procedures mentioned [6].

**2.3. Mass Loss Method.** Prewighed test pieces were immersed in triplicate in 100 mL of the solution containing various concentration of the inhibitor and in the absence of inhibitor for a predetermined time period as per ASTM G 1-2. The test specimens were removed and then washed with deionised water, dried, and reweighed.

**2.4. Electrochemical Measurements.** Electrochemical experiments, including corrosion potential, potentiodynamic polarisation curves, and electrochemical impedance spectroscopy (EIS), were performed in a three-electrode cell, using a Biologic Model V 10.23 operated with EC-Lab software. In this setup a platinum electrode, calomel electrode, and MS specimens were used as auxiliary, reference, and working electrodes, respectively, which were immersed in acidic medium in the presence and absence of different concentrations of the inhibitor.

**2.5. FT-IR Spectroscopy.** The FT-IR spectrum was recorded for TCF with a frequency ranging from 4000 to 400  $\text{cm}^{-1}$  using Perkin Elmer FT-IR spectrophotometer with the software OPUS version 6.5.

**2.6. Scanning Electron Microscope.** The surface morphologies of mild steel specimens after exposure to 1M HCl solution in the absence and presence of TCF extract for 3 h were examined by SEM using a JEOL Model JSM 6390 SEM instrument.

### 3. Results and Discussion

Figure 1 shows the anodic and cathodic polarisation curves of mild steel in 1 M HCl solution, without and with different concentrations of TCF extract. It can be seen that both the cathodic and anodic curves reflect lower current density in the presence of TCF than those recorded in the solution without TCF. This indicates that TCF extract inhibits the corrosion process. The electrochemical parameters, that is, corrosion current density ( $I_{\text{corr}}$ ), anodic ( $b_a$ ) and cathodic ( $b_c$ ) Tafel constants, and polarisation resistance ( $R_p$ ), are given in Table 1. The table divulges the fact that the addition of the inhibitor shifts the anodic ( $b_a$ ) and cathodic ( $b_c$ ) slopes, respectively. This denotes the suppression of both the anodic dissolution and cathodic hydrogen evolution by the inhibitor. Significant reduction in the  $I_{\text{corr}}$  values is noted in the presence of the inhibitor. The IE is found to increase with increase in concentration of the inhibitor affording a maximum efficiency of 71.4 percentage. The negligible shift in the  $E_{\text{corr}}$  values infers the mixed nature of the inhibitor under investigation [7]. It is evident from Table 1 that the  $R_p$  values increase with increasing TCF concentration. Inhibition performance of TCF is found to be 77.9 percentage.

The potentiodynamic polarisation results of studied inhibitors suggest that the inhibitors are first adsorbed onto the mild steel surface and impede the corrosion reaction by

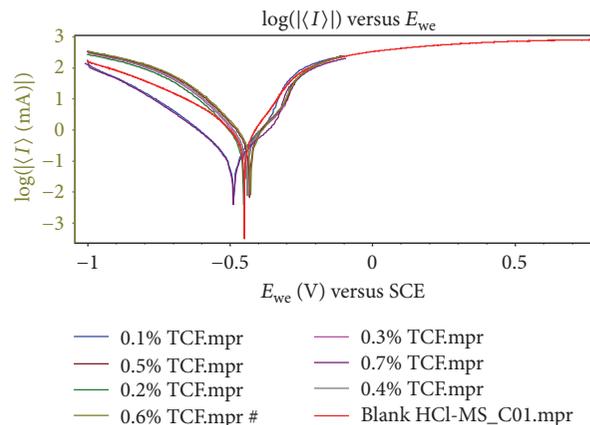


FIGURE 1: Potentiodynamic polarisation curves for MS in 1M HCl in the absence and presence of TCF extract.

merely blocking the reaction site of the electrode surface without affecting the anodic and cathodic reaction [8].

**3.1. Electrochemical Impedance Measurements.** The impedance spectral data of MS/HCl/TCF obtained from Nyquist plots (Figure 2) in 1 M HCl are given in Table 1. As observed, the impedance spectra exhibit a single depressed semicircle whose diameter increases with increasing concentration of the inhibitor implying a charge transfer process for the corrosion inhibition mechanism [9]. The figure also confirms the fact that the presence of the inhibitor did not modify the corrosion reaction of MS electrode in the presence of the inhibitor. The impedance parameters demonstrate the increase of charge transfer resistance ( $R_{\text{ct}}$ ) values with increase in concentration of the inhibitor. A maximum of 82.9 percentage IE is obtained at 0.7% TCF. Single capacitive semicircle noted in the Nyquist plot corresponds to a single time constant in the Bode representation [10].

It is clear from the table that  $C_{\text{dl}}$  values tend to decrease with increase in inhibitor concentration. This behaviour is the result of increase in surface coverage by the inhibitor molecules of plant extract which leads to increase in IE [11].

#### 3.2. Mass Loss Measurements

**3.2.1. Effect of Concentration and Immersion Time of TCF on MS/1M HCl.** The influence of TCF extract on the corrosion inhibition of MS has been assessed by mass loss measurements. Table 2 shows the variation of inhibition efficiency with increase in concentration of the inhibitor. This result indicates the inhibitive nature of the inhibitor on MS corrosion in 1 M HCl medium [12]. It is clear from the results that the IE increases steadily from 67.8 percentage at 0.1% concentration to 85.9 percentage at 0.7% concentration. The corrosion rate and inhibition efficiency of MS electrode exposed to various concentrations of TCF extract in 1 M HCl solution for various time intervals are tabulated in Table 2. From the table, it is noted that a maximum IE of 94.8 percentage for TCF is maintained till 6 h and thereafter a

TABLE 1: Electrochemical impedance parameters for corrosion of MS in the absence and presence of TCF in 1M HCl.

S. number	Conc. of TCF in %	Tafel polarisation parameters			Linear polarisation resistance parameters			Impedance parameters					
		$E_{corr}$ mV/SCE	$I_{corr}$ A/cm <sup>2</sup>	$b_a$ mV/decade	$b_c$ mV/decade	IE (%)	$R_p$ Ohm/cm <sup>2</sup>	IE (%)	$R_s$ ( $\Omega$ cm <sup>2</sup> )	$R_{ct}$ ( $\Omega$ cm <sup>2</sup> )	IE (%)	$C_{dl}$ ( $\mu$ F/cm <sup>2</sup> )	$\theta$
1	Blank	-475	0.0035	90	152	—	85.5	—	0.830	15.2	—	789	—
2	0.1	-433	0.0030	98	108	14.3	102	16.2	-0.13	19.4	21.6	631	20.20
3	0.2	-514	0.0015	95	129	57.1	159	46.2	1.59	27.4	44.5	617	0.22
4	0.3	-522	0.0013	99	134	62.9	168	49.1	1.67	32.8	53.7	548	0.31
5	0.4	-499	0.0013	88	138	62.9	198	56.8	1.89	61.9	75.4	411	0.48
6	0.5	-458	0.0013	94	127	62.9	278	69.2	1.78	65.4	76.8	320	0.59
7	0.6	-470	0.0011	85	129	68.6	321	73.4	2.01	78.2	80.6	265	0.66
8	0.7	-423	0.0010	84	128	71.4	386	77.9	1.60	103.1	82.9	219	0.72

TABLE 2: Inhibition efficiency as a function of immersion time and concentration for TCF in 1 M HCl.

Conc.%	1/2 h		1 h		3 h		6 h		12 h		24 h	
	CR (mpy)	IE (%)										
Blank	1032		1190		1238		2197		1561		1209	
0.1	333	67.8	260	78.1	350	71.7	625	71.6	601	61.5	545	54.9
0.2	307	70.3	226	81	264	78.6	426	80.6	474	69.8	495	59.1
0.3	273	73.5	200	83.2	233	81.2	315	85.7	435	72.1	458	62.1
0.4	196	81	162	86.4	166	86.6	226	89.7	342	78.1	377	68.8
0.5	179	82.7	145	87.8	148	88.0	200	90.9	318	79.6	312	74.2
0.6	154	85.1	128	89.2	135	89.1	143	93.5	279	82.2	241	80.1
0.7	146	85.9	102	91.4	90	92.7	114	94.8	202	87.1	160	86.8

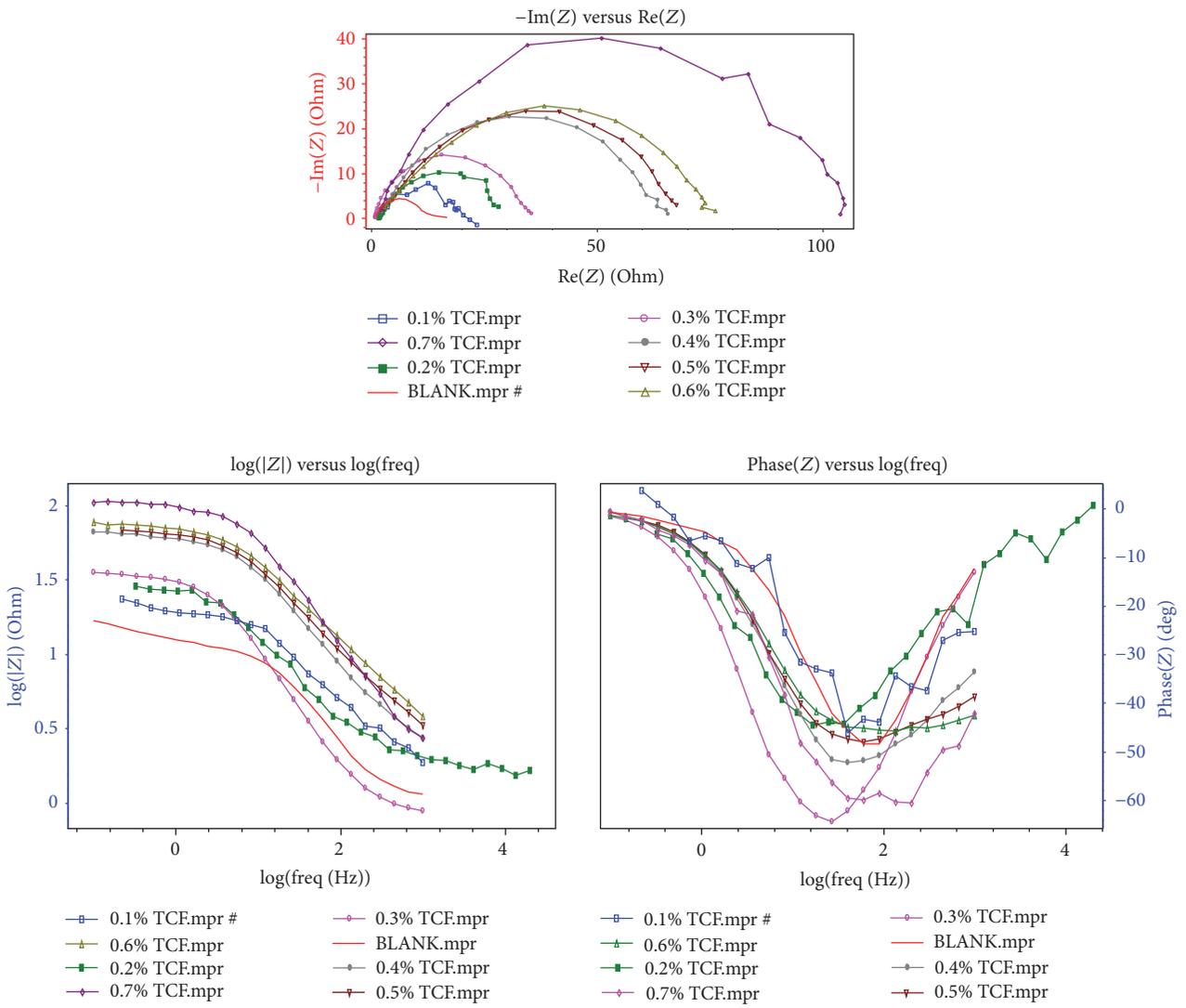


FIGURE 2: Nyquist and Bode plot of MS/1 M HCl/TCF.

TABLE 3: Relationship between inhibition efficiency and concentration for TCF/MS/1 M HCl systems at various temperatures.

Conc.%	Temperature (K)											
	303		313		323		333		343		353	
	CR (mpy)	IE (%)	CR (mpy)	IE (%)	CR (mpy)	IE (%)	CR (mpy)	IE (%)	CR (mpy)	IE (%)	CR (mpy)	IE (%)
Blank	1032		2755		6252		8146		9971		18091	
0.1	333	67.8	967	64.9	1307	79.1	2077	74.5	4188	58.0	7634	57.8
0.2	307	70.3	628	77.2	982	84.3	1750	78.5	3833	61.6	5174	71.4
0.3	273	73.5	540	80.4	757	87.9	1352	83.4	3490	65.0	4378	75.8
0.4	196	81	507	81.6	569	90.9	1238	84.8	3091	69.0	4125	77.2
0.5	179	82.7	479	82.6	539	91.4	1149	85.9	2353	76.4	3636	79.9
0.6	154	85.1	410	85.1	469	92.5	1075	86.8	1894	81.0	3383	81.3
0.7	146	85.9	386	86.0	388	<b>93.8</b>	863	89.4	1595	84.0	3039	83.2

slight decline is observed and the efficiency stabilises to 86.8 percentage (TCF) at 24 h.

Analysis of the tables indicates that IE increases with increasing concentration of the inhibitors. This indicates the dependence of inhibiting effect on the concentration of inhibitor molecules. This may be due to the increase in coverage of MS surface by the inhibitor molecules at higher concentration of the extract leading to a compact and coherent film on the surface of MS [13].

The IE of TCF increases with increasing time of immersion up to 6 h and then decreases to finally stabilise at 24 h to afford 86.8 percentage. This behaviour can be discussed on the basis that prolonged immersion of MS in acid solution [14]

- allows the cathodic or hydrogen evolution kinetics to increase presumably;
- increases the concentration of ferrous ions which decrease the corrosive nature of the acid.

**3.2.2. Effect of Temperature.** The kinetic and mechanistic aspects of corrosion may be gained by studying the effect of temperature on the corrosion of MS in the presence and absence of the inhibitor. It can be noted from Table 3 that the maximum IE obtained is 93.8 percentage in 1 M HCl. The values reflect that the IE increases up to 323 K affording an efficiency of 93.8 percentage and then a slight decrease is observed after that and at 353 K it is found to be at 83.2 percentage.

The decrease in the inhibition efficiency of the inhibitors with increase in temperature might be due to adsorption and desorption. Adsorption and desorption of inhibitor molecules continuously occur at the metal surface and an equilibrium exists between these two processes at a particular temperature. With the increase of temperature the equilibrium between adsorption and desorption processes is shifted leading to a higher desorption rate than adsorption until equilibrium is again established at a different value of equilibrium constant [15].

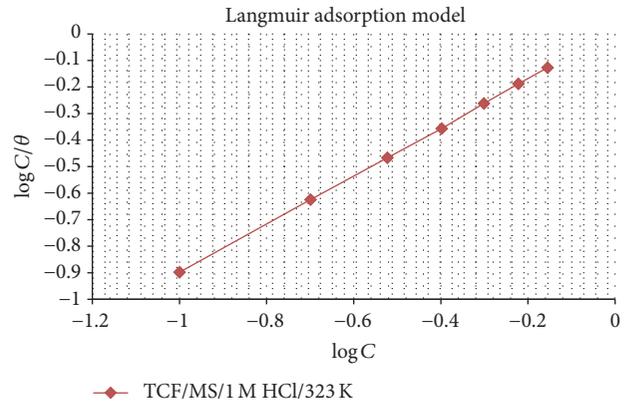


FIGURE 3: Langmuir adsorption isotherms.

**3.3. Langmuir Adsorption Isotherm.** Langmuir adsorption equation relates the degree of surface coverage to concentration of inhibitor according to

$$\log\left(\frac{C}{\theta}\right) = \log C - \log K. \quad (1)$$

A plot of  $\log(C/\theta)$  versus  $\log C$  from mass loss data obtained for the studied inhibitor yielded a straight line as represented in Figure 3. The slope deviates from unity. This deviation may be explained on the basis of the interaction among adsorbed species on the metal surface. It has been postulated in the derivation of Langmuir adsorption isotherm equation that adsorbed molecules do not interact with one another, but this is not the case of large organic molecules having polar atoms (or) groups which can be adsorbed on the cathodic and anodic sites of the metal surface as such adsorbed species interact by mutual repulsion or attraction [16]. It is also possible that the inhibitor studied can be adsorbed on the anodic and cathodic sites resulting in deviation from unit gradient.

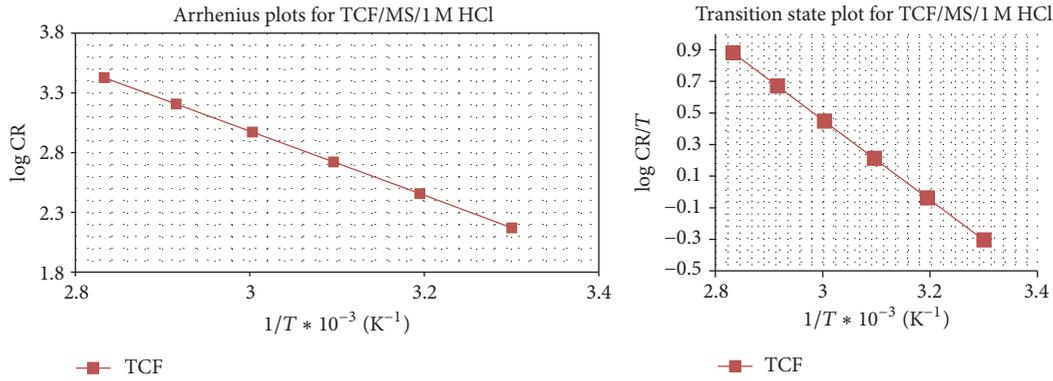


FIGURE 4: Arrhenius plots and transition state plots.

TABLE 4: Average values of activation parameters for MS corrosion in 1 M HCl in the absence and presence of TCF.

Inhibitor	$E_a$ (kJ/mol)	$\Delta H_a$ (kJ/mol)	$\Delta S_a$ (J/mol K <sup>-1</sup> )
Blank	47	44.6	-37.9
TCF	52.2	49.5	-36.8

### 3.4. Kinetic Parameters for Inhibition Process

3.4.1. *Energy of Activation.* The dependence of corrosion rate on temperature can be regarded as an Arrhenius-type process, the rate of which is given by

$$\log CR = \log A - \frac{E_a}{2.303RT}, \quad (2)$$

where CR is the corrosion rate of MS,  $A$  is Arrhenius or preexponential constant,  $E_a$  is the activation energy for the corrosion of MS,  $R$  is the gas constant, and  $T$  is the temperature.

The apparent activation energy for the corrosion of MS in 1 M HCl is calculated from the Arrhenius plot of  $\log CR$  against  $1/T$  (Figure 4) in the absence and presence of different concentrations of TCF. The  $E_a$  values are deduced from the slopes of these lines and the values of  $E_a$  for various concentrations of the inhibitor are tabulated in Table 4. It can be seen in the table that  $E_a$  is higher in the presence of the inhibitors than in their absence. The modification in the values of  $E_a$  may be attributed to the geometric blocking effect of adsorbed inhibitive species on the metal surface [17]. This observation further supports the proposed physisorption mechanism as report [18] shows that lower values of  $E_a$  in the presence of inhibitors in comparison to the free acid solution are indicative of chemical adsorption mechanism, whereas the opposite suggests a physical adsorption mechanism.

3.5. *Entropy of Activation and Enthalpy of Activation.* In order to calculate the enthalpy,  $\Delta H_a$ , and entropy,  $\Delta S_a$ , of activation for the corrosion process, the alternative formulation of

Arrhenius equation, also called transition state equation, is used:

$$\frac{CR}{T} = \frac{R}{Nh} \exp\left(\frac{\Delta S_a}{R}\right) \exp\left(\frac{\Delta H_a}{RT}\right), \quad (3)$$

where  $h$  is the Planck constant,  $N$  is the Avogadro number,  $\Delta S_a$  is the entropy of activation,  $\Delta H_a$  is enthalpy of activation,  $T$  is the absolute temperature, CR is corrosion rate, and  $R$  is the universal gas constant.

The relationship of  $\log(CR/T)$  versus  $1/T$  for MS corrosion in 1 M HCl in the absence and presence of different concentrations of TCF extracts is shown in Figure 4. Straight lines are obtained with slope of  $(-\Delta H_a/2.303R)$  and an intercept of  $(\log R/Nh + \Delta S_a/2.303R)$  from which the values of  $\Delta H_a$  and  $\Delta S_a$ , respectively, are computed and listed in Table 4.

The table reflects the fact that  $E_a$  and  $\Delta H_a$  are close to each other as expected from transition state theory concept and they are also found to vary in a similar manner in the presence of the inhibitors. It is also seen in Table 4 that  $E_a$  and  $\Delta H_a$  vary in the same manner, but, however, the values of  $\Delta H_a$  are lower than that of  $E_a$ . This has been reported in [19] indicating that the corrosion process must involve a gaseous reaction, simply hydrogen evolution reaction associated with decrease in total reaction volume.

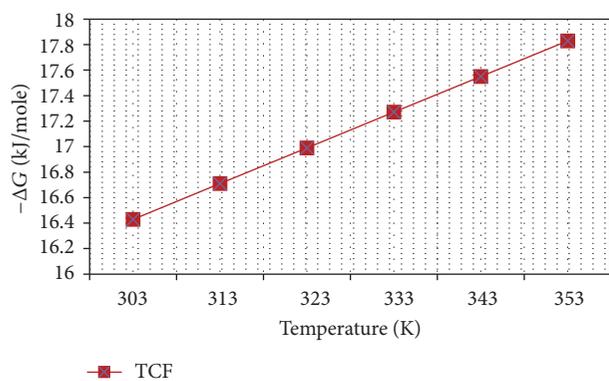
The positive values of  $\Delta H_a$  both in the absence and presence of additives reflect the endothermic nature of the steel dissolution process and they indicate that the dissolution of MS is difficult. The values of  $\Delta S_a$  in the absence and presence of the extracts are negative implying that the inhibitor molecules, freely moving in the bulk solution, are adsorbed in an orderly fashion onto the MS surface [20].

3.6. *Thermodynamic Adsorption Parameters.* Figure 5 clearly shows the dependence of  $\Delta G_{\text{ads}}^{\circ}$  on  $T$ , indicating the good correlation among thermodynamic parameters. The large and negative values of  $\Delta G_{\text{ads}}^{\circ}$  ensure the spontaneity of the adsorption process and stability of the adsorbed layer on the steel surface [21].

The calculated values of  $\Delta G_{\text{ads}}^{\circ}$  presented in Table 5 are negative which indicate that the adsorption of inhibitor

TABLE 5: Thermodynamic adsorption parameters.

System	Free energy of adsorption $\Delta G_{\text{ads}}^{\circ}$ (kJ/mol)						$\Delta S_{\text{ads}}^{\circ}$ J/mol	$\Delta H_{\text{ads}}^{\circ}$ kJ/mol
	303 K	313 K	323 K	333 K	343 K	353 K		
1 M HCl + 0.7% TCF	-15.5	-16.1	-19.0	-18.0	-17.2	-17.0	-27.5	-8.1

FIGURE 5: Best fit curve of  $-\Delta G_{\text{ads}}^{\circ}$  versus  $T$  for MS/TCF/1 M HCl.

molecules on the metal surface is a spontaneous process. Generally, values of  $\Delta G_{\text{ads}}^{\circ}$  around  $-20 \text{ kJ mol}^{-1}$  or lower are consistent with the electrostatic interaction between the charged molecules and the charged metal (physisorption); those around  $-40 \text{ kJ mol}^{-1}$  or higher involve charge sharing or transfer from organic molecules to the metal surface to form a coordinate type of bond (chemisorption) [22]. In the present work, the calculated  $\Delta G_{\text{ads}}^{\circ}$  values are almost slightly less negative than  $-20 \text{ kJ mol}^{-1}$  ranging from  $-15$  to  $-19 \text{ kJ mol}^{-1}$ . Hence it may be assumed that the adsorption of the inhibitor molecules is obeying physical adsorption; however chemical adsorption may not be excluded due to the complex nature of the corrosion inhibiting process. The positive sign of  $\Delta H_{\text{ads}}^{\circ}$  reflects the endothermic nature of dissolution which suggests the slow dissolution of MS [23]. The entropy of adsorption  $\Delta S_{\text{ads}}^{\circ}$  is negative because the inhibitor molecules, freely moving in the bulk solution, are adsorbed in an orderly fashion onto the mild steel surface, resulting in a decrease in entropy [24].

### 3.7. Surface Analytical Techniques

**3.7.1. FT-IR Spectral Studies.** Figure 6 illustrates the FT-IR spectrum of crude extract of TCF and the corrosion product of MS. From the results obtained, it may be noticed that O-H stretching at  $3387 \text{ cm}^{-1}$  (for TCF extract) shifts to  $3418 \text{ cm}^{-1}$ . The aliphatic and aromatic C-H stretching observed in crude plant extract at  $2924 \text{ cm}^{-1}$  and  $2855 \text{ cm}^{-1}$  shifts to  $3086 \text{ cm}^{-1}$  and  $3024 \text{ cm}^{-1}$ , respectively. A peak at  $2315 \text{ cm}^{-1}$  is noticed only in corrosion product which corresponds to  $\text{C}\equiv\text{N}$  stretching vibration. A peak at  $1628 \text{ cm}^{-1}$  corresponding to  $\text{C}=\text{O}$  stretching vibration is shifted to  $1736 \text{ cm}^{-1}$  in the corrosion product. Peaks that are shifted from ( $1443 \text{ cm}^{-1}$  to  $1427 \text{ cm}^{-1}$ ) and ( $1373 \text{ cm}^{-1}$  to  $1366 \text{ cm}^{-1}$ ) to ( $1258 \text{ cm}^{-1}$

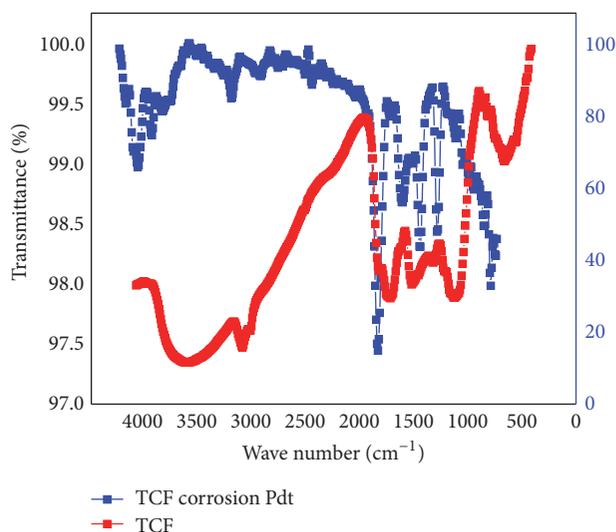


FIGURE 6: FT-IR spectrum of TCF and corrosion products in the presence of TCF.

to  $1219 \text{ cm}^{-1}$ ) and ( $1072 \text{ cm}^{-1}$  to  $1049 \text{ cm}^{-1}$ ) indicate the presence of C-O stretching and C-O-C stretching groups. The shift in the absorption frequencies of the TCF extract on the metal surface supports the interaction between the inhibitor and the metal surface. Also, some new bonds are noted in the spectrum of the corrosion product. This includes the  $\text{C}\equiv\text{N}$  stretch at  $2315 \text{ cm}^{-1}$ . This also indicates that some new bonds are also formed through these functional groups [25]. This emphasises the fact that the inhibitive nature of the extract is due to the formation of Fe-TCF complex on MS surface.

**3.8. Scanning Electron Micrograph of MS in the Presence of TCF Extract in 1 M HCl.** Surface morphology of the MS samples immersed in HCl with and without TCF is shown in Figures 7(a) and 7(b). Figure 7(a) indicates the finely polished characteristic surface of MS with some scratches that had arisen during polishing.

Figure 7(b) reveals that the immersed specimens are drastically damaged in the presence of 1.0 M HCl, due to the direct attack of aggressive acid. Figure 7(c) reflects the drastic change in morphology of MS surface in the inhibited solution containing 0.7% TCF extract. The smooth surface of MS in inhibited solution may be due to the phytochemical constituents present in TCF that hinder the dissolution of iron by forming a protective film on MS surface [26].

**3.9. Mechanism of Inhibition.** Phytochemical screening of TCF extract indicates the presence of phytoconstituents

TABLE 6: Preliminary phytochemical screening of the crude extract.

Plant	Phytochemical constituents							
	Flavonoids	Alkaloids	Terpenoids	Saponins	Tannins	Reducing sugar	Polyphenols	Anthraquinones
TCF	+++	-	++	+	-	+	+	-

+++ : appreciable amount; ++ : moderate amount; + : trace amount; and - : not detected.

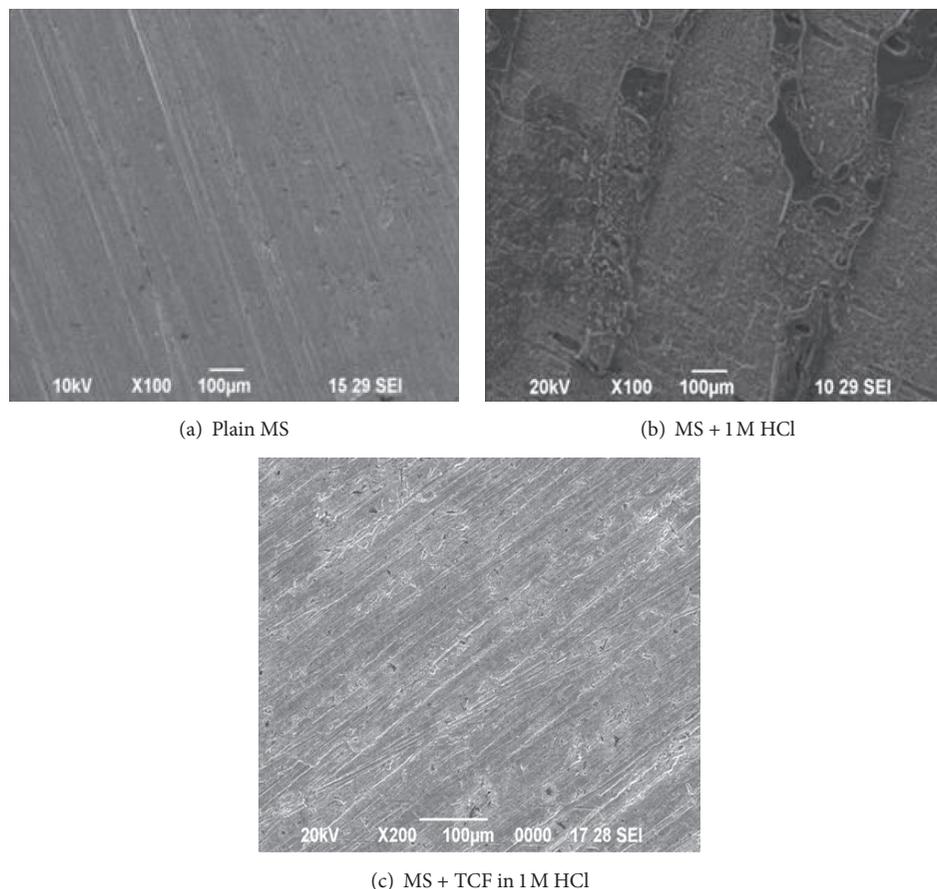


FIGURE 7: SEM images of MS corrosion in the absence and presence of TCF in 1 M HCl.

flavonoids, terpenoids, and polyphenols. Phytochemical screening results (Table 6) are consistent with the literature survey [27]. In aqueous acidic solution, the organic molecules of TCF exist either as neutral molecules or in the form of protonated organic molecules (cation).

The organic molecules might adsorb onto the metal surface by one or more of the following means: (i) interaction between the  $\pi$  electrons of the inhibitor molecules and vacant d orbital of surface iron atoms and (ii) the protonated inhibitors adsorption through electrostatic interactions between the positively charged molecules and the negatively charged metal surface. The efficiency of TCF might be due to the synergistic effect between the adsorbed  $\text{Cl}^-$  ions and protonated organic molecules of the inhibitor [28]. Thus it may be inferred that TCF effectively creates a barrier between the aggressive solution and the metal due to the adsorption of the inhibitor species onto the metal surface.

## 4. Conclusion

The investigated inhibitor performed in an effective manner to minimize the corrosion of MS in 1 M HCl medium. The results indicated a considerable reduction in the  $I_{\text{corr}}$  values in the presence of the inhibitors. The IE was found to increase with increase in concentration of the inhibitors. The inhibitors acted as mixed-type inhibitors. Analysis of the results of the mass loss measurements of MS infers that the inhibition efficiencies increased with increasing concentration of the inhibitors. Surface morphology of the metal indicated that the surface of the metal was protected by the adsorption of the active constituents of the plant species.

## Competing Interests

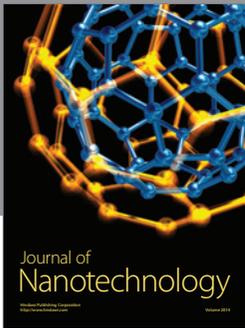
The authors declare that there are no competing interests regarding the publication of this manuscript.

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