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## *Grewia tiliaefolia* bark extract –An inhibitor on mild steel corrosion in hydrochloric acid medium

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### Abstract

The inhibition effect of *Grewia tiliaefolia* Bark extract on mild steel in hydrochloric acid medium was examined by weight loss methods and potentiodynamic polarization method. *Grewia tiliaefolia* Bark extract acted as a good corrosion inhibitor in 1.0 M hydrochloric acid. Inhibition efficiency value increased with inhibitor concentration. Polarization curves indicated that *Grewia tiliaefolia* Bark extract acted as mixed type inhibitor in 1.0 M hydrochloric acid. The stability of the adsorbed layer was studied and the inhibition of the extract components on the mild steel surface was proved by surface analysis methods.

**Keywords:** corrosion, *Grewia tiliaefolia* Bark (GTB), mild steel, corrosion rate, inhibition efficiency, weight loss method, electrochemical method.

### 1. Introduction

Corrosion control is important not only in environmental aspects but also in economic and aesthetical viewpoint. Corrosion, an irreversible interfacial reaction of a metal in aggressive media, affects the performance and efficiency of a metal and also leads to reduction of its service life [1, 2]. Acids are generally used in pickling baths to clean the machine parts in industries. Because of the general aggression of acid solutions, inhibitors are commonly used to reduce the corrosive attack on metallic materials. The known hazardous effects of most synthetic organic inhibitors and restrictive environmental regulations have now made researchers to focus on the need to develop cheap, non-toxic and environmentally benign natural products as corrosion inhibitors.

*Grewia tiliaefolia* Vahl, belongs to the family tiliaceae is generally found in forest of *Anangan mala*, which is a part of Western Ghats, in the northern end of Palakkad district, Kerala, India. *Grewia tiliaefolia* contain chemicals like D-erythro-2-hexenoic acid  $\gamma$ -lactone, Gulonic acid  $\gamma$ -lactone, Betulin, Friedelin, Lupeol, Tannins, Flavonoids, Hemicelluloses, Phenolics, Lupenol, and Lignin [3-6]. Literature showed the influence of these chemicals as corrosion inhibitors in field of metal corrosion study. However, *Grewia tiliaefolia* bark (GTB) extract has little been studied for the purpose of corrosion inhibition. The inhibition effect of this natural product on the corrosion of mild steel (MS) in 1M HCl was investigated by weight loss and potentiodynamic polarization methods. Results obtained for these independent methods were in good agreement.

### 2. Materials and methods

**2.1 Materials preparation:** The experiments were carried out by MS with the following composition (in weight percentage) C=0.091; Si=0.016; Mn=0.195; S=0.013; P=0.020; Ni=0.018; Mo=0.020; Cr=0.027 and Fe=99.6. The aggressive solution of 1M HCl was prepared. Bark of *Grewia tiliaefolia* Vahl (GTB) were collected and cut in to small pieces, air dried and powdered. The extracts were prepared by refluxing 25 g of powdered bark or leaves in 1M HCl for 3 h and kept overnight for cooling. The cooled extracts were filtered and made up to 500ml with 1M HCl to get 5% v/v concentration. The desired concentrations of the inhibitor were prepared by diluting the above stock solution with distilled water. The concentration range of GTB used was (0.25 to 0.5) volume %.

**2.2 Weight loss measurements:** Mild steel specimens were sheared from commercially available cold rolled MS sheet into 5 x 1 cm<sup>2</sup> coupons for immersion studies. The specimens were mechanically polished; their edges were abraded with fine grade emery papers (No: 400), degreased, rinsed with acetone, stored in desiccator and used for all studies.

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Mild steel coupons were weighed in a SHIMADZU Digital balance with an accuracy of 0.00001 g and then exposed to the selected aggressive media. In each experiment, samples were supported by a glass-hook and immersed as triplicates in 100 ml of solution (with and without inhibitors) for a predetermined time period viz., ½ h, 1 h, 3 h, 6 h, 12 h and 24h. The specimens were taken out, neutralized with saturated sodium bicarbonate solution, washed with distilled water, dried and reweighed. The resulted weight loss of the triplicates were averaged and used for further calculations.

- i) **Electrochemical measurements:** Electrochemical experiments were carried out using Biologic Science Instruments Model SP-150 Potentiostat/Galvanostat system with EC-Lab software. A conventional three - electrode cell assembly with mild steel as a working electrode (WE), a platinum foil as a counter electrode(CE) and standard calomel electrode (Hg/Hg<sub>2</sub>Cl<sub>2</sub>/sat, KCl) as the reference electrode (RE) was used. The working electrode was prepared from a CR steel sheet of 1x1 cm<sup>2</sup> size which was bridge welded to a conducting rod. The immersed area other than 1x1 cm<sup>2</sup> was painted and covered by polytetrafluoroethylene (PTFE) tape. The specimens were polished with emery paper no. 400, cleaned with acetone, washed with distilled water and finally dried at room temperature before being immersed in the acid solution. The electrolyte was taken into a 200 mL beaker with a specially designed lid, carrying three holes for maintaining the constant distance between the electrodes.
- ii) **The electrochemical impedance spectroscopy:** The EIS measurements were carried out at E<sub>corr</sub> after immersion on standing in air atmosphere with the electrochemical system which includes a digital potentiostat model. After the determination of steady -state current at a given potential, sine wave voltages (-1V; 1V) peak to peak, at the frequencies between 20 kHz to 0.1 Hz, 6 points per decay, were superimposed on the rest potential.
- iii) **Polarization curves:** The working electrode was covered with PTFE other than the exposed area of 1 cm<sup>2</sup> surface to the solution. The WE was immersed in at rest solution for 30 minutes until a steady - state open potential curve was recorded. The cathodic polarization was measured by polarizing from the E<sub>ocp</sub> in a cathodic direction under

potentiodynamic conditions corresponding to 1 mV/s using a SP150 model under unstirred conditions at 30 °C. After this scan, the anodic polarization curve was recorded by polarization from the E<sub>ocp</sub> in an anodic direction.

- iv) **Surface analysis:** F E I Quanta FEG 200-High Resolution Scanning Electron Microscope was used for the study of the change in surface morphology of metal surface. The polished mild steel specimen was immersed in 1 M HCl solution in the absence and presence of the optimum concentration of the green extracts for 6 h at room temperature. The specimen was cleaned with distilled water, dried and used for the analysis. The surface images were taken with the magnification of 2000x specimens.

### 3. Results and Discussion

**3.1 Corrosion rates and inhibition efficiency from weight loss method:** The anodic dissolution of iron coupled with the high solubility of corrosion products results in considerable weight loss for mild steel immersed in an acidic solution.



The results of weight loss measurements demonstrated a significant loss in the weights of specimens occurred when they were immersed in solution. The corrosion rate (CR) and inhibition efficiency (IE) were obtained using the following equations:

$$\text{CR(mpy)} = 534W/\text{DAT} \quad (1)$$

$$\text{IE(\%)} = \left( \frac{W_0 - W}{W_0} \right) \times 100 \quad (2)$$

where, w is the weight loss in g, D is the density of mild steel in gm / cm<sup>2</sup> (7.9 gm / cm<sup>2</sup>), A is the area of the specimen in cm<sup>2</sup>, T is the exposure time in hours, W<sub>0</sub> is the weight loss without inhibitor and W is the weight loss with inhibitor respectively.

Table 1 reflects the values of corrosion rate and inhibition efficiencies at room temperature (303±2) K in the presence of different concentrations of GTB in 1 M HCl. In the presence of extract, retarded the dissolution of the mild steel and IE increased with increase in the concentration of inhibitor.

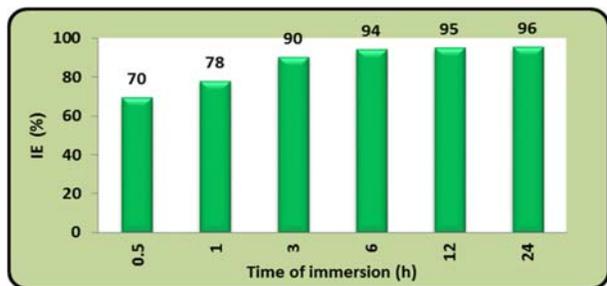
**Table 1:** Role of immersion time on CR and IE of GTB extract

Conc.(v/v %)	1/2 h		1 h		3 h		6 h		12 h		24 h	
	CR (mpy)	IE (%)										
0	2940.15	-	3101.95	-	3204.16	-	3407.97	-	2748.24	-	1890.00	-
0.25	1107.55	62.33	1034.62	66.65	846.82	73.57	851.19	75.02	659.12	76.02	391.85	79.27
0.3	1029.21	64.99	966.50	68.84	797.06	75.12	785.75	76.94	585.23	78.71	290.03	84.65
0.35	1001.46	65.94	899.73	70.99	623.00	80.56	665.30	80.48	495.31	81.98	246.47	86.96
0.4	967.92	67.08	857.97	72.34	563.45	82.41	606.21	82.21	414.60	84.91	202.11	89.31
0.45	934.38	68.22	736.18	76.27	488.99	84.74	461.83	86.45	307.08	88.83	148.49	92.14
0.5	893.67	69.60	682.75	77.99	309.21	90.35	192.1	94.36	128.14	95.34	76.97	95.93

The influence of GTB extract on MS corrosion was evaluated at various time intervals. The values of corrosion rate of MS in different immersion times are presented in Table 1. It had been found that the rates of corrosion of the blank increased with increasing immersion time up to 6 h and then decreased. This variation in corrosion rate may be due to the increase in conductance of the solution as a result of continuous addition of Fe<sup>2+</sup> ion caused by the corrosion of mild steel [7]. The decrease in corrosion rate after 6 h may be due to either a

decrease in solubility of the electrolyte as it slowly becomes saturated with the corrosion product or the formation of some surface film which retards the corrosion of mild steel.

The plot of inhibition efficiency versus corrosion time is illustrated in Figure 1. The inhibition efficiency increases with increasing immersion time of samples in the corrosive media, which can be attributed to the fact that the protective film formed on the metal surface tend to become more compact, stable, persistence and uniform by the increase of time [8].



**Fig 1:** Variation of inhibition efficiency with exposure time for MS corrosion in 1 M HCl in presence and absence of GTB extract

Hot acid solutions are generally used for removing mill scales (oxide scales) from the metal surface in various industries. The effect of temperature on the metal-inhibited acid reaction is very complex, because rapid etching occurs on the metal surface, inhibitor molecules get adsorbed and the inhibitor itself may decompose / undergo rearrangement [9]. The change in the corrosion rate with increase in temperature was studied in 1 M HCl both in the absence and in the presence of GTB extract. Weight loss measurements were taken at various temperatures (303-353 K) for ½ h of immersion. Corresponding CR and IE are summarized in Table 2. The corrosion rate increases with the rise of temperature.

**Table 2:** Results of weight loss measurements for MS corrosion in HCl in the absence and presence of different concentrations of GTB at different temperature

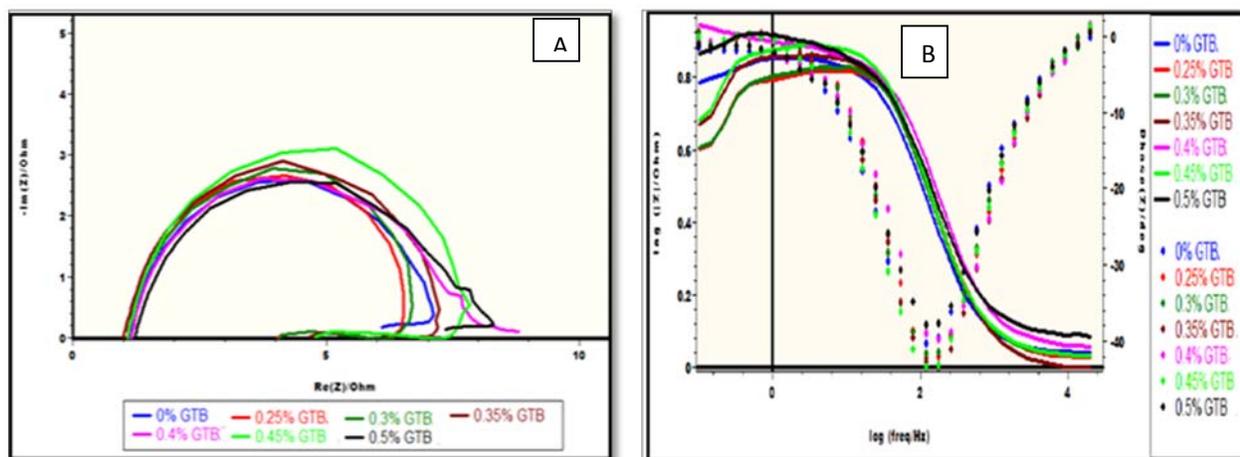
Conc.(v/v %)	303 K		313 K		323 K		333 K		343 K		353 K	
	CR (mpy)	IE (%)										
0	2940		3173		4617		12654		16519		28476	
0.25	1108	62.33	912	71.25	1577	65.84	5763	54.46	10023	39.32	14581	48.79
0.3	1029	64.99	895	71.79	1537	66.7	5210	58.83	9598	41.9	14241	49.99
0.35	1001	65.94	764	75.91	1326	71.27	3843	69.63	9033	45.32	14184	50.2
0.4	968	67.08	742	76.61	1089	76.41	3749	70.38	7855	52.45	13503	52.58
0.45	934	68.22	670	78.9	1020	77.91	3464	72.62	7792	52.83	12786	55.1
0.5	894	69.6	478	84.94	909	80.31	3351	73.52	6912	58.16	10777	62.16

It is noted that IE increased with temperature up to 313 K in different concentration of GTB. A slight decrease is observed at 323 K followed by a notable decrease up to 353 K. This is because; rise in temperature exponentially accelerates the rates of corrosion process in media where hydrogen gas evolution accompanies corrosion, resulting in higher dissolution rates of metals. Higher rates of hydrogen gas evolution increasingly agitate the metal/ corrodent interface and could hinder inhibitor adsorption or perturb already adsorbed inhibitor, especially when the interaction between the metal and the inhibitor is relatively weak. As a result the efficiency of the inhibitor is reduced when the temperature of the system is increased, a trend often attributed to physical rather than chemical adsorption of the inhibiting species on the corroding metal surface [10].

**3.2 Electrochemical Impedance Spectroscopy:** EIS is a non-destructive technique that characterizes bulk and interfacial properties of all sorts of materials (conductors, insulators and semiconductors). Many electrical parameters of the system can

be determined in a single EIS experiment with an additional advantage that the signal can be averaged over long periods to achieve higher accuracy. In general, EIS is a transient technique where an excitation is applied to the system and the response (as a function of frequency) is observed. Nyquist plots as well as Bode plots were used to express the impedance behavior in a system.

Impedance measurements were carried out under potentiodynamic conditions after reaching steady state at 303K. Nyquist plots were made from these experiments carried out in 1M HCl medium and represented in Figure 2. The impedance diagram in the absence of the GTB extract consists of a large capacitive loop with one capacitive time constant in Bode phase diagram. The shape of the capacitive loops suggests that charge transfer resistance controls the corrosion of mild steel. The existence of a single semicircle showed the presence of a single charge transfer process during dissolution, which was unaffected by the presence of an inhibitor molecule.



**Fig 2:** (A) Nyquist and (B) Bode plots for MS corrosion in different concentrations of GTB extract in 1 M HCl

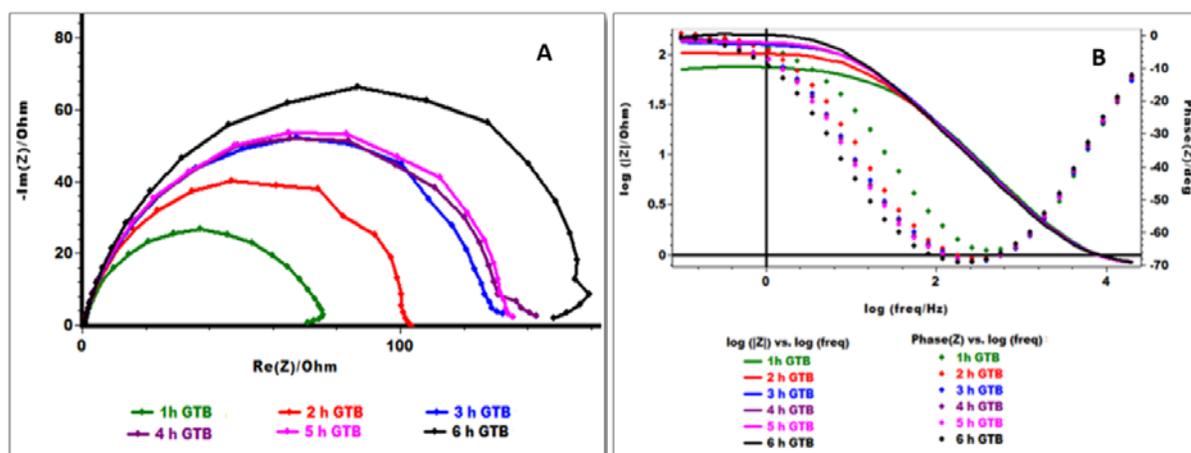
The slightly depressed nature of semicircle had the characteristic for solid electrodes and such frequency dispersion has been attributed to the microscopic roughness and other inhomogeneities of the solid electrode, such as those found in adsorption processes [11, 12]. The low frequency inductive loop may be attributed to the relaxation process obtained due to formation of  $\text{Fe}^{2+}$  - complexation and consequently the adsorption of  $\text{Cl}^-$  ions and  $\text{H}^+$  ion species on the same near the electrode surface.

Values of charge transfer resistance  $R_{ct}$  from these plots and the double layer capacitance  $C_{dl}$  were calculated from the frequency at which the impedance imaginary component  $-Z''$  is maximum and was reported in Table 3. It is obvious from the Table that the value of  $R_{ct}$  increased with concentration of the extracts and reached a maximum value in presence of 0.5% extract. The changes of  $R_{ct}$  can be related to the gradual adsorption of extract components on the surface and consequently to a decrease in the number of active sites necessary for the corrosion reaction.

**Table 3:** Impedance parameters of MS corrosion in presence of various concentrations of GTB extract in 1 M HCl

Con (v/v %)	0	0.25	0.3	0.35	0.4	0.45	0.5
$R_{ct}$ (W)	29.68	30.02	30.11	30.8	32.72	33.52	33.97
$C_{dl}$ ( $\mu\text{F}$ )	704.2	86.14	97	129.2	291.4	309.5	316

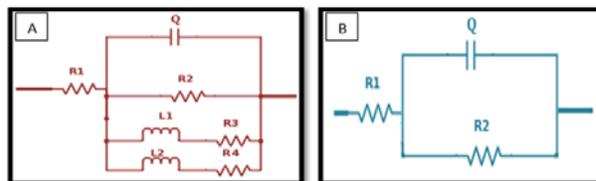
The capacitance in 0.25% was 86.14  $\mu\text{F}$  whereas in the case of 0.5% inhibitor concentration the capacitance was 316.00  $\mu\text{F}$  was reported in HCl media. A large charge transfer resistance is associated with a slower corroding system [13]. The decrease in  $C_{dl}$ , which can result from a decrease in local dielectric constant and / or an increase in the thickness of the electric double layer [14], suggested the adsorption of GTB molecules at the metal / solution interface [15]. Decrease in  $C_{dl}$  values and the increase in  $R_{ct}$  values and consequently of the inhibition efficiency may be due to either the gradual replacement of water by the adsorption of the extract molecules on the metal surface, which decreased the extent of dissolution reaction or due to the formation of a protective layer at electrode surface [16, 17].



**Fig 4:** Nyquist (A) and Bode (B) plots for MS corrosion in presence of GTB extract of GTL 1 at varying exposure time

The results showed that the immersion time has a significant influence on the diameter of the impedance spectra and therefore on the inhibition efficiency of the extract. The impedance parameters were reported in Table 4. It is clear that in uninhibited acid solutions the  $R_{ct}$  values decreased with

It is essential to develop approximate models for the impedance which can be used to fit the experimental data and evaluate the parameters which characterize the corrosion process. To determine the impedance parameters of a corrosion system, two types of equivalent circuit models were used. For a corrosion system, the formation of double layer 'metal - acid solution' interface was represented by the electronic equivalent circuit model in Figure 3(A) and for 'metal - inhibitor' system was represented in Figure 3(B). These equivalent circuit models were interpreted by analyzing the computer program EC Lab software V 10 .19 based upon the dielectric equivalent circuit.



**Fig 3:** The equivalent circuit models for (A) MS- inhibitor interface (B) MS- acid interface in test media

Figure 3(A) shows the electrical circuit model  $R_1(Q R_2(L_1R_3)(L_2R_4))$ , which consists of solution resistance,  $R_1$ , a CPE,  $Q$ , in parallel with parallel resistances  $R_2$ ,  $R_3$ ,  $R_4$ ;  $R_3$  and  $R_4$  are in series with inductors  $L_1$  and  $L_2$ , respectively. In Figure 3(B), the system consists of resistance,  $R_1$ , a CPE,  $Q$  and parallel resistance  $R_2$ .

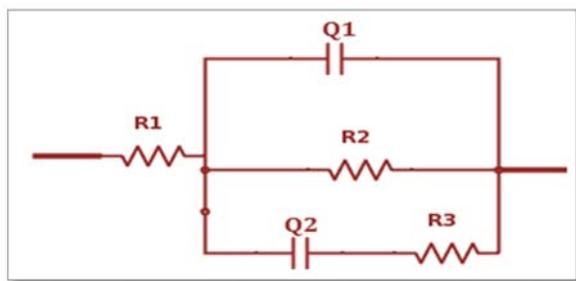
**Effect of Immersion Time:** GTB extract induced modifications in the electrochemical process kinetics in the mild steel / acid interface were investigated using impedance spectroscopy. EIS is useful technique for long time tests, because it does not significantly disturb the system, and it is possible to follow it over time. Immersion time experiments were carried out in 1M HCl containing 0.5% of the extract for 6 h at respective open circuit potentials and Nyquist plots were recorded every 60 minutes. The Nyquist and Bode plots are presented in Figure 4. It is clear from the plots that with increase in time the diameter of the diagram increases.

increase in immersion time. This may be related to the degradation of the corrosion product with prolonged exposure, which is often correlated to a decrease in double layer thickness.

**Table 4:** Impedance parameters of MS corrosion in presence of 0.5% of GTB in 1 M HCl at various immersion times

Time (h)	R <sub>ct</sub>		IE	C <sub>dl</sub> (μ F)	
	Blank	GTB		Blank	GTB
1	55.96	75.87	26.24	170	84.63
2	53.32	105.1	49.27	120	90.69
3	45.3	129.6	65.05	211	109.1
4	45.58	135	66.24	209	104.7
5	32.04	136.9	76.6	200	103.3
6	33.08	167.8	80.29	194	124.6

Oguzie *et al.*,<sup>[18]</sup> reported that if the impedance modulus in an inhibitor containing system would be greater than in uninhibited system at all frequencies the inhibitor would function by blocking the entire exposed surface of a metal. If this effect is noticed over a certain frequency range in presence of the inhibitor it would function by blocking only the active corrosion sites of the exposed metal surface.

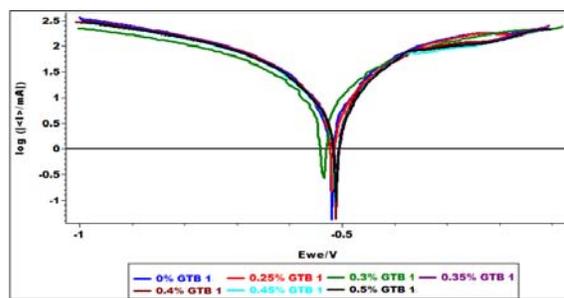
**Fig 5:** The equivalent circuit models for MS- inhibitor interface at various immersion time

The equivalent circuit model used to fit the experimental data is shown in Figure 5 and it explains the electrical circuit model R<sub>1</sub>(Q<sub>1</sub> R<sub>2</sub>(Q<sub>2</sub>R<sub>3</sub>), which consists of solution resistance, R<sub>1</sub>, a CPE, Q<sub>1</sub>, in parallel with parallel resistances R<sub>2</sub>, and R<sub>3</sub>; R<sub>3</sub> is in series with CPE, Q<sub>2</sub>.

**3.3 Polarization Methods:** The majority of corrosion phenomena is of electrochemical in nature and consists of reactions on the surface of the corroding metal. On the other hand the electrochemical measurements provide a great idea about the corrosion mechanism. Main advantages of these methods are short measuring time, high measurement

accuracy, and the possibility of continuous corrosion monitoring.

The effect of different GTB extract concentrations (0.25, 0.30, 0.35, 0.40, 0.45 and 0.50%) on the potentiodynamic polarization curves of mild steel after ½ h immersion time was shown in Figure 6. It was clear from the curves that the additives shift the corrosion potential of the mild steel towards a more negative potential. Currents of anodic and cathodic regions had lower values compared to that of the blank solution. The extract exerted efficient inhibitory effect on both the anodic metal dissolution and cathodic hydrogen evolution. This effect indicated that the studied GTB extract acted as a mixed type inhibitor.

**Fig 6:** Typical polarization curve for MS in 1 M HCl for various concentrations of GTB extract

Polarization parameters such as corrosion potential, corrosion currents and cathodic and anodic Tafel slopes ( $b_a$  and  $b_c$ ) are listed in Table 5. The presence of inhibitor molecules in the corrosive medium increased the anodic and cathodic over potentials there by decreased the corrosion current ( $I_{corr}$ ) density. This changes increased with increasing inhibitor concentration and the behavior supported the adsorption of extract constituents on the anodic and cathodic sites of the metal. The minimum recorded corrosion current is 3384.59  $\mu$  A in presence of 0.5% extract.

As per the table, the anodic ( $b_a$ ) and cathodic ( $b_c$ ) Tafel slopes do not change significantly in inhibited solution as compared to uninhibited solution. This observation suggested that GTB extract adsorbed on the metal surface by blocking the active sites of steel surface without affecting the mechanism of corrosion. This type of behavior had been observed for mild steel in acid solutions containing GTB<sup>[19]</sup>.

**Table 5:** Polarization parameters and corresponding IE of MS corrosion in 1 M HCl in different concentrations of GTB extract

Conc (%)	E <sub>corr</sub> (mV)	I <sub>corr</sub> ( $\mu$ A)	b <sub>a</sub> (mV/decade)	B <sub>c</sub> (mV/decade)	IE <sub>I<sub>corr</sub></sub> (%)	R <sub>p</sub> (W)	IE <sub>R<sub>p</sub></sub> (%)
0	-518.12	4448.81	97.3	115.4	-	2.31	
0.25	-510.16	4287.32	98.1	117.4	3.63	2.89	20.07
0.3	-512.45	3890.97	97.6	113.1	12.54	3.11	25.72
0.35	-508.21	3670.56	86.5	119.5	17.49	3.19	27.59
0.4	-511.99	3585.74	95.9	112.5	19.4	3.23	28.48
0.45	-512.94	3412.89	93.9	110.4	23.29	3.27	29.36
0.5	-514.3	3384.59	91.5	111.3	23.92	3.47	33.43

The IE calculated from  $I_{corr}$  values are listed in Table 5. Inhibition efficiency increases with the increase in inhibitor concentration. This indicates that as concentration of the extract increases more inhibitor molecules are adsorbed on the metal surface. Polarization resistance ( $R_p$ ) values for mild steel in the absence and presence of different concentrations of the extract were determined by linear polarization curves. The obtained results revealed that the polarization resistance increased with increasing concentration of the extract.

**3.4 Comparison of results of electrochemical studies and non electrochemical studies:** It was clear that all techniques showed that the corrosion inhibition efficiency increases with the increase of inhibitor concentration, reaching a maximum value at 0.5% of inhibitor (Figure 7). The discrepancy in the IE values obtained from different techniques can be interpreted as the result of different measurements time. The difference observed can be attributed to the difference in measurement methods and to the fact that the chemical methods give average corrosion rates, where as electrochemical methods gives instantaneous corrosion rates<sup>[20]</sup>.

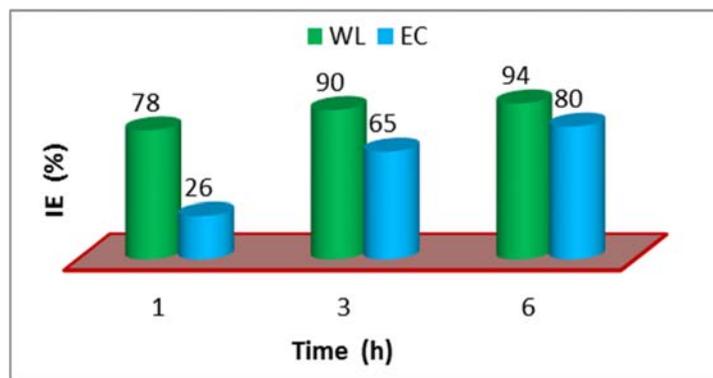


Fig 7: IE of GTB extract for MS corrosion in 1M HCl with weight loss (WL) and electrochemical (EC) methods

### 3.4 Surface analysis

**Scanning Electron Microscopic analysis:** The corrosion prevention ability of the plant extract was strongly supported

by the images recorded by scanning electron microscopic techniques. The photographs of different metal surfaces were given in Figure 8 (a, b and c).

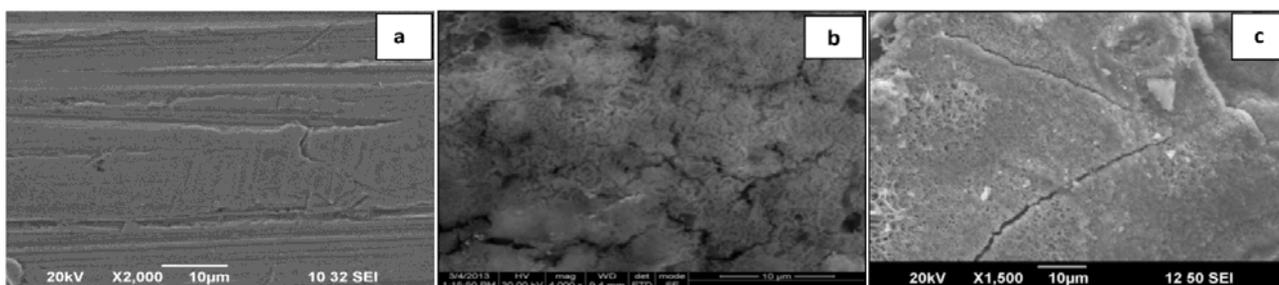


Fig 8: SEM images of (a) Polished MS (b) MS in HCl (c) MS in GTB extract

On comparing these micrographs, the specimen immersed in the inhibitor solutions has apparently smooth surface when compared with that of corroded rough and uneven surface of mild steel immersed in HCl alone (b). This is due to the adsorption of inhibitor molecules on the metal surface forming a protective layer [21]. SEM provides a two-dimensional projection or a two-dimensional image of a sample.

**Energy Dispersive X-ray Spectroscopy (EDAX) Analysis:** Figure 9 (a, b and c) presents to the EDAX spectra of mild steel samples exposed for 3 h in 1 M HCl solutions in the absence and presence of 0.5% extracts. The EDAX spectra in absence of extract Figure a show some additional lines of nitrogen, oxygen, chlorine and sulphur. These additional lines are due to nitrogen, oxygen, and chlorine of the adsorbed inhibitor species. This indicated that extract molecules were strongly adsorbed on the mild steel surface.

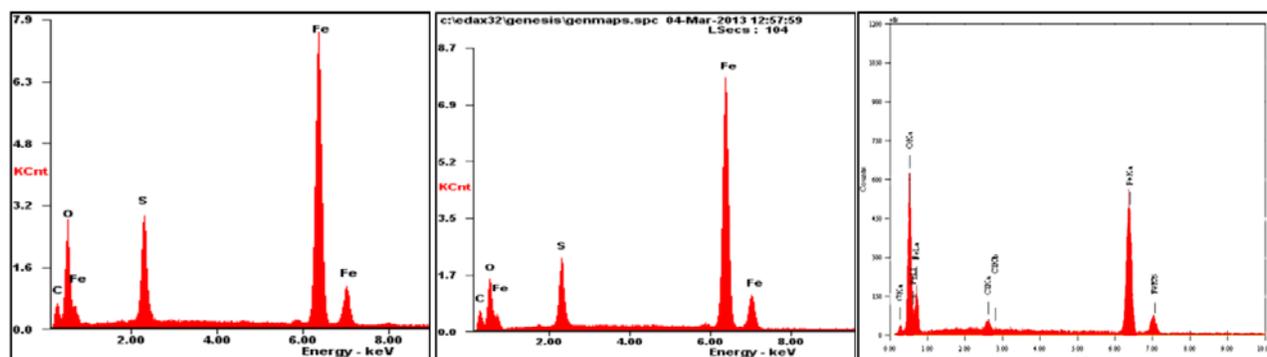


Fig 9: EDAX images of (a) Polished MS (b) MS in HCl (c) MS in GTB extract

**3.5 Mechanism of inhibition:** The inhibitor protected the metal from its deterioration was credited to the adsorption of the inhibitor molecules at the metal/solution interface, forming a protective film. Adsorption process can occur through the replacement of solvent molecules from metal surface by ions and molecules accumulated in the vicinity of metal/solution interface. Ions can accumulate at the metal/solution interface in excess of those required to balance the charge on the metal at the operating potential.

The bark of the GTB contains several phyto constituents and they contain electron rich atoms like nitrogen, oxygen and aromatic and heterocyclic rings. In aqueous acidic solutions, these constituents exist either as neutral molecules or as protonated molecules (cations). The inhibitors may adsorb on the metal/acid solution interface either by the electrostatic interaction of protonated molecules with already adsorbed chloride ions, a donor-acceptor interactions between the  $\pi$ -electrons of aromatic ring and vacant d orbital of surface iron

atoms or by the interaction between unshared electron pairs of hetero atoms and vacant d-orbital of iron surface atoms. Since chloride ions ion had a smaller degree of hydration, thus they could bring excess negative charges in the vicinity of the interface and favors more adsorption of the positively charged inhibitor molecules, which adsorbed through electrostatic interactions.

#### 4. Conclusion

On the basis of the experimental results obtained in the present study, the findings can be concluded as follows. GTB extract acted as an inhibitor for MS corrosion in 1 M HCl medium and showed maximum efficiency at 0.5% of concentration, Polarization studies revealed that GTB extract acted as a mixed type inhibitor. Surface analysis revealed the presence of a protective layer over the mild steel surface by the inhibitors through an adsorption process. The results of weight loss and electrochemical methods were in good agreement.

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