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Green corrosion inhibitor: A comparative study

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Abstract. A comparative study of the inhibitory effect of various parts of the plant *Mimusaps Elangi* (ME) extract (leaves, fruits, barks, seeds) on the corrosion of mild steel in 1 N HCl medium was investigated using weight loss method, potentiodynamic polarization and electrochemical impedance spectroscopy techniques. The polarization studies revealed that the plants extract act as mixed type inhibitor. It was found from the weight loss method that the inhibition efficiency of ME extracts increase in concentration dependents manner which was also supported by the results of electrochemical techniques. On comparison, maximum inhibition efficiency was found in ME leaves extracts with 98.50% at 20 ppm concentration. The SEM morphology of the adsorbed protective film on the mild steel surface has confirmed the high performance of inhibitive effect of the plant extract. Surface coverage values were tested graphically for suitable adsorption. Temperature studies revealed decrease in inhibition efficiency with increase temperature which suggests physisorption mechanism.

Keywords. Mild steel; corrosion test; EIS; SEM.

1. Introduction

Corrosion is the deterioration of metal by chemical attack or reaction with environment. It is a constant and continuous problem, often difficult to eliminate completely. Prevention would be more practical and achievable than complete elimination. Corrosion process develop fast after disruption of the protective barrier and are accompanied by a number of reaction that change the composition and properties of both the metal surface and the local environment, for example, formation of oxides, diffusion of metal cations into matrix, local pH change, and electrochemical potential. Mild steel suffer from severe corrosion in aggressive medium of acids and pickling process. Hydrochloric acid is widely used for pickling, descaling, and chemical cleaning of mild steel. Generally, organic compounds containing O, N, and S atoms are used as inhibitors to reduce the corrosion of mild steel in hydrochloric acid medium [1]. Environmental friendly inhibitors have attracted several researchers. Corrosion control of metals is of technical, economical, environmental and aesthetic importance. The use of inhibitor is one amongst the simplest choices of protective metals and alloys against corrosion particularly in acid solution. Corrosion inhibitor is a substance added in small concentration to an environment, effectively reduces the corrosion rate of a metal exposed to it. Large numbers of organic compound have been studied and are still being studied to assess their corrosion inhibition potential. However, most of these substances are not only expensive but also pose health and environment hazards prompting the search for their replacement. The plant extracts are considered as an incredibly rich source of environmentally acceptable corrosion inhibitor. A lot of natural products have been previously used as corrosion inhibitor for different metals in various environments [2–15]. Also plants have been recognized as source of naturally occurring compounds that are generally referred to as "green" compound, some with rather complex molecular structure and having a variety of physical, chemical and biological properties. A number of these compounds are enjoying use in traditional application such as pharmaceuticals and biofuels. Furthermore, there has been a growing trend in the use of natural and medicinal plant used as corrosion inhibitor as they are environmentally safe, readily available and renewable source of a wide range of chemical. Due to biodegradable, eco-friendly, low cost and easily availability, the extract of some common plants based chemical and their by-product have been tried inhibitor for metal under different environment and *Mimusaps Elangi* (ME) is one of the universal plants having medicinal activities.

Recently, many medicinal plants extract have been reported as effective corrosion inhibitor (*allium sativum* and *madhuca longifolia*). Medicinal values of *Mimusaps Elangi* plants lie in some phytochemical substances that produce a definite physiological action on human body

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[16]. In this study, same medicinal plants but various parts like leaves, seeds, barks, and fruits have been selected to study the inhibition effect on the corrosion of mild steel in 1 N HCl media.

2. Experimental procedure

2.1 *Preparation of mild steel specimen*

Mild steel strips were mechanically cut into strips of size 4 cm × 2 cm × 0.1 cm containing the composition of at% of C- 0.030, Mn- 0.169, Si- 0.015, P- 0.031, S - 0.029, Cr- 0.029, Ni- 0.030, Mo- 0.016, Cu- 0.017, the remainder Fe and provided with a hole of uniform diameter to facilitate suspension of the strips in the test solution for weight loss method. For electrochemical studies, mild steel strips of the same composition but with an exposed area of 1 cm^2 were used. Mild steel strips were polished by using emery paper of 400, 600, 800, 1000 and 1200 grade, subsequently degreased with acetone and finally washed with deionized water, and stored in the desiccators in 5 minutes. Accurate weight of the metal was taken using four digital electronic analytical balance (shimadzu ay220 model).

2.2 *Preparation of the plant extract*

The leaves, barks, fruits, and seeds of the medicinal plants *Mimusaps Elangi* were taken and cut into small pieces, and dried in room temperature and ground well into powder. 50 g of the powder from each was refluxed in 500 ml distilled water and kept overnight. The refluxed solution was then filtered carefully, the filtrate volume was made up to 250 ml using double distilled water which was the stock solution, and the concentration of the stock solution was expressed in term of ppm [17].

2.3 *Weight loss method*

Mild steel specimens were immersed in 200 ml of 1 N HCl solution without and with various concentrations of the inhibitors using glass hooks and rods for a predetermined time period (24 hours) at room temperature. The weights of the specimens before and after immersion were determined using four digit electronic analytical balance (shimadzu ay220 model). From the weight loss measurements, the corrosion rate was calculated using the following relationship.

$$\mathrm{CR\,(mmpy)} = \frac{\mathbf{K} \times \mathrm{Weight\,Loss}}{\mathrm{D} \times \mathrm{A} \times \mathrm{t\,(in\,hours)}} \tag{1}$$

where K = 8.76 × 10^4 (constant), D is density in gm/cm^3 (7.86), W is weight loss in grams and A is area in cm^2.

The inhibition efficiency (%) was calculated using equation (2)

$$\mathrm{IE\,\%} = \frac{\mathrm{W}_0 - \mathrm{W}_i}{\mathrm{W}_0} \times 100 \tag{2}$$

where W_0 and W_i are the weight loss in the absence and presence of the inhibitor, respectively.

2.4 *Potentiodynamic polarization methods*

Potentiodynamic polarization measurements of the samples were carried out using CHI660E electrochemical analyzer. The polarization measurements were made to evaluate the corrosion current, corrosion potential from Tafel slope. Experiments were carried out in a conventional three electrode cell assembly with mild steel specimen of 1 cm^2 area which was exposed and the rest being covered with red lacquer, was used as working electrode, a rectangular Pt foil as the counter electrode, and a saturated calomel electrode as standard reference electrode. A time interval of 15 minutes was given for each experiment to attain the steady state open circuit potential. The polarization was carried from a cathodic potential of −800 mV (vs SCE) to an anodic potential of −200 mV (vs SCE) at a sweep rate of 1 mV per second. From the polarization curves, Tafel slopes, corrosion potential, and corrosion current were calculated. The inhibitor efficiency was calculated using the formula:

$$\mathrm{IE\,\%} = \frac{\mathrm{i_{Corr}} - \mathrm{i_{*Corr}}}{\mathrm{i_{Corr}}} \times 100 \tag{3}$$

where i_{corr} and i_{*corr} are corrosion current in the absence and presence of inhibitors.

2.5 *Electrochemical impedance method*

The electrochemical AC-Impedance measurements of the samples were also performed using CHI660 E electrochemical analyzer. Experiments were carried out in a conventional three electrode cell assembly as that used for potentiodynamic polarization studies. A sine wave with amplitude of 10 mV was superimposed on the steady state open circuit potential. The real part (Z′) and the imaginary part (Z″) were measured at various frequencies in the range of 100 KHz to 10 MHz. A plot of Z′ versus Z″ was made. From the plot, the charge transfer resistance (R_{ct}) was calculated, and the double layer capacitance (C_{dl}) was then calculated using formula:

$$\mathrm{C_{dl}} = \frac{1}{2\pi} f_{max} R_{ct} \tag{4}$$

where R_{ct} is charge transfer resistance, and C_{dl} is double layer capacitance. The experiments were carried out in the

Table 1. Percentage of inhibition efficiency (IE %) and corrosion rate (CR) at different concentration of inhibitor in 1 N HCl medium.

Parts of *Mimuaps Elangi* plant	Conc.of the extract (ppm)	Weight loss (g)	Corrosion rate (mmpy)	Inhibition efficiency (%)
Mimuaps Elangi leaves	Blank	0.1107	64.258	–
	5	0.0102	0.986	80.58
	10	0.0087	0.875	86.80
	15	0.0067	0.754	89.04
	20	0.0020	0.638	98.50
Mimuaps Elangi barks	5	0.0066	4.817	80.70
	10	0.0047	2.318	88.18
	15	0.0035	2.031	93.72
	20	0.0022	0.116	97.34
Mimuaps Elangi fruits	5	0.0083	4.817	65.20
	10	0.0040	2.321	72.84
	15	0.0025	1.290	86.37
	20	0.0012	0.934	97.17
Mimuaps Elangi seeds	5	0.0120	6.965	81.01
	10	0.0110	3.385	90.24
	15	0.0089	1.992	94.56
	20	0.0003	0.170	98.32

absence and presence of different concentration of inhibitor.

$$IE\% = \frac{R_{ct} - R_{ct}^{0}}{R_{ct}} \times 100 \quad (5)$$

where R_{ct} and R_{ct}^{0} are the charge transfer resistance values in the inhibited and uninhibited solution, respectively.

2.6 *Scanning electron microscopy*

The mild steel specimen immersed in blank and in the inhibitor solution for a period of one day was removed, rinsed with double distilled water, dried and observed in a scanning electron microscope to examine the surface morphology. The surface morphology measurements of mild steel were examined using (JEOL) computer controlled scanning electron microscope.

Table 2. Electrochemical parameters from polarization measurement and calculated values of inhibition efficiency.

Parts of *ME* plant	Conc. (ppm)	E_{corr} (mV/SCE)	i_{corr} (mA/cm^2)	b_c (mV/dec.)	b_a (mV/dec.)	IE (%)
Mimuaps Elangi leaves	Blank	−0.446	3.781×10^{-3}	203.95	132.52	*
	5	−0.445	1.469×10^{-3}	197.55	104.54	61.14
	10	−0.445	1.255×10^{-3}	192.49	101.64	66.80
	15	−0.454	1.609×10^{-3}	184.84	124.28	95.74
	20	−0.452	6.914×10^{-4}	159.97	097.62	81.71
Mimuaps Elangi bark	Blank	−0.471	5.220×10^{-3}	199.01	140.52	*
	5	−0.460	4.524×10^{-4}	174.71	070.51	91.33
	10	−0.479	6.154×10^{-4}	146.57	094.24	88.21
	15	−0.474	4.642×10^{-4}	145.47	091.02	91.10
	20	−0.477	2.308×10^{-4}	136.70	074.16	95.57
Mimuaps Elangi fruits	Blank	−0.466	3.785×10^{-3}	203.95	132.52	*
	5	−0.450	1.061×10^{-3}	147.32	073.13	71.96
	10	−0.466	7.255×10^{-4}	133.36	091.72	80.83
	15	−0.464	3.236×10^{-4}	137.74	075.71	91.45
	20	−0.492	6.071×10^{-4}	133.29	102.65	83.96
Mimuaps Elangi seeds	Blank	−0.472	6.488×10^{-3}	208.25	168.62	*
	5	−0.464	4.022×10^{-3}	205.53	132.84	38.01
	10	−0.464	2.819×10^{-3}	199.36	126.98	56.58
	15	−0.472	1.145×10^{-5}	168.30	111.51	98.23
	20	−0.470	1.735×10^{-3}	166.61	111.27	97.32

*We are not calculating the inhibition efficiency (IE %) for blank. Instead leaving an empty place we are fixing

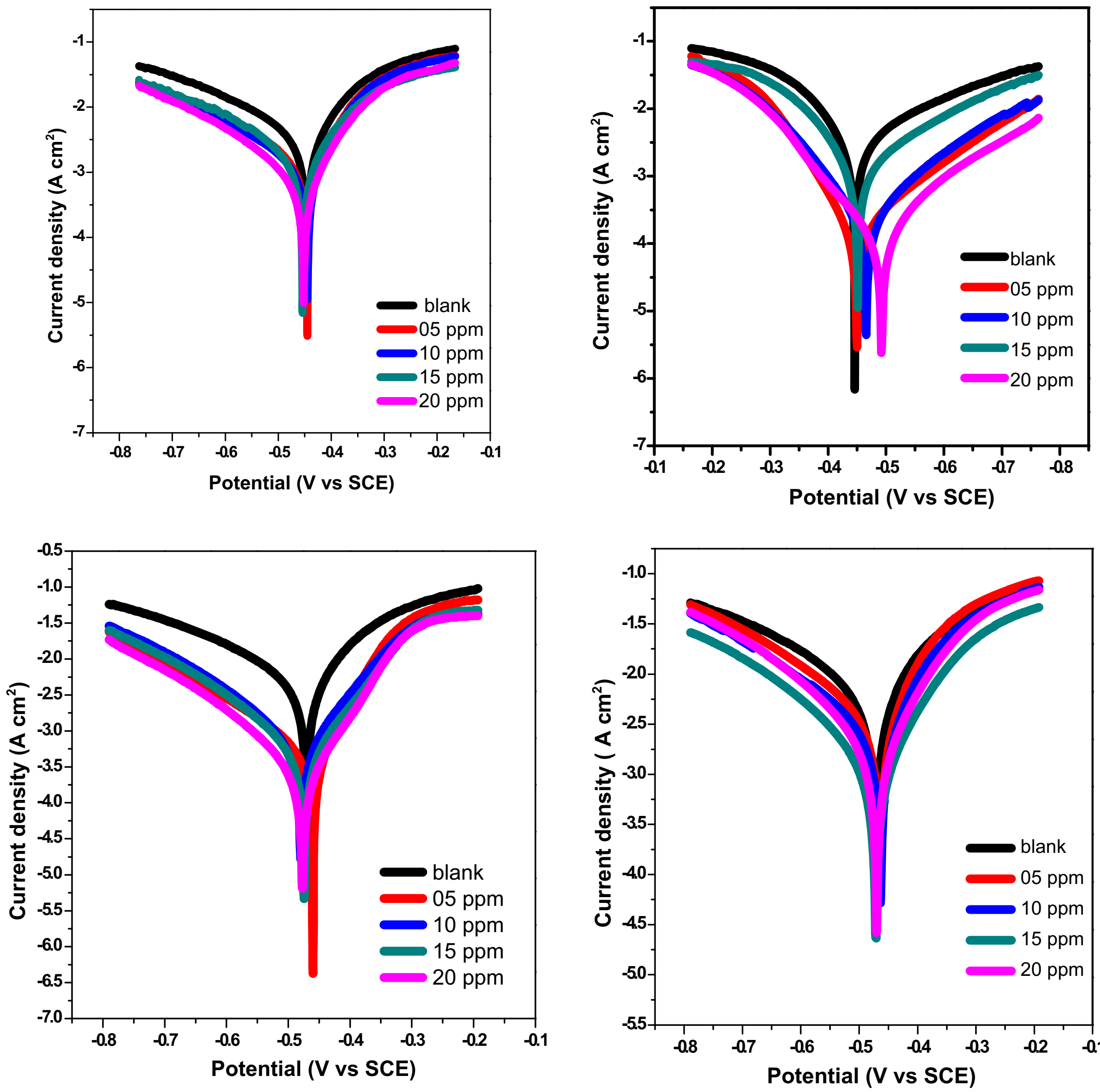

Figure 1. Tafel plots for mild steel in 1 N HCl solution in the absence and presence of different concentration of *Mimusaps Elangi* extracts of (**a**) leaves, (**b**) barks, (**c**) fruits and (**d**) seeds.

3. Results and discussion

3.1 *Weight loss method*

The weight loss studies were done in 1 N HCl acid in the absence and presence of various concentration of the plant extract ranging from 5 to 20 ppm. Using the weight loss data, the corrosion rate and inhibition efficiency have been calculated and the values are given in table 1. It was observed from the table that with the addition of the plant extract to 1 N HCl acid, the weight loss of mild steel decreased, the corrosion rate also decreased, while the inhibition efficiency increased. The optimum concentration for *Mimusaps Elangi* leaves was found to be 20 ppm with maximum inhibition efficiency of 98.50%, barks at 20 ppm with maximum inhibition efficiency of 97.34%, fruits at 20 ppm with maximum inhibition efficiency of 92.18%, seeds at 20 ppm with maximum inhibition efficiency of 98.32% for a period of one day of immersion time. This result indicated that the plant extract could act as effective corrosion inhibitor for mild steel in 1 N HCl. The order of inhibition efficiency among the same plant but different parts of extracts on mild steel in 1 N HCl was found to be *Mimusaps Elangi* leaves > seeds > barks > fruits.

3.2 *Potentiodynamic polarization studies*

Electrochemical parameter like corrosion potential (E_{corr}), current density (i_{corr}), cathodic Tafel slope (bc), anodic Tafel slope (ba), percentage of inhibition efficiency according to polarization studies are shown in table 2. It was observed from the table that the corrosion current density (i_{corr}) decreases with increasing concentration of the

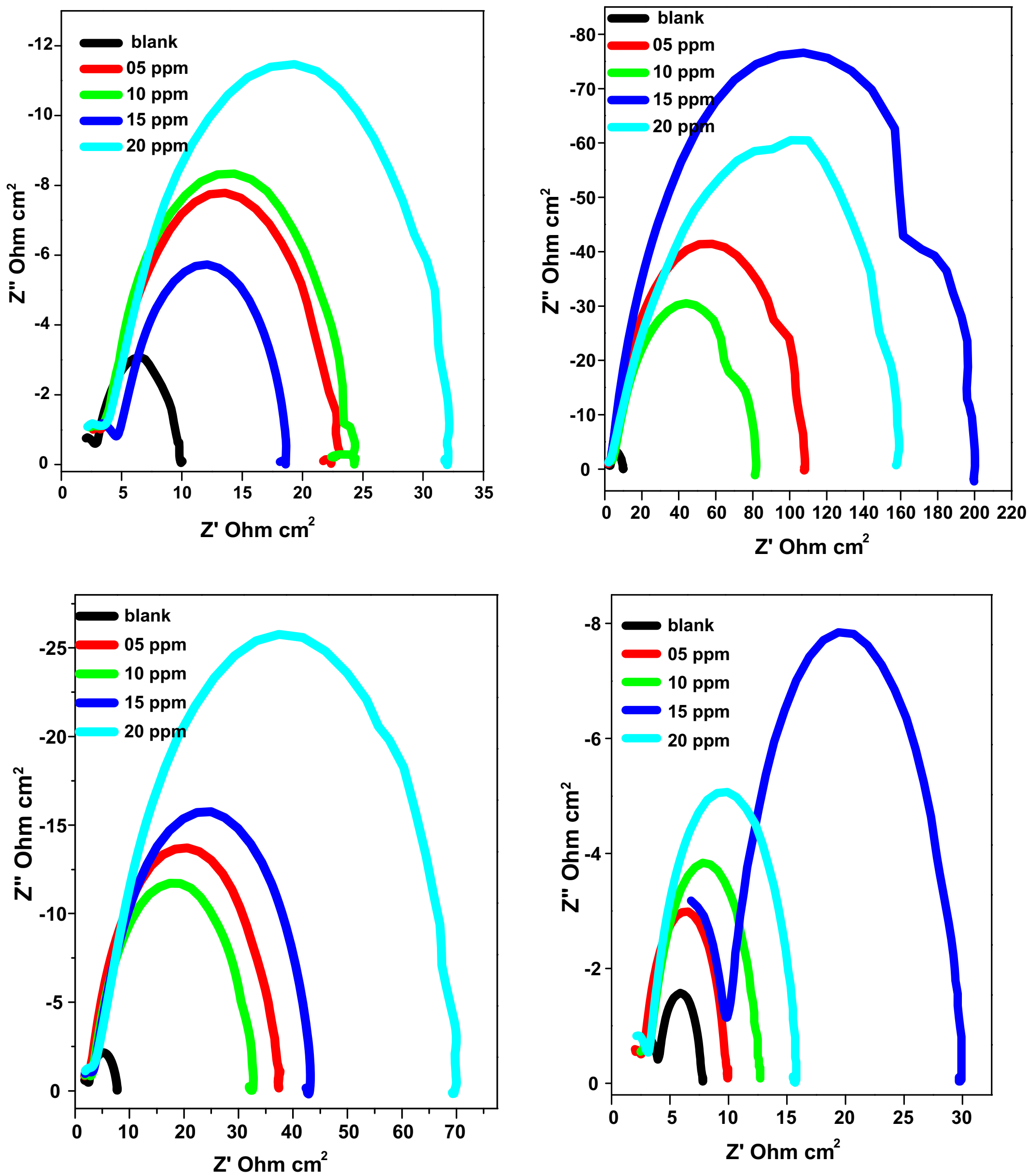

Figure 2. Nyquist plots for mild steel in 1 N HCl acid solution without and with presence of different concentration of *Mimusaps Elangi* extract of (**a**) leaves, (**b**) bark, (**c**) fruits and (**d**) seeds.

inhibitors. The polarization studies revealed that the corrosion current density (i_{corr}) markedly decreased with the addition of the extract and the corrosion potential shifts to less negative values upon addition of the plant extract. Moreover, the values of anodic and cathodic Tafel slope are slightly changed indicating that this behavior reflects the plant extract's ability to inhibit the corrosion of mild steel in 1 N HCl solution via the adsorption of its molecule on both anodic and cathodic sites.

As the increased concentration of the plant extract from 5 ppm to 20 ppm, the maximum inhibition efficiency of 98.23% was observed for *Mimusaps Elangi* seeds extract at 15 ppm, for leaves with 95.74% at 15 ppm, bark with 95.57% at 20 ppm, and for fruits with 91.10% at 15 ppm of the extract. It was observed from figure 1 that the anodic and cathodic curves showed lower current density in the presence of ME extracts than those recorded in the solution without ME extracts. This indicates that ME extracts inhibits the corrosion process. The corrosion current density values decreased considerably for green inhibitor in the acid medium.

However, the shift in the values of corrosion potential (E_{corr}) for ME plant extract is not significant. Generally, an inhibitor can be classified as cathodic or anodic type if the shift of corrosion potential in the presence of the inhibitor was more than 85 mV, with respect to that in the absence of the inhibitor [18–20]. From the results, the charges of E_{corr} are less than 85 mV for studied plants extract, which

Table 3. Impedance parameter for mild steel in 1 N HCl acid solution in the absence and presence of varied concentration of inhibitor.

Parts of *Mimuaps Elangi* plant	Concentraion (ppm)	R_{ct} (ohm cm^2)	C_{dl} (μF/cm^2)	IE (%)
Mimuaps Elangi leaves	Blank	7.642	6.763×10^{-3}	*
	5	21.239	9.549×10^{-4}	64.06
	10	22.006	8.723×10^{-4}	65.27
	15	15.465	1.241×10^{-3}	50.58
	20	31.034	4.487×10^{-4}	75.53
Mimuaps Elangi barks	Blank	6.384	1.162×10^{-3}	*
	5	36.672	3.183×10^{-4}	82.59
	10	31.751	4.246×10^{-4}	79.89
	15	42.888	2.358×10^{-4}	85.11
	20	72.732	8.604×10^{-5}	91.22
Mimuaps Elangi fruits	Blank	7.469	6.835×10^{-3}	*
	5	111.248	3.481×10^{-5}	93.28
	10	82.984	6.332×10^{-5}	90.99
	15	203.45	1.026×10^{-5}	96.32
	20	166.375	1.621×10^{-5}	95.51
Mimuaps Elangi seeds	Blank	4.670	2.148×10^{-2}	*
	5	8.557	6.276×10^{-3}	45.43
	10	10.060	4.140×10^{-3}	53.57
	15	28.959	6.961×10^{-4}	83.87
	20	14.375	2.194×10^{-3}	67.54

*We are not calculating the inhibition efficiency (IE %) for blank. Instead leaving an empty place we are fixing

Table 4. Phytochemical screening test for extract of *Mimuaps Elangi*.

Phytochemical test	Leaves	bark	fruit	Seeds
Alkaloids	+	+	+	+
Carbohydrates	+	+	−	−
Proteins	+	+	+	−
Saponins	−	−	+	+
Thiols	+	−	−	−
Tannins	−	−	+	−
Flavanoids	−	+	+	+
Phenol	−	+	+	−
Glycosides	−	+	+	+

(+) Presence, (−) Absence

indicates that ME extracts act as a mixed type inhibitor for the corrosion of mild steel in 1 N HCl medium [7, 21–30].

3.3 *Electrochemical impedance studies*

The electrochemical impedance spectroscopy was also used to study the characterization of electrode behavior in 1 N HCl solution without and with the addition of plants extracts. Figure 2 shows the Nyquist plots of various parts of *Mimusaps Elangi* plants like leaves, fruits, barks and seeds at various concentrations (5–20 ppm). The parameter deduced from the fit of Nyquist diagram for 1 N HCl medium containing various concentration of *Mimusaps Elangi* are given in table 3. It was observed from the figure that the Nyquist plots are almost in a semicircular appearance, indicating that the charge-transfer process mainly controls the corrosion of mild steel [31–35].

Deviations of perfect Circular shapes are often referred to the frequency dispersion of interfacial impedance. This anomalous phenomenon may be attributed to the inhomogeneity of the electrode surface arising from surface roughness or interfacial phenomena. In fact, in the presence of the plant extracts, the charge transfer resistance (R_{ct}) values have enhanced and the values of double layer capacitance (C_{dl}) were brought down to the maximum extent. The decrease in C_{dl} showed that the adsorption of the inhibitor takes place on the metal surface in acidic solution. Impedance studied that the irregular value of C_{dl} at the inhibitor concentration was not defined. A good agreement was observed between the results of weight loss and electrochemical methods.

3.4 *Phytochemical screening method*

Phytochemical screening of the aerial parts of plant's powder (aqueous) extract was tested in order to find the presence of various chemical constituent included alkaloids, carbohydrates, proteins, saponins, triterpinoids and tannins and the results are listed in table 4.

3.5 *Surface examination studies*

Surface examination of mild steel specimen was made using JEOL scanning electron microscope (SEM). The mild steel specimens after immersion in 1 N HCl solution

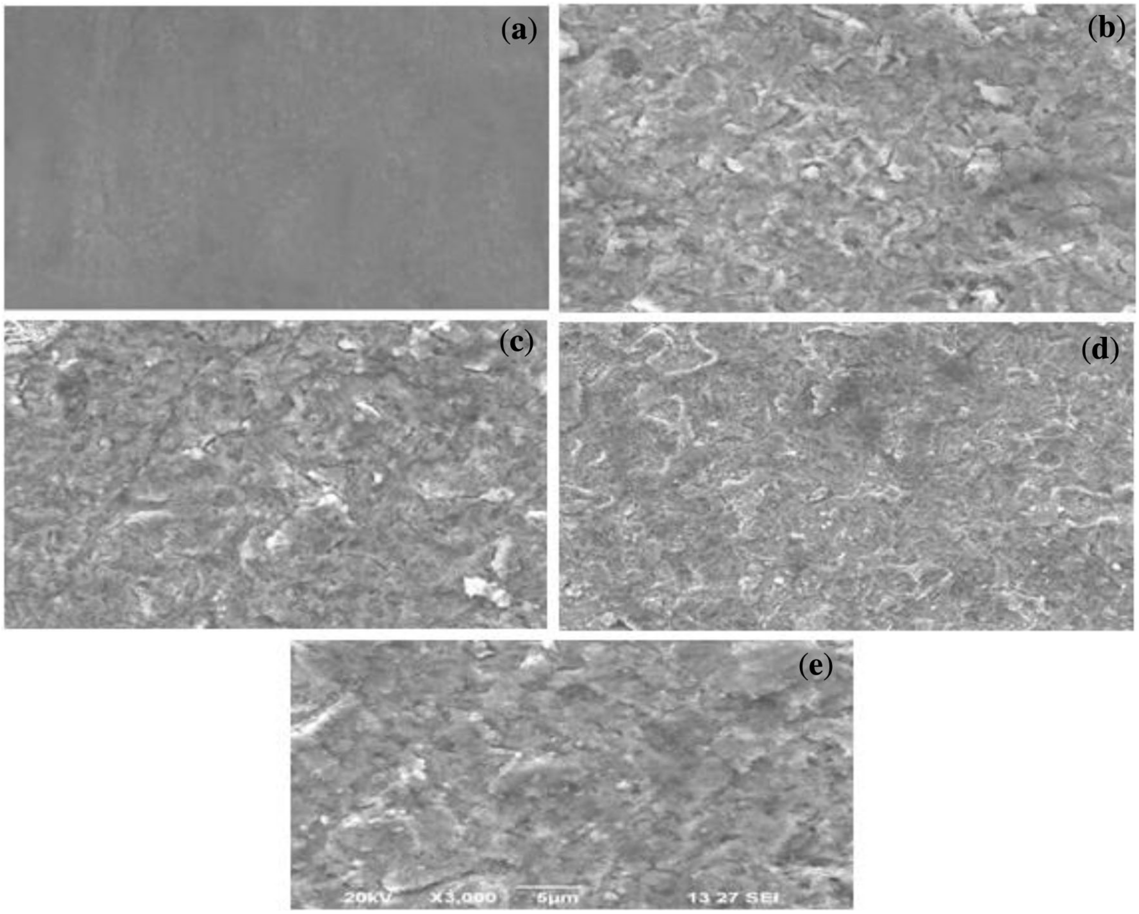

Figure 3. SEM image of the surface of mild steel after immersion for 24 hours in 1 N HCl solution (**a**) blank and in the presence of optimum concentration of the plant extracts from, (**b**) leaves, (**c**) bark, (**d**) fruits and (**e**) seeds.

Table 5. Inhibition efficiency as a various immersion time.

Parts of *Mimuaps Elangi* plant	Conc. (ppm)	Inhibition efficiency (%)					
		1 h	3 h	5 h	7 h	9 h	12 h
Mimuaps Elangi leaves	5	57.98	59.48	64.56	54.39	64.22	54.56
	10	65.39	69.59	70.54	66.76	70.14	78.72
	15	74.95	81.36	77.16	77.96	82.49	87.95
	20	83.16	92.16	84.15	80.37	93.76	98.19
Mimuaps Elangi barks	5	70.11	70.30	60.53	76.46	65.78	72.12
	10	74.08	85.19	77.28	83.12	66.28	83.38
	15	79.35	91.06	86.19	87.22	77.92	92.02
	20	91.93	93.83	95.05	90.09	89.78	96.91
Mimuaps Elangi fruits	5	70.81	78.90	72.44	74.21	80.89	75.02
	10	76.15	86.16	77.63	76.78	89.28	79.53
	15	87.34	94.56	84.60	82.59	94.19	88.98
	20	94.21	97.89	92.19	93.65	95.66	97.16
Mimuaps Elangi seeds	5	68.10	70.93	72.65	75.78	76.87	79.21
	10	79.98	84.24	85.33	86.98	82.96	83.56
	15	88.98	89.94	89.89	87.48	89.08	91.33
	20	95.62	96.37	97.25	93.09	94.54	98.60

Table 6. IE at various temperatures.

Parts of *Mimuaps Elangi* plant	Conc. of the extract (ppm)	IE (%)		
		303 K	313 K	323 K
Mimuaps Elangi leaves	5	59.48	60.24	46.48
	10	69.59	77.54	55.36
	15	81.36	83.74	68.04
	20	91.02	87.22	73.66
Mimuaps Elangi barks	5	65.71	56.58	59.58
	10	73.89	62.24	64.86
	15	77.48	74.41	69.24
	20	80.45	77.13	75.50
Mimuaps Elangi fruits	5	66.12	59.90	47.41
	10	67.90	61.55	60.55
	15	73.65	66.86	66.27
	20	74.97	72.12	79.80
Mimuaps Elangi seeds	5	39.25	50.29	40.02
	10	64.48	60.73	54.82
	15	71.49	66.69	68.18
	20	77.59	74.78	73.10

in the presence of optimum concentration of the plant extracts for one day, at room temperature, were taken out, dried, and kept in desiccators. The SEM images of mild steel immersed in 1 N HCl in the absence and presence of the inhibitor is shown in figure 3. SEM studies revealed that the plants extract which was adsorbed on the metal surface decreased the metal surface from corrosion attack.

3.6 *Effect of immersion time*

The variation of inhibition efficiency for different concentration of Plant extract of ME was listed in table 5. Maximum inhibition efficiency for 1 N HCl was found to be 97.89% at 7 h with 20 ppm concentration of the inhibitor. This behavior may be attributed to the increase of the surface coverage by the extract, which retards the corrosion of mild steel. Increase in inhibition efficiency from 12 hours shown strong adsorption of constituents present in the plant extract on the surface of mild steel giving it a protective layer. From this it clearly indicated that ME plants extract acted as a very good corrosion inhibitor for mild steel in HCl solution.

3.7 *Effect of temperature*

The effect of temperature on the corrosion inhibition properties of ME extract was studied by exposing the mild steel to 1 N HCl containing 5, 10, 15, 20 ppm of the plants extract in the temperature range of 303–333 K and the data obtained was listed in table 6. The data in table 6 indicate that the leaves extract is effective as inhibitor for mild steel in 1 N HCl up to 303 K and decrease thereafter. The inhibition showed a maximum 91.02% at 303 K leaves extract in 1 N HCl.

3.8 *Adsorption isotherms*

The results of weight loss study (table 6) show that the percentage of IE increases with increase in the concentration of inhibitor. This suggests that the corrosion inhibitive activity is mainly due to adsorption of various components of plant species on to the MS surface, particularly adsorption of the basic constituents like alkaloids, flavonoids, polyphenols, hydrolysis products of proteins, amine compounds which are present in the plant extract may be the reason for anticorrosion activity of the analyzed plant species. In the case of *ME (Leaves, barks, fruits, seeds)* increase of temperature increases the IE but in most of the cases the temperature increases the IE decreases. It suggests that the inhibition occurred through chemisorption of phytoconstituents on the MS surface. The increase of temperature decreases the hydrogen evolution overvoltage that leads to the spurt in the cathodic reaction. On the other hand, increase of temperature accelerates the chemisorption of the inhibitor on the metal surface. When the latter effect is predominant the final result is an increase of the inhibiting effect, which was observed in most investigated plants. Weight loss data are quite useful in determining inhibitor adsorption characteristics. Such data are applied in construction of adsorption isotherms which give detailed information on adsorption mechanism. Well known isotherm Temkin isotherm was tested for all the data. For Temkin isotherm, surface coverage (θ) was plotted against ln C (figure 4). A straight line was obtained for all the plants indicating that the green inhibitors follow Temkin isotherms.

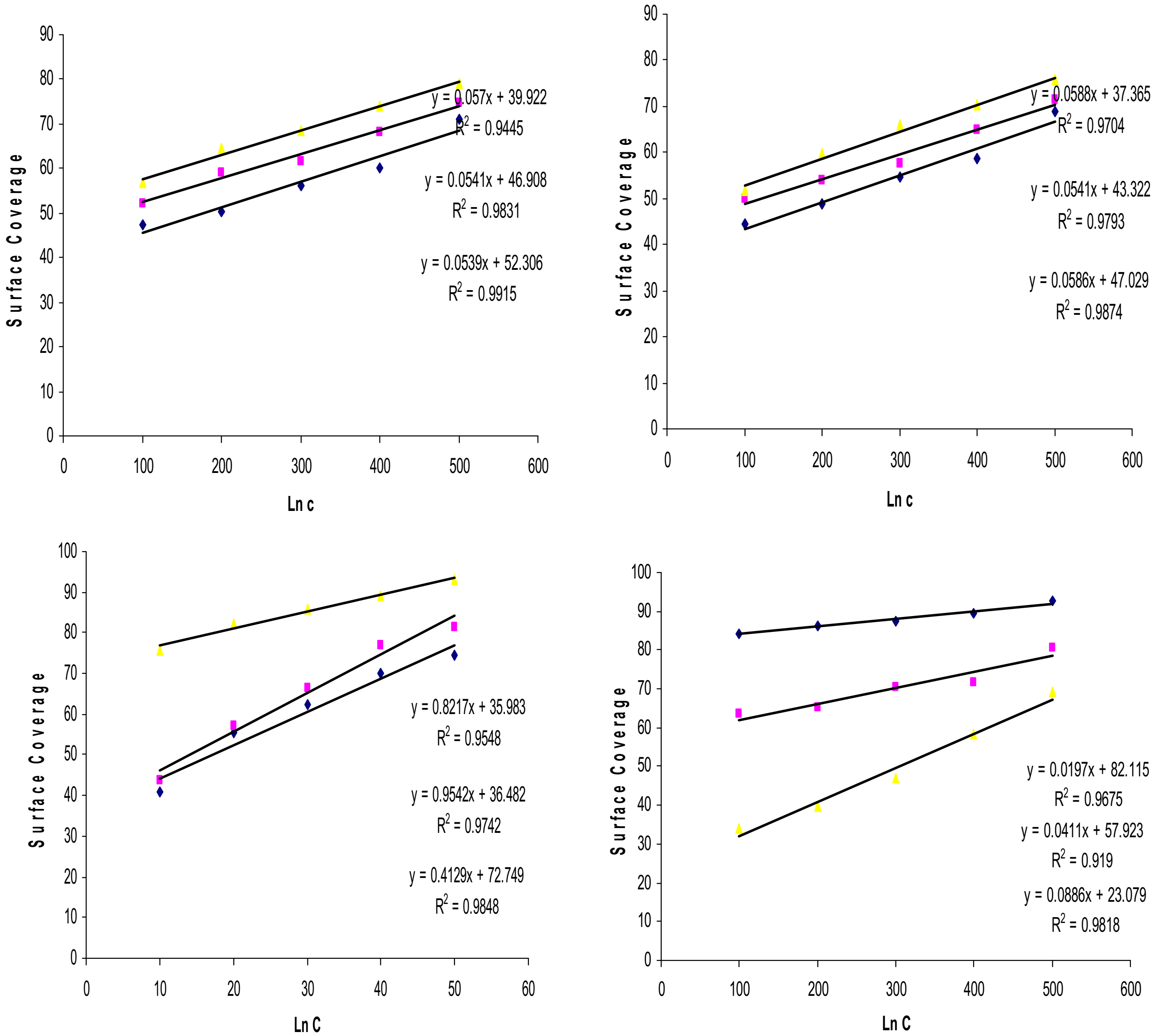

Figure 4. Temkin adsorption isotherm plot for mild steel in 1 N HCl containing different concentration (**a**) leaves, (**b**) fruits, (**c**) barks and (**d**) seeds of the extract.

4. Mechanism of corrosion inhibition

From the results obtained from different electrochemical and mass loss measurements, it can be concluded that ME plants inhibits the corrosion of mild steel in 1 N HCl by adsorption at mild steel interface. It is a general assumption of natural inhibitors at the metal surface interface is the first step in the mechanism of the inhibitor action. Natural molecules may be adsorbed on the metal surface in four ways namely (i) electrostatic interaction between the charged molecules and the charged metal, (ii) interaction of unshared electron pairs in the molecules with the metal, (iii) interaction of pi electron with the metal and (iv) a combination of type.

In general, ME plants contains alkaloids, amino acids, proteins, carbohydrates, tannins, with the heteroatoms like N, O, etc. which may act as reaction centers for the adsorption process. The inhibition of active dissolution of the metal is due to the adsorption of the inhibitor molecules on the metal surface forming a protective film. The inhibitor molecules can be adsorbed onto the metal surface through electron transfer from the adsorbed species to the vacant electron orbital of low energy in the metal to form a co-ordinate type link. The inhibition efficiency depends on many factors including the number of adsorption centers, mode of interactions with metal surfaces, molecular size and structure. It is well known that iron has co-ordinate affinity towards nitrogen, sulphur and oxygen bearing ligands. Hence, adsorption on iron can be attributed to co-ordination through carbonyl linkage, hetero atom (N and O) and pi electron of aromatic ring. These are unshared electron pairs on N and O which are capable of forming a coordination bond with iron. ME plants extract is more effectively adsorbed. From all the above facts, it is confirmed that the investigated ME plants follow type (iv) mechanism [36, 37].

5. Conclusion

Mimusaps Elangi plants act as efficient corrosion pickling inhibitor on mild steel in 1 N HCl acid. The use of *Mimusaps Elangi* plants as corrosion inhibitor was environmentally safe, nontoxic, ecofriendly, cost effective and easily available. The extracts of *Mimusaps Elangi* plants showed maximum efficiency of 98.50% leaves at the optimum concentration of 20 ppm for one day immersion time at room temperature. Results obtained in non-electrochemical methods (weight loss method) have good agreement with the electrochemical methods. The *Mimusaps Elangi* plants extracts act as a mixed type inhibitor on the metal surface. SEM examination showed that there was improvement in the surface morphology of the as corroded inhibited mild steel compared to uninhibited samples. The adsorption fits well to the Temkin adsorption isotherm. Temperature study suggests that the physisroption mechanism. The results suggest that *a Mimusaps Elangi plant is* a corrosion inhibitor for mild steel in HCl and they can be used to replace toxic and non-bio gradable inhibitors.

List of symbols

CR	Corrosion rate
ppm	Parts per million
Cdl	Double layer capacitance
Rct	Charge transfer resistance
Ecorr	Corrosion potential
icorr	Current density
θ	Surface coverage area
ba	Anodic Tafel slope
bc	Cathodic Tafel slope
z′	Real part
z″	Imaginary part
g	Gram
cm	Centimeter
w	Weight
%	Percentage

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