Chemical Science Review and Letters ISSN 2278-6783

Research Article

Heliconia rostrata Flower Extract – A New Eco-Friendly Inhibitor for Mild steel Acid Corrosion

A.Mathina[1*] and R.Rajalakshmi[2]

[1]Department of Science and Humanities, Faculty of Engineering, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore-641043, Tamil Nadu, India
[2]Department of Chemistry, Faculty of science, Avinashilingam Institute for Home Science and Higher Education for Women, Coimbatore-641043, Tamil Nadu, India

Abstract

The inhibition effect of ***Heliconia rostrata*** flower extract (HRFE) on mild steel corrosion in 1M HCl has been studied by conventional mass loss, electrochemical impedance and Potentiodynamic polarization techniques. The inhibition efficiency increased with increase in concentration of plant extract. Potentiodynamic polarization curves showed that HRFE acted as mixed inhibitor in hydrochloric acid. This was supported by the impedance measurements which showed a change in the charge transfer resistance and double layer capacitance indicating adsorption of HRFE on the mild steel surface. Scanning electron microscopy (SEM) technique was used to ascertain the inhibitive nature of the examined inhibitor. Overall results obtained were encouraging and hence bring to light a new ecofriendly material for the corrosion inhibition of mild steel in Hydrochloric acid medium.

Keywords: *Heliconia rostrata*, corrosion inhibition, Potentiodynamic polarization, SEM, Acid Medium

***Correspondence**
A.Mathina
Email: madhimohamed@gmail.com

Introduction

Corrosion is the destructive attack on a metal or metal alloy by chemical or electrochemical reaction with its environment [1]. The protection of metals against corrosion has attracted much attention globally as a result of huge losses of natural resources and finances that are sustained annually all over the world due to corrosion. Mild steel is widely used in most of the chemical industries due to its low cost and easy availability for fabrication. In aggressive environment it suffers severe corrosion. So it has to be protected. Corrosion inhibitors are compounds that are added in small quantities to an environment to prevent corrosion of metals. Most of the efficient acid inhibitors are organic compounds containing nitrogen, sulphur and/or oxygen atoms in their molecule [2, 3].Due to the currently imposed environmental requirements for friendly corrosion inhibitors, there is a growing interest in the use of natural products such as leaves or seeds extract. So the trend of using them has become increasingly important in the recent years. Green corrosion inhibitors are preferred because they are environmentally friendly. Natural products of plant origin contain different organic compounds (e.g. alkaloids, tannins, pigments organic and amino acids) and most are known to have inhibitive actions [4,5]. Various natural products,e.g. Tobacco extract [6],aloe extract[7],*Mahasudarshana Churna* extract[8], *Azadirachta Indica* extract [9], Natural Honey [10,11], some Herbs extracts [12], *Opuntia* extract [13], etc. have been reported to be very good inhibitors. Our research team also investigated the plant extracts for corrosion inhibition studies which include sprouted seeds of *Phaseolus aureus*, *Cocos nucifera* Shell, seed extract of *Cyamopsis tetragonoloba*, petiole extract of *Cocos nucifera*, staminate flower extract of *Cocos nucifera* and leaf extract of *Ervatamia coronaria,Cocos nucifera L. Peduncle*, leaf extract of *Mundulea sericea* and leaves extract of *Dodonaea Viscosa(L)* [14-23].Therefore, the present focus is to investigate the corrosion behaviour of mild steel in 1 M HCl solution in the presence of *Heliconia rostrata flower* extract (HRFE) using mass loss, Potentiodynamic polarization and electrochemical impedance techniques. *Heliconia rostrata* is one of the most recognized and widely grown species. This plant has downward-facing flowers, the flowers thus providing a source of nectar to birds. Heliconia rostrata has a pendent inflorescence and the bracts are red with greenish yellow edges. It is a very popular species and one of the more common in cultivation.

Materials and Methods

Mild steel specimen was used. Mild steel(MS) specimens were cut into 1×5 cm^2 strips with 2 mm thickness, mechanically polished, washed in double distilled water, dried, stored in a dessicator and used for the entire immersion studies. 1 M HCl solutions were prepared from analytical grade reagent HCl and de-ionized water.

Preparation of plant extract

Heliconia rostrata flowers were collected from the nearby locality and shade dried. 25 g of the dried flowers were refluxed with 500 mL of 1M HCl for 3 hours and kept overnight. The cooled extract was filtered and made up to 500 mL (5% extract). Phytochemical screening of the Heliconia rostrata flower extract was carried out using standard procedure [24].

Mass loss method

Pre weighed 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. The test specimens were removed and then washed with de-ionised water, dried and reweighed. From the initial and final masses of the specimen, the mass loss was calculated as per ASTM G1-2 [25, 26] procedure. From the mass loss, corrosion rate, inhibition efficiency and surface coverage were determined using the following relationship.

$$\text{Corrosion Rate (mpy)} = \frac{K \times W}{DAT}$$

K = Constant-$3.45*10^{-6}$ (mpy), W = Mass loss in grams; D = Density of mild steel in mg / cm^3; A = Area of the specimen in cm^2; T = Exposure time in hours

$$\text{Inhibitor Efficiency (\%)} = \frac{CR_{blank} - CR_{inh}}{CR_{blank}} \text{ x } 100$$

CR_{blank} = Corrosion rate of mild steel in acidic medium; CR_{inh} = Corrosion rate of mild steel in the presence of inhibitor.

$$\text{Surface Coverage } (\theta) = \frac{W_o - W}{W_o}$$

W_o = Mass loss of mild steel without inhibitor (blank); W = Mass loss of mild steel in the presence of the inhibitor.

The experiments were performed for various parameters such as:
- Concentration variation (0.1%, 0.2%, 0.3%, 0.4%, 0.5%, 0.6%,0.7%)
- Different time intervals (½ h , 1 h , 3 h , 6 h , 12 h and 24 h)
- Effect of Temperature (303K, 313K, 323K, 333K, 343K and 353K)

Electrochemical measurements

Potentiodynamic measurement

A conventional three-electrode system, consisting of mild steel as working electrode, platinum foil as counter electrode, and saturated calomel as reference electrode was used for the polarization measurement. Electrochemical measurements were carried out using Biologic model v1023 operated with EC lab software. The system includes a potentiostat, personal computer, and frequency response analyzer(FRA). Potentiodynamic polarization studies were carried out from a cathodic potential of -0.1V to an anodic potential of -1V with respect to corrosion potential at sweep rate of 2m/sec.AC signals of 10mV amplitude and a frequency spectrum from 20 to 0.1 Hz were impressed and the Nyquist representation of the impedance data were analyzed with Z view[27] software[28].

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 concentration of the inhibitor **.**

The inhibitor efficiency was calculated using the following equation

$$\text{Inhibition efficiency (\%)} = \frac{I_{corr(blank)} - I_{corr(inh)}}{I_{corr(blank)}} \text{ x } 100$$

$I_{corr\ (blank)}$ and $I_{corr\ (inh)}$ are linear corrosion current in the absence and presence of the inhibitor respectively.

I.E from LPR technique

$$\text{Inhibition efficiency (\%)} = \frac{R_{p(inh)} - R_{p(blank)}}{R_{p(inh)}} \text{ x } 100$$

$R_{p(inhi)}$ and $R_{p(blank)}$ are linear polarization resistance in the presence and absence of the inhibitor respectively.

Impedance Spectroscopy:

The impedance spectral response of mild steel in the presence of HRFE was recorded by means of Biologic model v1023 operated with EC lab software. In this method an AC signal of 5 – 10 mV of frequency 10 KHz to 10MHz is applied to the system. Impedance data can be presented in the form of Nyquist or Bode plot. From the data, the R_{ct} and C_{dl} values are obtained.

The I.E can be calculated using the equation,

$$\text{Inhibition efficiency (\%)} = \frac{R_{ct(inh)} - R_{ct(blank)}}{R_{ct(inh)}} \text{ x } 100$$

$R_{ct(inh)}$ and $R_{ct(blank)}$ are charge transfer resistance in the presence and absence of the inhibitor respectively.

With the help of the double layer capacitance C_{dl}, θ can be calculated using the equation,

$$\text{Surface Coverage } (\theta) = \frac{C_{dl(blank)} - C_{dl(inh)}}{C_{dl(blank)}}$$

$C_{dl\ (blank)}$ and $C_{dl\ (inh)}$ are the double layer capacitance in the absence and presence of the inhibitor respectively.

Surface Analytical Technique

Scanning electron microscope

The surface morphologies of mild steel specimens after exposure to 1M HCl solution in the absence and presence of extracts for 6h were examined by SEM using a **JEOL MODEL JSM 6390** SEM instrument.

Results and Discussion

Mass loss measurements:

Effect of concentration

Mass loss is one of the reliable methods for monitoring corrosion rate. The IE of MS exposed to 1M HCl as a function of concentration of the inhibitor is shown in table1 and depicted in figure 1.It has been established that corrosion rate decreases as the concentration of inhibitor increases. Corrosion inhibition enhances with increase in concentration of plant extract. This suggests that more inhibitor molecules are adsorbed on the metal surface at higher concentration, leading to higher surface coverage [29]. Further, the phytochemical components of the extracts adsorbed onto the mild steel surface result blocking of the reaction sites in the metal, and protecting the metal surface from the attack of the corrosive active ions in the acid medium

Effect of immersion time

The immersion time is one of the important parameters to assess the stability of the inhibitive behavior. In the present investigation, the effect of immersion time (0.5h-24h) on corrosion inhibition of HRFE at room temperature was investigated. From **table 1**, it is observed that, the inhibition efficiency increases with immersion time from ½ h to 3h. A maximum efficiency of 94.42% was obtained at 3 hr and then a slight decrease in IE of 93% is observed at 12h.

This decrease is attributed to the increased desorption of inhibitor molecules from the metal surface. However the IE stabilized to 90.00% at 24h. The dependence of IE on the immersion time and concentration of the extract is depicted in figure 1.

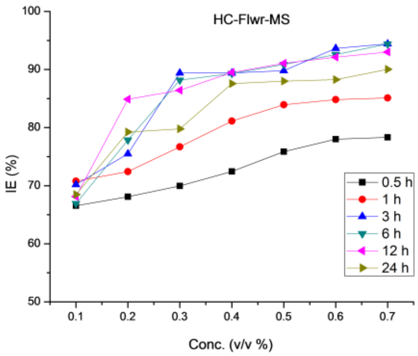

Figure 1 Effect of concentration of the inhibitor on mild steel in 1M HCl at room temperature

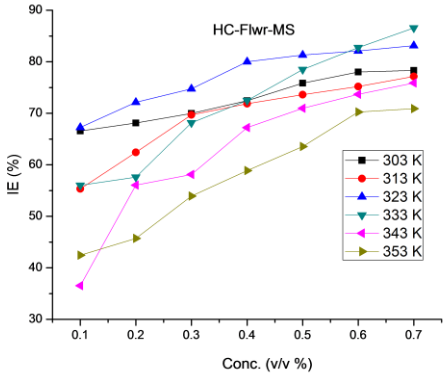

Figure 2 Effect of concentration of the inhibitor on mild steel in 1M HCl at higher temperature

Effect of Temperature

The effect of temperature on the mass loss and the corrosion rate of mild steel coupons in 1M HCl without inhibitor (blank) and with various concentrations of HRFE are examined from 303K to 353K. Inhibition efficiencies calculated in the presence of HRFE on mild steel corrosion in 1 M HCl and at each experimental temperature (303 K, 313 K, 323 K, 333 K, 343 K and 353 K) are listed in Table 2 and depicted in Figure 2.

Analysis of the Table 2 and Figure 2 indicate that as the concentration of the inhibitor increase, the IE also increases at all studied temperatures. Maximum inhibition is obtained at 0.7% concentration of the studied plant extracts for all the tested temperatures .The inhibition efficiency increases up to 333 K, and then a decrease in inhibition efficiency is observed from 343 K.

This can be explained by Putilova[30] that the decrease in the inhibition efficiency of the inhibitor with increase in temperature might be due to adsorption and desorption of inhibitor. Adsorption and desorption of inhibitor molecules continuously occurs 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 against established at a different value of equilibrium constant [31].

Table 1 Inhibition efficiency of mild steel in1M HCl in presence and absence of *Heliconia rostrata flower extract*

Conc (%)	1/2 h		1h		3h		6h		12h		24h	
	CR	IE(%)	CR	IE(%)	CR	IE(%)	CR	IE(%)	CR	IE(%)	CR	IE(%)
Blank	1032	-	1273	-	1482	-	1734	-	1762	-	1232	-
0.1	345	66.60	372	70.80	442	70.20	573	66.90	562	68.10	389	68.50
0.2	329	68.10	351	72.40	363	75.50	384	77.90	266	84.90	256	79.20
0.3	310	70.00	297	76.70	157	89.40	205	88.20	239	86.40	249	79.80
0.4	284	72.50	240	81.10	157	89.40	185	89.30	185	89.50	153	87.60
0.5	249	75.90	205	83.90	151	89.80	158	90.90	157	91.10	148	88.00
0.6	227	78.00	193	84.80	94	93.70	129	92.60	139	92.10	145	88.30
0.7	224	78.30	190	85.10	83	**94.42**	97	94.40	123	93.00	123	90.00

Table 2 Inhibition efficiency of mild steel in1M HCl in presence and absence of *Heliconia rostrata flower extract* at different temperatures

Conc (%)	303K		313K		323K		333K		343K		353K	
	CR	IE(%)	CR	IE(%)	CR	IE(%)	CR	IE(%)	CR	IE(%)	CR	IE(%)
Blank	1032	-	2791	-	6613	-	8342	-	17090	-	19362	-
0.1	345	66.56	1247	55.31	2166	67.25	3670	56.00	10847	36.53	11147	42.43
0.2	329	68.11	1049	62.40	1843	72.13	3537	57.60	7509	56.06	10512	45.71
0.3	310	69.97	846	69.68	1670	74.74	2659	68.13	7157	58.12	8924	53.91
0.4	284	72.45	786	71.85	1323	79.99	2297	72.46	5606	67.20	7967	58.85
0.5	249	75.85	736	73.62	1237	81.30	1794	78.49	4963	70.96	7061	63.53
0.6	227	78.02	692	75.20	1184	82.10	1439	82.75	4498	73.68	5764	70.23
0.7	224	78.33	637	77.16	1117	83.11	1120	86.57	4124	75.87	5638	70.88

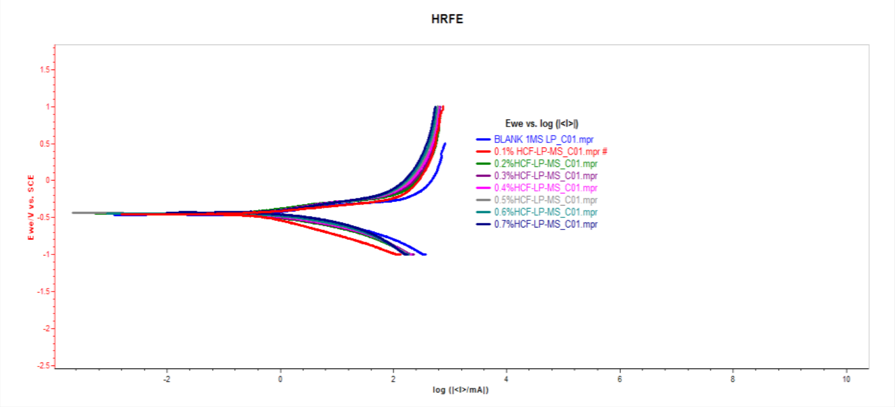

Figure 3 Electrochemical polarization curves for Mild Steel in 1M HCl solution in the absence and Presence of various concentrations of HRFE extract

Electrochemical measurements

Electrochemical studies will be helpful to predict the nature of the inhibitor- anodic, cathodic or mixed type inhibitor and to predict a suitable mechanism for the inhibition process. Figure 3 shows that the Potentiodynamic polarization curves for HRFE in 1MHCl without and with various concentration of HRFE at room temperature.

The values of Potentiodynamic polarization parameters namely corrosion current (E_{corr}), corrosion current density(I_{corr}),Tafel slopes(b_a and b_c), linear polarization resistance(R_p) are recorded in table 3.

Table 3 Electrochemical polarization parameters for MS in 1M HCl solution in the absence and presence of various concentrations of HRFE extract

Conc (%)	**Tafel polarisation parameters**					**Linear polarisation resistance parameters**	
	-E_{corr} mV/ SCE	**I_{corr} μA/cm^2**	**b_a mV/dec**	**b_c mV/dec**	**IE (%)**	**R_p Ohm/cm^2**	**IE (%)**
Blank	494	1846	134	138	-	13.5	-
0.1	428	692	119	108	62.48	27.8	51.44
0.2	444	406	107	82	78.00	35.3	61.76
0.3	438	391	103	96	78.81	41.6	67.55
0.4	456	390	83	194	78.89	48.2	71.99
0.5	429	309	92	105	83.26	54.6	75.27
0.6	409	257	73	139	86.08	71.5	81.12
0.7	401	237	70	133	87.18	75.2	82.05

Inspection of table 3 reveals that I_{corr} decreases considerably with increasing concentration of the inhibitor [32]. This confirms the inhibitive nature of extract and the adsorption of the plant extract on the metal surface. Further, the table infers that there is no change in E_{corr} values in the presence of the inhibitor. An inhibitor may be classified as anodic or cathodic type when the difference in Ecorr value is 85 mv/sec for each addition of the inhibitor [33]. As there is no such significant shift in the values, it can be inferred that the mode of adsorption is through mixed means. The IE is found to increase with increase in concentration of the inhibitor. A maximum of 87.18% inhibition was obtained with 0.7% concentration.

Impedance Spectroscopy:

The Nyquist plots for MS in 1 M HCl in the absence and presence HRFE are shown in Figure 4. From figure 4, it can be seen that the impedance spectra are not perfect semicircle [34]. A clean electrode without a passive film especially in the case of corroding electrode immersed in acid solutions gives rise to an impedance spectrum consisting of perfect semicircle. The depressed semicircle is either due to the presence of pores on the electrode surface or due to the adsorption of the inhibitor. In the present case it may be due to the adsorption of the inhibitor. The diameter of the semicircle gives the change transfer resistance (R_{ct})[35].

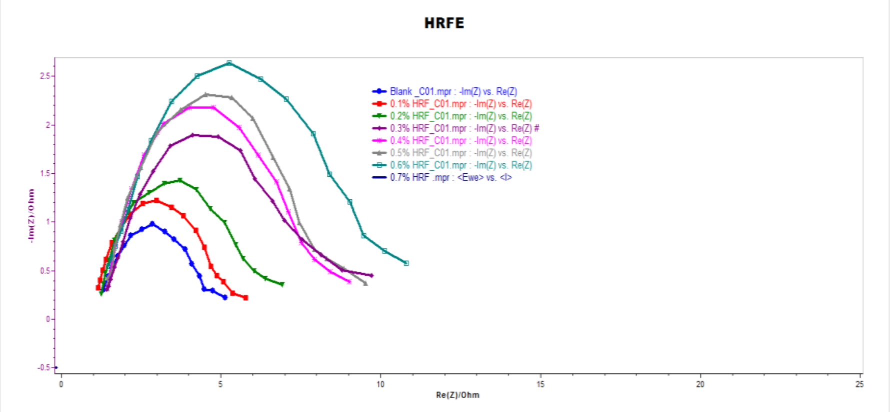

Figure 4 Nyquist plot for MS in 1M HCl in the absence and presence of various concentrations of HRFE extract

The impedance parameters, namely charge-transfer resistance (R_{ct}), solution resistance (R_s), the constant phase element (Y_o) related to the capacity of the double layer and the exponent (n), relevant to the capacitive semicircle of the mild steel in1M HCl in presence of HRFE extract are listed in table 4.

Table 4 Impedance parameters for the corrosion of MS in 1M HCl in the absence and presence of various concentrations of HRFE

Conc(%)	**Rs**	**y0**	**n**	**R_{ct}**	**IE (%)**	**f max**	**Cdl**	**θ**	**τ**
Blank	1.305	46075	0.47	3.5	-	15.6	2951	-	0.0102
0.1	1.199	35536	0.54	4.5	22.9	21.4	1664	0.44	0.0075
0.2	1.414	32014	0.57	5.0	30.5	25.2	1270	0.57	0.0063
0.3	1.565	26762	0.62	6.0	41.9	24.6	1089	0.63	0.0065
0.4	1.421	23594	0.65	6.7	48.8	22.9	1031	0.65	0.0070
0.5	1.324	23034	0.65	6.9	50.0	24.4	944	0.68	0.0065
0.6	1.657	16192	0.74	9.8	64.9	20.8	779	0.74	0.0077
0.7	1.159	11928	0.80	13.4	74.1	19.6	608	0.79	0.0081

As it can be seen from Table 4 the R_{ct} values increases with increasing the concentration of the inhibitors [36]. This may be attributed to the adsorption of the active constituents of the inhibitor species on the metal/solution interface. On the other hand, the values of C_{dl} decrease with an increase in the inhibitors concentration. This situation is due to the result of an increase of surface coverage by the inhibitor, which led to an increase in the inhibition efficiency .This decrease in the C_{dl}, which can result from a decrease in local dielectric constant [37] and/or an increase in the thickness of the electric double layer, suggests that the phytoconstituents in the investigated plant extracts function by adsorption at the metal /solution interface. Thus, the change in C_{dl} values is caused by to the gradual replacement of water molecules by the adsorption of the inhibitor molecules on the metal surface, decreasing the extent of the metal dissolution [37].

Figure 4 shows depressed Nyquist plots which are not perfect semicircles as expected from the theory of EIS. This difference can be explained by non-ideal behaviour of double layer as a capacitor. Therefore it is necessary to use a constant phase element, CPE, instead of double layer capacity to account for non-ideal behaviour. This CPE, which is considered as a surface irregularity, causes a greater depression in Nyquist semicircle diagram, where the metal-solution interface acts as a capacitor with irregular surface [38].

Nyquist impedance plots were analysed by fitting the experimental data to a simple circuit model shown in Figure.5 which includes the solution resistance (Rs), charge transfer element (Rct), constant phase element (CPE) and surface inhomogeneity (n) and the values are depicted in Table 4. These parameters are calculated from the non-linear least square fit of the equivalent circuit as depicted in Figure-5.

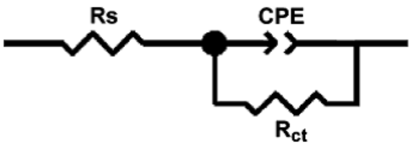

Figure 5 Equivalent circuit model for Nyquist plots

The impedance function of a CPE is defined by the mathematical expression given below:

$$Z_{CPE} = Y_o^{-1} (i\omega)^{-n}$$

The double layer capacitance (C_{dl}) derived from the CPE are also presented, using the following equation

$$C_{dl} = (Y_o \, Rct^{\,n-1})^{1/n}$$

where Y_o is the CPE constant ,ω is the sine wave modulation angular frequency, $i^2 = -1$ is the imaginary number, $n= \alpha/ (\pi/2)$ in which α is the phase angle of CPE and n is the CPE exponent ($0 \leq n \leq 1$) which measures the deviation from the ideal capacitive behaviour and it represents the surface irregularity. The constant phase element (CPE) is used in the place of capacitor to compensate the non-homogeneity of the surface that causes a greater depression in Nyquist semicircle diagram[39].

If the electrode surface is considered as homogeneous and plane, the exponential value (n) becomes equal to 1.0 and the metal-solution interface acts as a capacitor with regular surface.

After analyzing the impedance results in Table 4, it is obvious that the exponent (n), increases with the concentration of HRFE and reaches a maximum value at 0.7%. The lower n value for uninhibited solution (n=0.47) indicates a surface inhomogeneity resulting from surface metal roughening and/or formation of corrosion products on the surface. The values of n lies between 0.54 and 0.80 in the case of inhibited solutions. Addition of inhibitor increases n value indicating reduction of surface inhomogeneity due to the adsorption of investigated inhibitor on the most active adsorption sites at the mild steel surface. Experimentally determined values of n for the corroding metal electrode which lies around 0.9 [40] can also be seen from Table 4 in the present case. Also, the addition of investigated inhibitors to the corrosive solution decreases the double layer capacitance (C_{dl}) and it reflects the time constant (τ) value**)**.

The interface time constant (τ) and the double layer capacitance value (C_{dl}) of the CPE can be calculated by the following equations. [41].

$$C_{dl} = (Y_o R_{ct}^{1-n})^{1/n}$$

$$Y_o = \tau^n / R_{ct}$$

The relaxation time (τ) of the surface, that is, the time required for attaining the charge distribution to equilibrium[42] is given by:

$$\tau = C_{dl} \times R_{ct}$$

When the plant extract concentration is increased to 0.7% in the corrosive medium of 1M HCl, the interface (τ) parameter changes while the capacitance (C_{dl}) value decreases signifying that the charge and discharge rates to the metal–solution interface is greatly decreased. This shows that there is agreement between the amounts of charge that can be stored (i.e. capacitance) and the discharge velocity in the interface (τ).The double layer between the charged metal surface and the solution is considered as an electrical capacitor. The adsorption of investigated inhibitor on the mild steel surface decreases its electrical capacity because they displace the water molecules and other ions originally adsorbed on the surface.

In conclusion, the results of the electrochemical studies were in good agreement with the results of gravimetric studies with slight deviations. This is due to the difference in immersion period of MS in the aggressive media [43].

Scanning electron micrograph of mild steel in the presence of Extract in 1M HCl

SEM photographs obtained for mild steel surface immersed in 1M HCl solutions at room temperature for 3h immersion in the absence and presence of 0.7% of optimum concentration of HRFE extracts are shown in Fig.6 & Fig.7.It can be noted that the smooth surface observed in plain mild steel is highly corroded with etched grain boundaries and corrosion products after its immersion in 1M HCl. But in the presence of HRFE extract, SEM images reveal that a good protective adsorbed film formed on the specimen surface, which suppresses the rate of corrosion is being responsible for the inhibition. This observation clearly proves that the inhibition is due to the formation of an insoluble stable film through the process of adsorption of the phytoconstituents present in extract on the metal surface.

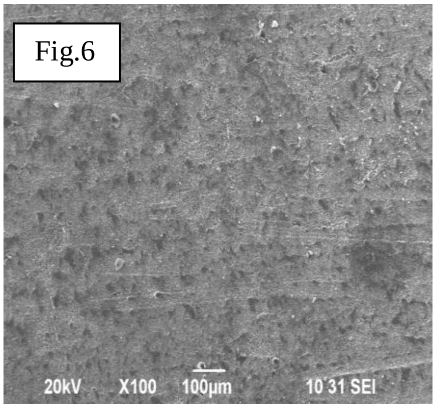

Figure 6 MS in Blank

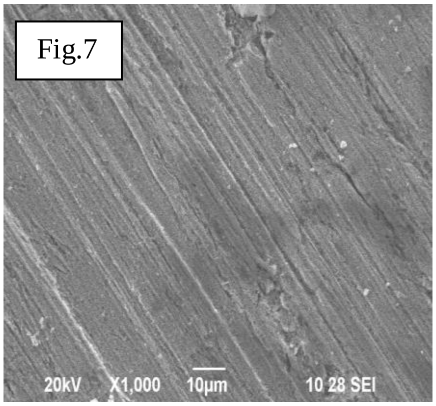

Figure 7 MS in the presence of HRFE

Mechanism of Inhibition

Phytochemical screening of ***Heliconia rostrata*** flower extract was carried out using standard procedure [24] and listed in the table 5.

Table 5 Phytochemical screening of ***Heliconia rostrata*** flower extract

Phytochemical component	Flavonoids	Alkaloids	Tannins	Terpenoids	Anthra quinones	Coumarin	carbohydrates	phenols
Heliconia rostrata	-	-	-	+	-	+	+	+

The main constituents of the extract are phenolic compounds, terpenoids and coumarins and proteins. [44].

It is often not possible to assign a single general mechanism of action to an inhibitor, because the mechanism may change with experimental conditions. Thus, the predominant mechanism of action of an inhibitor in acidic solutions may vary with factors such as concentration of the extracts, the nature of the anion of the acid, the presence of other species in the solution, the extent of reaction to form secondary inhibitors and the nature of the metal [45].

It is generally accepted that corrosion inhibition is achieved through the interaction between inhibitor molecules and the metal surface, resulting in the formation of an inhibitive surface film.[46,47].The corrosion inhibition of these compounds was usually attributed to their adsorptive interaction with the metal surface[48,49]. A bond may be formed between electron lone pair and/or electron cloud of the donor atoms of the inhibitor and the metal surface and reducing the corrosive attack.[50]

In aqueous acidic solutions, the main constituents exist either as neutral molecules or as protonated molecules (cations). The inhibitors may adsorb on the metal/acid solution interface by one and/or more of the following ways:

- Electrostatic interaction of protonated molecules with already adsorbed chloride ions,
- Donor-acceptor interactions between the p-electrons of aromatic ring and vacant d orbital of surface iron atoms,
- Interaction between unshared electron pairs of hetero atoms and vacant d orbital of iron surface atoms.

In the present situation two modes of adsorption could be considered:

i. The neutral HRFE may adsorb onto the metal surface via the chemisorption mechanism, involving the displacement of water molecules from the metal surface and sharing electrons between the O atoms and Fe. The HRFE molecules can also adsorb on the metal surface on the basis of donor-acceptor interactions between π-electrons of aromatic ring and vacant d-orbitals of Fe.

ii. The protonated HRFE may adsorb through electrostatic interactions between the positively charged molecules and the negatively charged metal surface. In other words, there may be a synergism between Cl^- and HRFE, which improves the inhibitive capability of the inhibitor.

The effective performance of the inhibitor may also be due to the phytochemical constituents of the plant extract which cover a wider area of the metal surface thus minimising the corrosion.

Conclusion:

From the above findings, it can be concluded that the HRFE extract acts as an effective inhibitor at different experimental condition. The effectiveness can be attributed to the adsorption of the phytochemical constituents of the extract on the metal surface and blocking its active sites. The mass loss and electrochemical measurements showed that inhibition efficiency increased with an increase in concentration of the plant extract. Potentiodynamic polarization studies show that the extract acts as mixed-type inhibitor. SEM images confirm that the surface is smoother in presence of studied inhibitor and the smoothness of the surface is due to the formation of a compact protective film of the inhibitor on the metal surface thereby inhibiting the corrosion of mild steel.

References

[1] Uhlig H H, Corrosion and Corrosion Control-An Introduction to Corrosion Science and Engineering, John Wiley and Sons, New York, 1971.
[2] Lebrini M, Robert F, Blandinieres P A, Roos C, Int. J. Electrochem. Sci 2011, 6, 2443-2460.
[3] Raja PB, Sethuraman M G, Material Lett 2008, 62, 113-116.
[4] Zakvi S J, Mehta G N, J. Electrochem. Soc India 1988, 37,237.
[5] Ekpe U J, Ebenso E E , Ibok U J, J. W. Afr. Sci. Assoc, 1994 ,37, 13.
[6] Davis, Guy D, Corrosion, 2001, 58.
[7] N. O. Eddy, S. A. Odoemelam, Pigment & Resin Technology 2009, 38(2), 111-115.
[8] Zakvi S J, Mehta G N, J. Electrochem. Soc. India 1988, 37(3), 237-239.
[9] Okafor, Peter C, Eno E. Ebenso, Udofot J. Ekpe. Int. J. Electrochem. Sci, 2010, 5,978-993.
[10] El-Etre AY, Corrosion Science 1998, 40(11) ,1845-1850.
[11] El-Etre AY, Abdallah M, Corrosion Science 2000, 42(4), 731-738.
[12] Khamis E, Alandis N, Materialwissenschaft und Werkstofftechnik 2002, 33(9), 550-554
[13] El-Etre AY, Corrosion science 2003, 45(11) 2485-2495.
[14] Vijayalakshmi P R, Rajalakshmi R, Subhashini S, E-Journal of Chemistry, 2010, 7(3), 1055-1065.
[15] Rajalakshmi R, Subhashini S, Leelavathi S, Femina Mary R, Oriental Journal of Chemistry, 2008 24(3), 1085-1090.
[16] Vijayalakshmi P R, Rajalakshmi R, Subhashini S,Asian Journal of Chemistry, 2010, 22(6), 4537-4548.
[17] Subhashini S, Rajalakshmi R, Prithiba A, Mathina A , E-Journal of Chemistry, 2010, 7(4) ,1132-1137
[18] Vijalakshmi P R, Rajalakshmi R, Subhashini S,Portugaliae Electrochimica Acta ,2011, 29(1), 9-12.
[19] Rajalakshmi R, Safina S, E-Journal of Chemistry, 2012 , 9(3) 1632-1644.
[20] Rajalakshmi R, Safina S, Asian Journal of Chemistry, 2012, 24 (10), 4401-4407.
[21] Vijayalakshmi P R, Rajalakshmi R,NACE Corrosion Conference Expo, 2013, 1-15.
[22] Leelavathi S, Rajalakshmi R, NACE Corrosion Conference and Expo 2013, 1-15.
[23] Leelavathi S, Rajalakshmi R, Journal of Materials and Environmental Science, 2013, 4(5), 625-638.
[24] Harborne J B, Phytochemical Methods: A guide to modern techniques of plant analysis, Chapman and Hall, New York, 1973, 279.
[25] Abdallah M, Portugaliae Electrochimica Acta, 2004, 22, 161-175.
[26] ASTM G1-03, Standard practice for preparing, cleaning and evaluating corrosion test specimens, 2003, ASTM International, west Conshohocken, USA
[27] Rajalakshmi R, Sathiyanarayana S, Marikkannu C, Sivakamasundari S, ISAEST VII, India, 2002, 142-145.
[28] ASTM G1-03, Standard practice for preparing, cleaning and evaluating corrosion test specimens, 2003, ASTM International, west Conshohocken, USA.
[29] Akalezi C O, Enenebaku C K, Oguzie E E, Journal Material and Environmental Science, 2013, 4(2), 217-226.
[30] Putilova I N, Balezin S A, Barannik P, Metallic corrosion inhibition, 1960,Pergamon Press, NewYork,USA
[31] Rawat N S, Singh A K, Bull electrochem,1987, 3, 7.
[32] Muralidharan S, Quraishi M A,Iyer S V K, Corrosion Science, 1995, 37(11), 1739-1750.
[33] Satapathy A K, Gunasekaran G, Sahoo S C, Kumar Amit, Radrigues P V, Corrosion Science, 2009,51,2848-2856
[34] Bentiss F, Jama C, Mernari B, El Attari H, El Kadi L, Lebrini M, Traisnel M, Lagren M, Corrosion Science, 2009,51,1628-1635.
[35] Tsuru T, Haruyama S, Gijutsu B, Journal of the Japanese Society of corrosion Engineering, 1978, 27,573-579.
[36] Quraishi M A, Dileep Kumar Yadav ,Ishtiaque Ahamad. , The Open Corrosion Journal, 2009, 2, 56-60.
[37] McCafterty E, Hackerman N, Joural of Electrochemical Society, 1972, 119(2),146-154.
[38] Cruz J, Pandiyan T, Ochoa E G, J. Electroanal. Chem., 2005, 8 583.
[39] Lopez D A, Simison S N, De Sanchez S R,Corrosion Science,2005, 47,735.
[40] Hosseini M, Stijn Mertens F L, Mohammed Ghorbani, Mohammed R Arshadi, Materials Chemistry and Physics , 2003, 78(3), 800-808.
[41] Guo Gao, Cheng Hao Liang, Corrosion Science, 2007, 49(9), 3479-3493.
[42] Toshima S, Uchida T, Electrochimica Acta, 1970, 15, 1717-1732.
[43] El-Etre A Y, Abdullah M, El-Tantaury Z E,Corros. Sci., 2004, 47,385.

[44] Sebastian Estrada G, John Quintana C, Silvia L. Jimenez, Juan C, Alarcon P, Jaime A. Pereanez J. Leidy J. Vargas, 2009, 16 (2) p. 252-257.
[45] Shreir L L, Jarman R A, Burstein G T, Corrosion metal environment reaction. London: Butterworth-Heinemann, 1, 1994, 4-160.
[46] Antonijevic M M, Petrovic M B, Int. J. Electrochem. Sci 2008, 3.1, 1-28.
[47] Sastri V,corrosion Inhibition Mechanisms,john wilely & sons Inc,Hoboken,NJ,2011.
[48] Quraishi M A, Ansari F A, Jamal D, Materials chemistry and physics 2003, 77.3, 687-690.
[49] Fekry A M, Riham Mohamed R, Electrochimica Acta 2010, 55.6, 1933-1939.
[50] Khaled K F, Applied Surface Science,2010, 256,22.6, 6753-6763

Publication History

Received	06th Jan 2016
Revised	28th Jan 2016
Accepted	09th Feb 2016
Online	30th Mar 2016