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Exploring Nelumbo nucifera aqueous leaves extract as a green corrosion inhibitor for mild steel in acid medium

[1]A. Mushira Banu and [1*]K. Riaz Ahamed

[1*]PG and Research Department of Chemistry,
Jamal Mohamed College (Autonomous), Tiruchirappalli-20, India.

Abstract

The corrosion mitigation of mild steel in 1.0 M H_2SO_4 by the *Nelumbo nucifera* (NN) leaves extract have been studied at various temperatures using weight loss methods, potentiodynamic polarization and electro-chemical impedance spectroscopy techniques. The results show that the inhibition efficiency increases with the increase of the leaves extract concentration. The adsorption of the natural components present in the leaves extract on the mild steel surface obeys Langmuir, Temkin and El-Awady adsorption isotherms. From the electrochemical polarization measurement, the increment of corrosion current values and the variation of b_c and b_a exhibits the mode of inhibition. AC impedance studies confirm the formation of protective layer formation on the mild steel by R_{ct} and C_{dl} values. This study concludes that the leaves extract act as an excellent natural inhibitor.

Keywords: *Nelumbo nucifera* extract, Mild steel, Weight loss, Adsorption isotherms, Polarization, Impedance.

I. Introduction

Industrial development and growth of a country is measured by the usage of iron and steel products. Mild steel is one of the most useful alloys and it is neither hard nor pliable. It is low-priced as well as flexible. Due to the environment, the surface of the mild steel has corrosion products. To prevent corrosion, various methods are adopted. The usage of corrosion inhibitors is best method to control corrosion. Nowadays, by consuming extracts of plant products environ mental toxicity was avoided. Conventional organic compounds are significantly replaced by green inhibitors [1]. Extract of *Annona muricata L.* was investigated as anti-corrosive agent of mild steel in 1.0 N HCl[2]. Chebouat *et al*. (2013) have used *Ephedra alata* as an effective green corrosion inhibitor on mild steel corrosion in HCl medium[3]. Corrosion inhibition of mild steel in 1.0 M HCl by *Terminalia avicennioides*[4] has been reported by Ijuo et al., (2018). *Pongmaia pinnata* act as a corrosion inhibitor for mild steel in 1 N suphuric acid[5].

The existing effort is deal with to assess the inhibition potential of an aqueous extract of *Nelumbo nucifera* leaves in controlling corrosion of mild steel in 1.0 M H_2SO_4 medium. Weight loss method and electrochemical methods such as polarization study and AC impedance spectra have been used.

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II. Experimental Section

2.1 *Nelumbo nucifera*

Fresh leaves of *Nelumbo nucifera* were collected from trichy district. The aqueous extract the leaves was prepared and used for present study. The plant picture is shown in Fig. 1. The leaves were authenticated and identified by Dr. John Britto, The Rapient Herbarium and Centre for Moduler Systematics, St.Joseph's college, Trichirappallli, Tamilnadu, India.

Fig. 1. *Nelumbo nucifera* leaves

Botanical Study

Botanical name: *Nelumbo nucifera*; Tamil name: Aambal*;* Kingdom: Plantea*;* Order: **Proteales**; Family: **Nelumbonaceae**; Genus: ***Nelumbo***; Species: ***N. nucifera***

2.2 Phyto-chemical screening of *Nelumbo nucifera*

Nishkruti R Mehta *et al*. 2013, gives the phyto-chemical screening of *Nelumbo nucifera* leaves. The study authorizes the presence of nuciferine as a major component in leaves extract[6].

2.3 Extract preparation

The fresh leaves of *Nelumbo nucifera* were collected and dried in shade and then crumbled to powder. *Nelumbo nucifera* powder (10g) was boiled with 100 ml double distilled water and condensed upto 50 ml. The extract was left to cool down and then filtered using Whatman filter paper. From that 0.2% to 1.0% concentrations were prepared[7].

III. Materials and chemicals used

3.1 Composition of mild steel

The chemical composition of the mild steel used were C-0.1%, Mn-0.4%, S- 0.026%, P-0.06% and Fe- 99.41%. The steel was cut to form different coupons of dimensions 1x4x0.1 cm was mechanically polished to mirror finished and degreased with acetone and used for the weight loss method.

For polarization, cylindrical mild steel rod embedded in Teflon with an exposed area of 1cm^2 was used. The electrodes were refined with emery papers of 0/0, 2/0, 3/0, and 4/0 grades and degreased with acetone, dried and used[8].

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3.2 Acids

1.0 M H_2SO_4, was used of G.R. Grade

3.3 Weight loss method

Weight loss measurements were performed in 1.0 M H_2SO_4 with and without the presence of various concentrations of leaves extract was carried out. The corrosion rate, surface coverage and inhibition efficiency were calculated[9] by using the following expressions (1-3),

$$\text{Corrosion rate (C.R)} = 87.6\times W/ D\times A\times T \qquad (1)$$

W= Weight loss in mg, D=Density in gm/cm^3, A= Area of mild steel coupon in cm^2,
T= Immersion time in hrs.

$$\text{I.E (\%)} = (W_0-W_i/W_0) \times 100 \qquad (2)$$

Where, W_0 = Weight loss in absence of inhibitor
W_i = Weight loss in presence of inhibitor

$$\text{Surface coverage } (\ominus)=\text{I.E./100} \qquad (3)$$

3.4 Potentiodynamic polarization studies

Potentiodynamic polarization studies were completed for mild steel specimens in the presence and the absence of the leaves extract. Polarization measurements were performed to calculate the corrosion current, corrosion potential and Tafel slopes b_c and b_a. The polarization cells comprise a three-electrode assembly.

3.5 AC Impedance measurements

The instrument used for polarization was also used for AC impedance study. The cell setup was the same as that used for polarization measurements. Cell impedance was measured at various frequencies in ohms. The values of charge transfer resistance, R_{ct} and the double layer capacitance, C_{dl} were calculated.

IV. Results and discussion

4.1 Weight loss studies

Table-1 establishes the inhibition efficiency of different percentages of *Nelumbo nucifera* leaves extract in 1.0 M H_2SO_4 at various temperatures. Maximum inhibition efficiency 76.47% is shown by 1.0 % of inhibitor concentration at room temperature. The corrosion rate decreases with increase the concentration of the inhibitor[10]. But when the temperature increases from 303 K to 333 K the corrosion rate increases and the inhibition efficiency values decreases from 76.47% to 53.31% at 333 K.

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Table-1: Inhibition effect on corrosion of mild steel in 1.0 M H_2SO_4 by *Nelumbo nucifera* leaves extract

System	Inhibitor Concentration, V/V (%)	303 K		313 K		323 K		333 K	
		C. R (mpy)	I.E. (%)	C. R (mpy)	I.E. (%)	C. R (mpy)	I.E. (%)	C. R (mpy)	I.E. (%)
NN-H_2SO_4	Blank	142.09	-	252.15	-	362.21	-	462.51	-
	0.2	73.83	48.03	188.07	25.41	263.30	27.30	363.60	21.38
	0.4	66.87	52.94	172.74	31.49	231.25	36.15	316.24	31.62
	0.6	55.72	60.78	111.45	55.80	171.35	52.69	274.44	40.66
	0.8	47.36	66.66	84.98	66.29	126.77	65.00	241.01	47.89
	1.0	33.43	**76.47**	75.22	**70.16**	114.23	**68.46**	215.93	**53.31**

4.2 Adsorption isotherms

Adsorption isotherms are usually used to designate the adsorption process. The most commonly used isotherms consist of: Langmuir, Temkin and the recently expressed thermodynamic/kinetic model of El-Awady et al. The establishment of adsorption isotherms that describe the adsorption of a phytochemical constituents present in the leaves extract can provide important evidence to the nature of the metal-inhibitor interaction[11]. Adsorption of the organic molecules occurs as the interaction energy between molecules and metal surface is higher than that between the H_2O molecules and the metal surface.

With the intention of attain the adsorption isotherm, the degree of surface coverage (θ) for various concentrations of the inhibitor has been calculated according to its equation. Langmuir isotherm was tested for its fit to the experimental data. Langmuir isotherm is given by

$$C/\theta = 1/K_{ads} + C$$

Where θ is the degree of surface coverage, C is the concentration of the inhibitor and K_{ads} is the equilibrium constant of the process of adsorption[12].

It is important to known this part of the study, tables (2-5) and Figs.(2-4) depicts the obtained values and graphs were fitted for various isotherms and the best fit was obtained with all the three isotherms at all the temperatures except Langmuir at 313 K.

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Table-2: Langmuir adsorption isotherm for the inhibition of corrosion of mild steel in 1.0 M H_2SO_4 using NN leaves extract

C, (%)	C/Θ-303 K	C/Θ-313 K	C/Θ-323 K	C/Θ-333 K
0.2	0.4164	0.7870	0.7326	0.9354
0.4	0.7555	1.2702	1.1065	1.2650
0.6	0.9871	1.0752	1.1387	1.4756
0.8	1.2001	1.2068	1.2307	1.6704
1.0	1.3077	1.4253	1.4607	1.8758

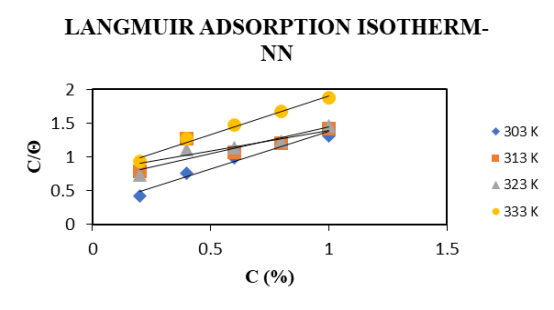

Figure 2: Plot of Langmuir adsorption isotherm for the adsorption of aqueous leaves extract of NN on the surface of the mild steel

Table-3: Temkin adsorption isotherm for the inhibition of corrosion of mild steel in 1.0 M H_2SO_4 using NN leaves extract

2+log C	Θ-303 K	Θ-313 K	Θ-323 K	Θ-333 K
1.3010	0.4803	0.2541	0.2730	0.2138
1.6020	0.5294	0.3149	0.3615	0.3162
1.7781	0.6078	0.5580	0.5269	0.4066
1.9030	0.6666	0.6629	0.6500	0.4789
2.0000	0.7647	0.7016	0.6846	0.5331

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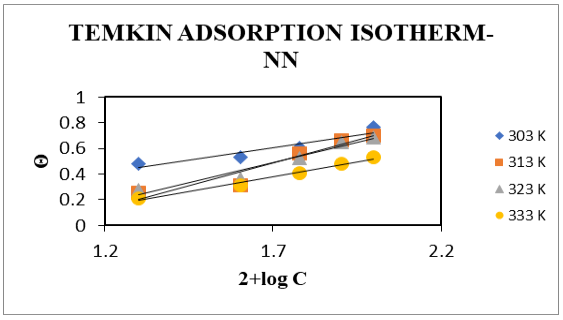

Figure 3: Plot of Temkin adsorption isotherm for the adsorption of aqueous leaves extract of NN on the surface of the mild steel

Table-4: El-awady adsorption isotherm for the inhibition of corrosion of mild steel in 1.0 M H_2SO_4 using NN leaves extract

2+log C	2+log(Θ/1-Θ)			
	303 K	313 K	323 K	333 K
1.3010	1.9657	1.5323	1.5746	1.4344
1.6020	2.0511	1.6624	1.7529	1.6650
1.7781	2.1902	2.1012	2.0467	1.8358
1.9030	2.3009	2.2936	2.2688	1.9633
2.0000	2.5118	2.3712	2.3365	2.0575

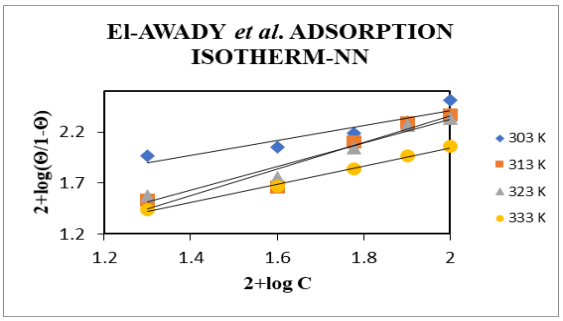

Figure 4: Plot of El-awady adsorption isotherm for the adsorption of aqueous leaves extract of NN on the surface of the mild steel

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Table-5: Adsorption isotherms parameters for inhibition of corrosion of mild steel in 1.0 M H_2SO_4 using NN leaves extract

Isotherm	Temperature, K	Slope	Intercept	Regression coefficient, R^2
Langmuir	303	1.1136	0.2653	0.9668
	313	0.6065	0.7890	0.6377
	323	0.7902	0.6597	0.8985
	333	1.1431	0.7586	0.9873
Temkin	303	0.3853	0.0517	0.8964
	313	0.7039	0.7102	0.9135
	323	0.6306	0.5835	0.9465
	333	0.4589	0.3982	0.9850
El-Awady	303	0.7253	0.9588	0.8688
	313	1.3103	0.2574	0.9231
	323	1.1601	0.0043	0.9544
	333	0.8961	0.2528	0.9956

4.3 Potentiodynamic polarization studies

Table-6 and **Fig. 5** inferred the values of potentiodynamic parameters such as corrosion current (I_{corr}), corrosion potential (E_{corr}) and the cathodic Tafel slopes (b_c and b_a) for the different concentrations of green inhibitor understudy. It can be seen that the chemical component present in the leaves extract adsorbed on metal surface. The present study exposes NN leaves extract behave as mixed type inhibitor[13-15].

Table-6: Corrosion parameters obtained from polarization curves for mild steel in 1.0 M H_2SO_4 in the presence and absence of inhibitor

System	Concentration of inhibitor, (v/v%)	$-E_{corr}$, mV/SCE	I_{corr}, A/cm^2	b_c, mV/decade	b_a, mV/decade	LPR	% I.E.
NN-Leaves extract	Blank	0.473	3.103×10^{-3}	6.032	10.29	8.60	-
	0.2	0.468	1.478×10^{-3}	171.9	94.30	18.00	**52.22**
	1.0	0.454	6.613×10^{-4}	130.4	90.90	35.20	**75.56**

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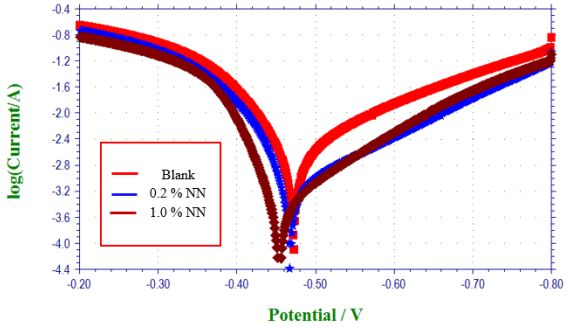

Figure 5: Potentiometric polarization curve for mild steel in 1.0 M H_2SO_4 in the absence and presence of NN leaves extract

4.4 AC impedance study

Table-7 and **Fig.6** indicates the AC impedance curves and values for different inhibitor concentration. The R_t values increases and C_{dl} values decreases with inhibitor concentration. The impedance values as well as phase angle values also increasing with the concentration of NN leaves extract. These results suggest the formation of protective film on the metal surface. It can be also seen from **table-8** that there is a close agreement between the values of inhibition efficiencies obtained from different techniques[16-21].

Table-7: Corrosion parameters obtained from impedance study for mild steel in 1.0 M H_2SO_4 in the presence and absence NN leaves extract

System	Concentration of inhibitor, (v/v %)	R_{ct}, Ω	C_{dl}, μF/cm^2	Imp	P.A	I.E. (%)
NN - Leaves extract	Blank – H_2SO_4	2.1510	7.657×10^{-7}	0.5337	27.37	-
	0.2	4.5127	3.640×10^{-7}	0.8948	31.06	**52.46**
	1.0	7.7050	2.137×10^{-7}	2.3270	59.31	**69.47**

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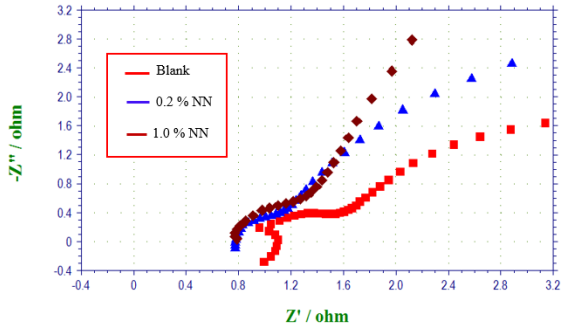

Figure 6: AC impedance diagram for mild steel in 1.0 M H_2SO_4 in the absence and presence of NN leaves extract

Table-8: Comparison of inhibition efficiencies measured by weight loss, polarization and impedance studies

[Inhibitor], (v/v%)	Inhibition efficiency (%)		
	Weight loss study	Polarization study	Impedance study
0.2	48.03	52.22	52.46
1.0	76.47	75.56	69.47

V. Summary and conclusion

The inhibitive impact of *Nelumbo nucifera* leaves extract on the corrosion of mild steel in 1.0 M H_2SO_4 was studied by weight loss method, polarization and impedance measurements. The inhibition efficiency values determined by these techniques showed close agreement. NN leaves extract shows the maximum inhibition efficiency 76.47% at higher concentration. The adsorption of phyto-chemical constituents obeys Langmuir, Temkin and El-Awady isotherms. The formation of protective layer have confirmed by electrochemical techniques. These results proposed *Nelumbo nucifera* leaves extract is a safe, affordable and sustainable inhibitor.

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