International Journal of Advanced Science and Research
ISSN: 2455-4227
Impact Factor: RJIF 5.12
www.allsciencejournal.com
Volume 3; Issue 1; January 2018; Page No. 115-122

Schiff base as green corrosion inhibitor for carbon steel in 1M Hydrochloric acid solutions

Anjoo Bala, Vikas, Gobind Goyat, Suresh Kumar, * Hari Om
Department of Chemistry, M. D. University, Rohtak, Haryana, India

Abstract

The corrosion inhibition efficiency (IE%) of Propylenediamine-bis(Isatin) PDBI Schiff base as a corrosion inhibitor for carbon steel samples were tested in absence and presence of various concentrations of inhibitor in 1M HCl solution was investigated by weight loss, potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques. Weight loss measurements were conducted different immersion time at temperature of 298K. The results obtained showed increase in inhibition efficiency (IE %), surface coverage (θ) but decrease in corrosion rate (CR) with increase in the concentration of the inhibitor. Inhibitor found to perform best at 300ppm of concentration with 98.63% inhibition efficiency for 24hr of immersion time. Langmuir adsorption isotherm was obeyed by the inhibitor. Thermodynamic parameters regulating the adsorption process were calculated and adsorption found to physical in nature. Polarization measurements data depicted the inhibitor as mixed type in nature.

Keywords: carbon steel, HCl, corrosion inhibitor, electrochemical impedance, adsorption isotherm, SEM

1. Introduction

Metals and alloys are frequently used as industrial appliances in various heavy industries such as carbon steel is used as a construction material in making tanks, pipelines, drums and heat exchangers. After coming in contact with some salts, inorganic compounds and gases, the metals undergo corrosion attack [1-3].

Corrosion process frequently occurs in metals as they have great tendency to get corroded in the presence of oxygen and moisture on metals surface which provides suitable conditions for corrosion process to occur. In these mechanism two electrochemical reactions takes place on metal surface which involves oxidation at anodic site and reduction at cathodic site, respectively. But in industries main reason for corrosion is the use of different types of acids such as hydrochloric, nitric and sulphuric acid, primarily used as aggressive solutions for removing undesirable scales like rust or mill scales, salts from steel surface and these acts as a cleaning agent in acid pickling, descaling, oil well acidization, for cleaning tanks, pipelines and in regeneration of ion exchange resins etc. [4-8].

In acidic medium hydrogen evolution reaction predominates and this acidic attack destroys the useful properties and life of metals [9]**.** So the use of corrosion inhibitors becomes necessary in these conditions. Success of a corrosion inhibitor can be counted by its tendency to displace water molecules from the metals surface and thereby resulting in blocking the active corrosion sites. So, the electronic structure of compounds, physic-chemical properties associated with functional groups, steric effect, electron density on donor atom, interaction of π-orbital with metal d-orbital on metals surface are the factors responsible for proper adsorption of inhibitor molecules on carbon steel surface that leads to the formation of corrosion protective film [10-11].

Heterocyclic compounds containing oxygen-, nitrogen-, and sulfur are often reported as efficient and effective corrosion inhibitors [12, 15]. Schiff bases and others organic compounds which are having the general formula $R–C{=}N–R^0$ where R and R^0 are aryl, alkyl or cycloalkyl or heterocyclic groups which are prepared by the condensation of an amine and a carbonyl group, are reported to be inhibitors with good potential in acidic media. The benefits associated with mostly Schiff base compounds are that they can be synthesized easily from cheap material [16, 19].

Substitution of polar groups such as ($—NH_2$, —OH, —SH, etc.) in the N-heterocyclic rings functions to increase in the electron density and thereby increases adsorption ability. Here the present research is directed towards the development of the economical, having non-toxic and eco-friendly characteristics and novel corrosion inhibitors from natural resources [20, 24]. Aim of the present study is to examine the influence of Propylenediamine-bis(Isatin) PDBI inhibitor on corrosion of carbon steel in 1M HCl acidic solution by employing weight loss measurements, potentiodynamic polarization, electrochemical impedance, scanning electron microscopy and quantum chemical calculations techniques.

2. Materials and methods

Solution preparation

Acidic solution of 1 M concentration was prepared by diluting concentrated HCl of analytical grade 37% and the stock solution of inhibitor was prepared in the ratio 10: 1 in water: ethanol mixture by volume; to ensure solubility by using 1M HCl solution. This solution in turn used to make different concentrations of inhibitor by diluting with 1M HCl.

Sample preparation

Carbon steel sheets having following composition (C = 0.19, Mn = 0.26, Si = 0.01, S = 0.017, P = 0.019, Cu=0.01, Cr=0.05. Mo=0.01 and balance Fe) were used for corrosion study. Carbon steel samples were cut in rectangular shape in $3\times 1 cm^2$ dimensions. The samples were mechanically polished with different mesh grades emery papers (100-1000), washed with distilled water, degreased in acetone, dried in hot air blower and then placed in desiccator.

Weight loss measurement

Weight loss measurements were conducted by adopting well established method described previously [25, 26]. Experiments were performed at fixed temperature and different immersion time in absence and presence of various concentrations of corrosion inhibitor. Prior to every experiment the initial weight of carbon steel samples were taken and then immersed in the test solution (50mL) for immersion period of 4, 8, 16 and 24h. After the elapsed time specimens were taken out, washed with distilled water, dried and then weighed accurately. All the experiments were conducted in wooden air thermostat.

From weight loss data; the surface coverage (θ), inhibition efficiency (IE %) and corrosion rates (CR) of inhibitor for carbon steel were calculated by using the following equations:

$$(\theta) = \frac{W_o - W_i}{W_o} \quad (1)$$

$$(IE\%) = \frac{W_o - W_i}{W_o} \times 100 \quad (2)$$

Where, w_i and w_O stand for the carbon steel coupon in presence and absence of inhibitor respectively.

The corrosion rate CR (mmy^{-1}) of carbon steel was calculated using the relation:

$$(CR) = \frac{87.6 \times \Delta w \times 10^3}{AtD} \quad (3)$$

where Δw is the weight loss of the carbon steel samples (gm), A is area of the sample (cm^2), t is exposure time (h) and D is the density 7.68(g cm^{-2})

Electrochemical Measurements

The electrochemical measurements were done by using a three-electrode cell assembly at room temperature where a platinum foil acts as a counter electrode, saturated calomel electrode as the reference electrode and a working electrode of carbon steel having 1 cm^2 area was immersed in the test solution and the rest being covered by using epoxy resin [27]. The working electrode was abraded by using emery papers of different mesh grades, washed with water, and degreased with acetone. All electrochemical measurements were carried out using computerized AUTOLAB Salartron Model 1280B potentiostat at open circuit potential.

All experiments were carried out after immersion for 30 min in the test solution (no deaeration, no stirring) to attain a stable value of E_{corr}.

Electrochemical impedance was carried out in frequency range of 10 kHz to 0.01 Hz with signal amplitude of 10 mV at the corrosion potential and the experimental measurements were automatically controlled by Z-view software. All experiments were measured after immersion for 30 min in 1 M HCl in presence and in absence of inhibitors. The impedance data were plotted in the form of Nyquist plots (Z_{real} vs. Z_{img}) and Bode plots. Charge transfer resistance (R_{ct}) and double layer capacitance (C_{dl}) were calculated by using data from Z-view software.

The Tafel polarization measurement was carried out from cathodic potential at a scan rate 1mV s^{-1} obtained by changing electrode potential from -250 to + 250mV (SCE vs. OCP) in order to study the influence inhibitor of corrosion inhibition on carbon steel.

3. Results & Discussion

Weight Loss Measurements

Effect of PDBI on Inhibition Efficiency

Inhibition efficiency (IE%) and surface coverage (θ) values obtained from the weight loss measurements in absence of inhibitor and in the concentration range (50-300ppm) in 1M HCl for 24h of immersion at 298 K are shown in Fig 1. Table 1 shows calculated data and increasing trends in inhibition efficiency with increase in inhibitor concentration and maximum efficiency estimated is 98.63% at 300ppm which indicates that PDBI is a good corrosion inhibitor for carbon steel in 1 M HCl. This type of behaviour occurs due to the strong interaction of the compound with metal and resulted in the adsorption of the inhibitor molecules on metal surface [28].

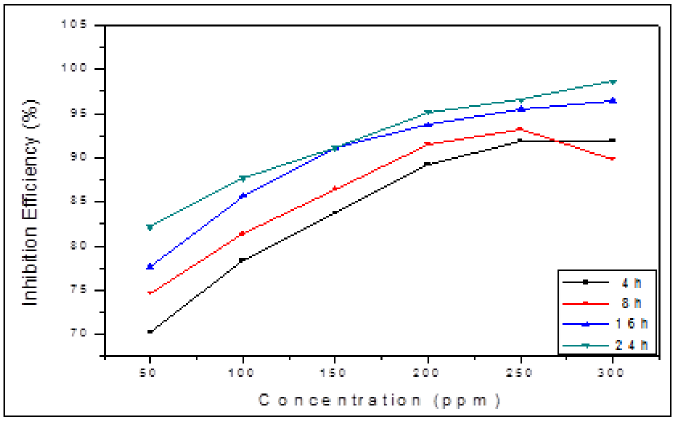


Fig 1: Deviation recorded in inhibition efficiency (IE %) on carbon steel surface in absence and in presence of different concentrations of inhibitor, for different immersion time at 298K.

Table 1: Weight loss parameters for carbon steel, in absence and in different concentrations of inhibitor solution in 1 M HCl for different time periods.

Time period	Conc. (ppm)	Wt. loss (gm)	C_R (mmy-^{1})	IE%	Surface coverage (θ)
4h	0	0.037	35.16	-	-
	50	0.011	10.45	70.27	0.70
	100	0.008	7.60	78.37	0.78
	150	0.006	5.70	83.78	0.83
	200	0.004	3.80	89.18	0.89
	250	0.003	2.85	91.89	0.91
	300	0.003	2.85	91.89	0.91
8h	0	0.059	28.04	-	-
	50	0.015	7.12	74.57	0.74
	100	0.011	5.22	81.35	0.81
	150	0.008	3.80	86.44	0.86
	200	0.005	2.37	91.52	0.91
	250	0.004	1.90	93.22	0.93
	300	0.006	2.85	89.83	0.89
16h	0	0.112	26.61	-	-
	50	0.025	5.94	77.67	0.77
	100	0.016	3.80	85.71	0.85
	150	0.010	2.37	91.07	0.91
	200	0.007	1.66	93.75	0.93
	250	0.005	1.18	95.53	0.95
	300	0.004	0.95	96.42	0.96
24h	0	0.146	23.12	-	-
	50	0.026	4.11	82.19	0.82
	100	0.018	2.85	87.67	0.87
	150	0.013	2.05	91.09	0.91
	200	0.007	1.10	95.20	0.95
	250	0.005	0.79	96.57	0.96
	300	0.002	0.31	98.63	0.98

Effect of PDBI on corrosion rate

The corrosion rate of carbon steel after exposure to 1 M HCl solution for 24h in absence and in presence different concentrations of inhibitor was calculated in mmy^{-1} are plotted with concentration in Fig 2.

It is noticed from results that corrosion rate decreases as the concentration of the inhibitor increases suggesting that the corrosion inhibition enhances with the inhibitor concentration. This behavior described the fact of increase in adsorption amount and coverage of metal surface by the inhibitor with concentration increase [29].

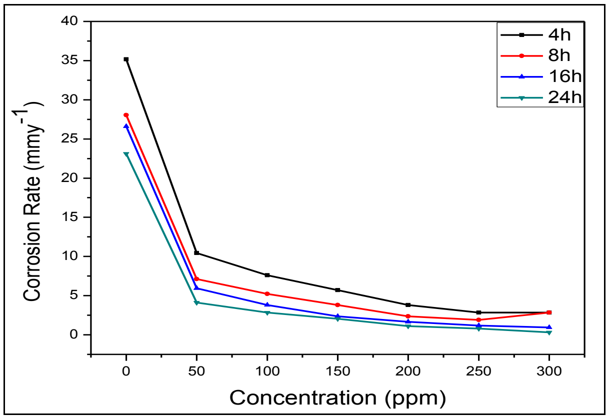


Fig 2: Deviation recorded in corrosion rate (CR) for carbon steel surface in absence and in presence of different concentrations of inhibitor, for different immersion time at 298K.

Electrochemical measurements

Electrochemical impedance measurements studies

The corrosion behaviour of carbon steel was investigated by impedance measurement at 298 K temperature after immersion in 1M HCl solution with and without different concentrations of PDBI as an inhibitor for 30 min. The impedance spectra of carbon steel are present in the form of Nyquist plots are shown in Fig 3. The Nyquist plots are exist in semicircle in nature and diameter of semicircle increases with increasing the concentration of corrosion inhibitor. It shows the impedance of inhibited mild steel increase with increasing the concentration of inhibitor. It is also seen that the impedance is not perfectly semicircle in 1M HCl solution which can be attributed to frequency dispersion as a result of the no homogeneity and roughness of electrode surface [30-34].

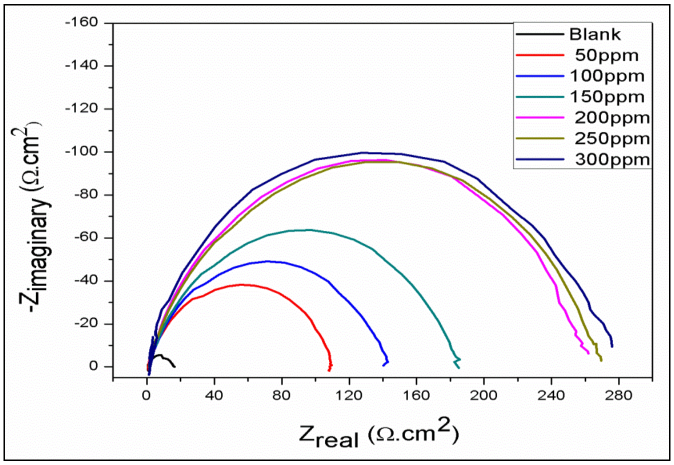
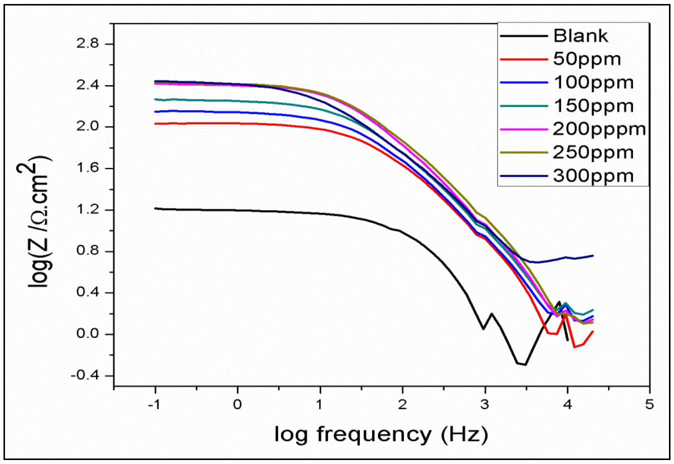


Fig 3: Nyquist plots for carbon steel in absence and presence of different concentrations of inhibitor in 1M HCl solution at room temperature.

Figure 4(a, b) presents the Bode and Phase plot for the same impedance data between log Z impedance vs. log frequency and between phase angle vs. log frequency at different concentrations of inhibitor. Impedance performance suggests that greater values of phase angles at higher frequency give indication of more capacitance [35].



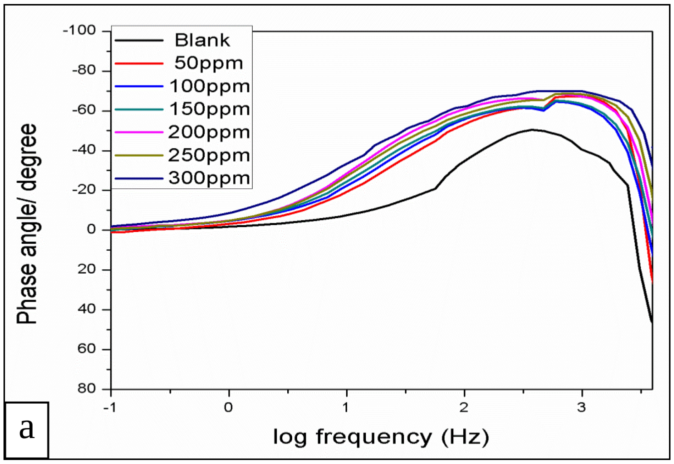


Fig 4: (a) Bode and **(b)** Phase plots of carbon steel in absence and in presence of different concentrations of PDBI as corrosion inhibitor in 1M HCl solution at room temperature.

The experimental results obtained from electrochemical impedance measurement such as charge transfer resistance (Rct), double layer capacitance (C_{dl}), and percentage inhibition efficiency

(% IE_{EIS}) are listed in Table 2. The value of charge transfer resistance calculated from the difference in impedance (Z_{real}) at lower to higher frequencies [36]. The double layer capacitance value calculated from the frequency at which the imaginary component of impedance is ($-Z_{max}$) maximal and R_{ct} value by using following equation [37, 39].

$$C_{dl} = \frac{1}{2\pi f_{max}} \times \frac{1}{R_{ct}} \qquad (4)$$

Where, Where, f_{max} is the frequency value at the top of semicircle of Z_{real} axis, $\pi = 3.14$ and R_{ct} is the charge transfer resistance with inhibitor concentration, respectively.

The percentage inhibition efficiency was obtained from R_{ct} value with different concentration of inhibitor by using following equation [40].

$$IE_{EIS}\,\% = \left(1 - \frac{R^0_{ct}}{R_{ct}}\right) \qquad (5)$$

Where, R^0_{ct} and R_{ct} represent the charge transfer resistance without and with different concentrations of inhibitor.

Table 2. Electrochemical impedance parameters of carbon steel in absence and in presence of different concentrations of PDBI as inhibitor in 1M HCl solution.

Inhibitor name	**Concentration (ppm)**	**R_{ct} (Ω.cm²)**	**C_{dl} (µ F/cm²)**	**Inhibition efficiency (IE_{EIS} %)**
Propylenediamine-bis(isatin) PDBI	0	15.88	417.96	-
	50	108.8	61.00	85.40
	100	141.59	46.87	88.78
	150	184.14	36.04	91.34
	200	260.56	25.47	93.90
	250	268.46	24.72	94.08
	300	274.94	24.14	94.22

From the Table 2 it can be seen that on increasing the inhibitor concentration tin 1 M HCl solution, the charge transfer resistance (Rct) value increases but double layer capacitance value decreases. The decreases in double layer capacitance value (C_{dl}) in comparison with absence of inhibitor in solution could result from a decrease in local dielectric constant and/or an increases in the thickness of the electrical double layer, which suggest that corrosion inhibitor functions by adsorption at metal/solution interface [41, 42] .

Potentiodynamic Polarisation Measurements

The representative potentiodynamic polarization as cathodic and anodic polarization curves for mild steel in 1.0 M HCl solution in absence and presence of different concentrations of PDBI are shown in figure 5.

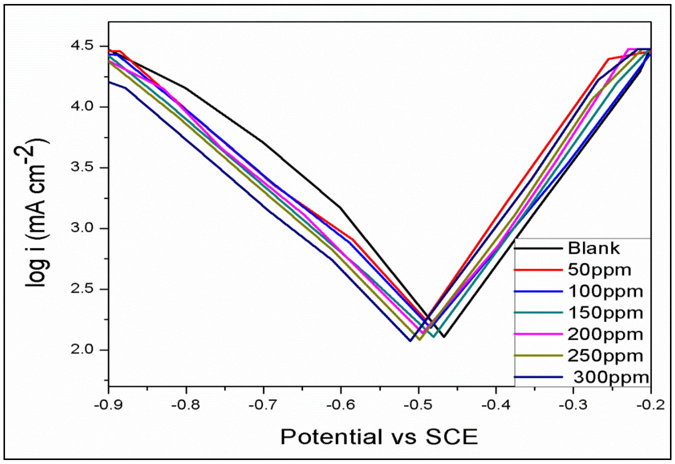


Fig 5. Tafel polarization curve of inhibitor in absence and in presence of inhibitor in 1M HCl.

It can be seen from the figure that on addition of corrosion inhibitor in 1 M HCl solution effect both cathodic and anodic polarization curves or it shifted the both cathodic and anodic branches of Tafel curve to lower value of current density. The corrosion inhibitor slow down both cathodic hydrogen evolution reaction and the anodic dissolution of carbon steel surface and inhibition of both type reaction increases with increasing the inhibitor concentration hence shows that PDBI act as mixed type inhibitor.

The experimental polarization parameters were obtained by the extraplotation of Tafel slope including corrosion potential (E_{corr}), corrosion current density (I_{corr}), cathodic (β_c) and anodic (β_a) Tafel constant and inhibition efficiency are illustrated in Table 3.

Table 3. Tafel polarization data of inhibitor for carbon steel in 1M

Inhibitor name	Concentration (ppm)	β_a mV dec^{-1}	β_c mV dec^{-1}	-E_{corr} (mV vs SCE)	I_{corr} (µA.cm^{-2})	IE_{pp} %
Propylenediamine-bis(isatin) PDBI	0	778	1369	-0.506	5.72	-
	50	649	968	-0.494	1.69	70.45
	100	626	937	-0.461	1.45	74.65
	150	709	818	-0.497	1.35	76.39
	200	664	793	-0.473	1.06	81.46
	250	591	674	-0.468	0.68	88.11
	300	518	696	-0.461	0.62	89.16

By inspection of Table 3 it is clearly seen that the cathodic (β_a), anodic (β_c) Tafel constant values slightly change and the corrosion current density (I_{corr}) decreased hence corrosion rate of carbon steel obviously reduced in the presence of the corrosion inhibitor. But the values of cathodic Tafel constant are higher than anodic which show the inhibitor effect on the cathodic hydrogen evolution reactions than on the anodic dissolution reactions. These results show that there is formation a protective thin layer film on steel surface which reduced the corrosion process.

The values of corrosion current density (Icorr) calculated by using following equation (Stern-Geary equation).

$$I_{corr} = \frac{\beta_a X \beta_c}{2.303(\beta_a + \beta_c)} X \frac{1}{R_p} \qquad (6)$$

Where, R_p is the polarization resistance, β_a and β_c are the cathodic and anodic Tafel constant, respectively.

The percentage inhibition efficiency is calculated by using following equation [43].

$$IE_p\% = \left(1-\frac{I_{corr^i}}{I_{corr^0}}\right) \times 100 \qquad (7)$$

Where, I_{corr^0} and I_{corr^i} are the corrosion current densities without and with different concentrations of inhibitor, respectively. The maximum percentage inhibition efficiency that are depend upon the corrosion current density value found to be 89.16% at 300ppm concentrations solution.

Also, there are no definite trends of corrosion potential (E_{corr}) value with presence of different concentration of inhibitor in 1M HCl solution. This indicates the non-interference of inhibitor in the anodic dissolution or cathodic hydrogen evolution reactions independently suggesting that this inhibitor act as mixed type inhibitor [44-46].

It was reported by various researchers and Riggs [47]. that i) if the displacement in E_{corr} value in the presence of corrosion inhibitor with respect to absence of inhibitor is higher than 85 mV, the inhibitor is recognized as an anodic or a cathodic type inhibitor ii) if the change in E_{corr} value is less than 85 mV, the inhibitor is recognized as mixed type inhibitor [48]. In the present study the maximum displacement of corrosion potential (E_{corr}) value is 45 mV which indicates that the PDBI act as mixed type corrosion inhibitor.

Adsorption Isotherm

Weight loss measurement gives idea about the effectiveness of Schiff base in terms of its inhibition efficiency and surface coverage on metal surface. But brief explanation can be given through adsorption of inhibitor molecule on metal surface. Adsorption isotherm provides necessary and useful information related to the mode of interaction between the metal/solution interfaces. Physical adsorption and chemical type of adsorption gives idea for better explanation. Degree of adsorption found to depends upon the chemical structure and composition of inhibitor molecules, temperature and electrochemical potential at metal/solution interface [49]. Out of the various isotherms, the Langmuir isotherm found to be best graphically fitted adsorption isotherm for tested inhibitor.

Langmuir adsorption isotherm can be expressed by the following equation:

$$\frac{C_{inh}}{\theta} = \frac{1}{K_{ads}} + C_{inh} \qquad (8)$$

Where, C_{inh} represents the inhibitor concentration, θ is the degree of the coverage on the metal surface and K_{ads} = equilibrium constant for the adsorption–desorption process. The straight line plot of C/θ vs concentration is shown in Fig6.

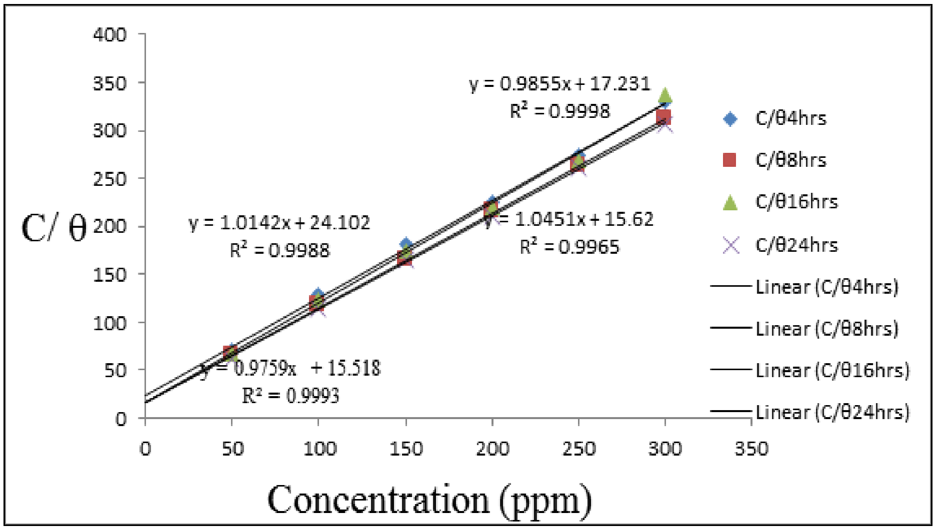


Fig 6: Langmuir adsorption plots for carbon steel in 1M HCl solution for different immersion time.

Slope line values for 4, 8, 16 and 24h immersion time shows values equal to 0.998, 0.999, 0.996 and 0.999 respectively. The values are close to unity indicates that the Langmuir adsorption isotherm is being obeyed. The intercepts of slope line is used to calculate the equilibrium constant for adsorption- desorption process which in then utilized to calculate the standard Gibbs free energy of adsorption according to the equation:

$$\text{Van'th off equation} = \frac{1}{55.5}\exp\left(\frac{\Delta G_{ads}}{RT}\right) \quad (9)$$

Where, R is the universal gas constant; T, is the thermodynamic temperature.

The calculated values of K_{ads} and ΔG^0_{ads} are compiled in Table 4. The high value of the adsorption equilibrium constant points towards the high adsorption ability hence stronger interaction of inhibitor molecules on the carbon steel surface for different immersion time. The K_{ads} data support PDBI as a good corrosion inhibitor for carbon steel in acidic medium. The average values ΔG^0_{ads} were recorded -27.11, -27.94, -28.18 and -28.20 kJ mol^{-1}, respectively. The negative values of standard free energy of adsorption points towards the spontaneity in adsorption for both inhibitors on carbon steel surface and strong interaction and stability of the adsorbed layer [50–54].

The negative value of ΔG^0_{ads} obtained through using equation points to the spontaneity of the reaction and stability of the adsorbed inhibitor layer. The ΔG^0_{ads} of near about -20 kJmol^{-1} or less negative is considered as physisorption which shows interaction between charged inhibitor molecules and charged metal surface. If the value is around -40 kJ mol^{-1} or more negative then it indicates charge sharing or transfer between inhibitor molecules and metal surface through coordinate bond (chemisorptions) [55-59].

In the case of this inhibitor the values of ΔG^0_{ads} are in the range between -27.11 kJ mol^{-1} to -28.20 kJ mol^{-1} which suggest adsorption mechanism as the combination of both physisorption and chemisorptions on carbon steel surface. But predominantly physisorption contributes more towards the adsorption process. All negative ΔG^0_{ads} values imply the adsorption of the inhibitor on metal surface as a spontaneous process.

Table 4: Thermodynamic adsorption parameters of PDBI inhibitor on carbon steel surface for different immersion periods at 298 K.

Inhibitor name	Immersion time	Log 55.5k	ΔG^0_{ads} /kJ mol^{-1}
Propylenediamine-bis(isatin) PDBI	4hr	4.75	-27.11
	8hr	4.89	-27.94
	16hr	4.93	-28.18
	24hr	4.94	-28.20

SEM Study

SEM images of carbon steel surface 1M HCl solution and in 250ppm concentration of PDBI inhibitor for 24h of immersion period at 298 K are shown in Fig 7. This technique was selected in order to support our results. As shown in Fig 7(a) carbon steel surface shows some abraded scratches in polished area, in (b) due to absence of inhibitor and in presence of corrosive solution it undergo dissolution thereby showing highly porous and deep holes on metal surface due to aggressive attack of corrosive medium.

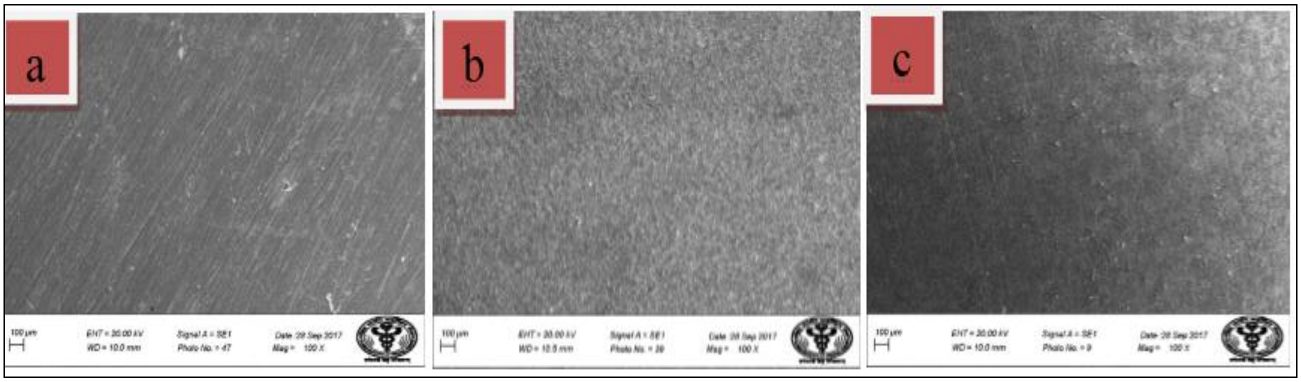


Fig 7: SEM images of carbon steel samples after of immersion period of 24h (a) polished surface before corrosion (b) in 1M HCl (c) in 250ppm of PDBI.

However in Fig (c), the surface of metal appears smooth and show formation of a protective film after the addition of inhibitor in 250ppm concentration.

The inhibitor molecules are adsorbed on the steel surface and protected the metal against corrosion. SEM results are in good agreement with the inhibition efficiency observed from other techniques.

4. Conclusions

1. Studied inhibitor i.e Propylenediamine-bis(Isatin) PDBI found good inhibitor for carbon steel in 1 M HCl solution at 298 K.
2. Weight loss parameters shows increase in inhibition efficiency upto 98.63% and surface coverage (θ) but decrease in corrosion rates with concentration and immersion times at 298 K.
3. Potentiodynamic curves reveals inhibitor as mixed type.
4. Inhibitor obeys Langmuir adsorption isotherm and thermodynamic parameter points towards adsorption as physiosorption.
5. SEM study shows that corrosion inhibition is due to adsorption of PDBI at carbon steel/ acid solution interface.

5. References

1. James CF, Ranjani VS, Robert WS. Jr., Ind. Eng. Chem. Res. 2012; 51:5273.
2. Mahbuboor RC, Ming-Kai H, Radisav DV, David AD. Ind. Eng. Chem. Res. 2012; 51:4230.
3. Fan HB, Fu CY, Wang HL, Guo XP, Zheng JS, Br. Corros J. 2002; 37:122.
4. Zhang K, Xu B, Yang W, Yin X, Liu Y, Chen Y. Corros. Sci., 2015; 90:284.
5. Abd El-Nabey BA, Khamis E, Sh Ramadan M, El-Gindy A. Corros. 1996; 52:71.
6. Shaban SM, Aiad I, El-Sukkary MM, Soliman EA, El-Awady MY. Mol J Liq. 2015; 203:20.
7. Farag AA, Ali TA. Ind J Eng. Chem, 2015; 21:627.
8. Yousefi A, Javadian S, Dalir N, Kakemam J, Akbari J, RSCAdv. 5, 2015; 11697.
9. Dud Y, Govea-Rueda R, Galicia M, J. Phys. Chem., 109, 2005; 2674.
10. Bentiss F, Lagrenée M, Traisnel M, J. Corros, 56, 2000; 733.
11. Bentiss F, Traisnel M, Lagrenée M, J. Appl. Electrochem, 31, 2001; 41.

12. Bouklah, M, Ouassini, A, Hammouti, B. *et al*, Appl. Surf. Sci, 252, 2006; 2178.
13. Tebbji, K, Oudda, H, Hammouti, B. *et al*, Appl. Surf. Sci, 241, 2005; 326.
14. El Ouafi , A, Hammouti, B, Oudda, H. *et al*, Anti Corros. Meth. Mater, 49, 2002; 199.
15. Fekry, AM, Ameer, MA. Int. J. Hydrogen Energy, 35 , 2010; 7641.
16. Behpour M, Ghoreishi SM, Gandomi Niasar A, Soltani N, Salavati-Niasari M, J. Mater. Sci. 44, 2009; 2444.
17. Asan A, Soylu S, Kıyak T, Yıldırım F, Corros. Sci. 48, 2006; 3933.
18. Behpour M, Ghoreishi SM, Soltani N, Salavati-Niasari M, Hamadanian M, Gandomi A, Corros. Sci. 50, 2008; 2172.
19. Abdel-Gaber AM, Masoud MS, Khalil EA, Shehata EE,Corros. Sci.51,2009; 3021.
20. Struck S, Schmidt U, Gruening B, Jaeger IS, Hossbach J, Preissner R, Genome Inform, 20, 2008; 231.
21. Newman DJ, Cragg GM, Snader KM, J. Nat. Prod, 66, 2003; 1022.
22. Newman DJ, Cragg,GM. J. Nat. Prod. 70, 2007; 461.
23. Harvey AL, Drug Discov. Today, 13, 2008; 894.
24. Raja PB, Sethuraman MG, Mater. Lett, 62, 2008, 113.
25. Quraishi MA, Ahamad I, Singh AK, Shukla SK, Lal B, Singh V. Mater Chem Phys 112, 2008; 1035.
26. Mathur PB, Vasudevan T, Corros, 38 , 1982; 171.
27. Ahamad I, Quraishi MA, Corros. Sci. 51, 2006; (2009).
28. Choudhry RS, Sharma S, Indian J. Chem Tech. no, 6,1999; 202.
29. Zhao TP, Mu GN, Corros. Sci., 41, 1999; 1937.
30. Xianghong L, Deng S, Fu H, Corros. Sci, 55, 2012; 280.
31. Abu-Dalo Muna A, Al-Rawashdeh Nathir AF., Ayman Ababneh, Desalination 313, 2013; 105.
32. Stanly Jacob K, Geetha Parameswaran, Corros. Sci. 52, 2010; 224.
33. Quraishi MA, Ambrish Singh, Vinod Kumar Singh, Dileep Kumar Yadav, Ashish Kumar Singh, Mater. Chem. Phys. 122, 2010; 114.
34. Hazwan Hussin M, Jain Kassim M, Mater. Chem. Phys. 125, 2011; 461.
35. Popova A, Christov M, Corros. Sci, 48, 2005; 3208.
36. Behpour M, Ghoreishi SM, Soltani N, Salavati-Niasari M, Hamadanian M, Gandomi A, Corros. Sci, 50, 2008; 2172.
37. Amin MA, Khaled KF, Mohsen Q, Arida HA, Corros. Sci, 52, 2010; 1684.
38. Daoud D, Douadi T, Issaadi S, Chafaa S, Corros. Sci, 79, 2014; 50.
39. Kumar H, Om H, Kumar P, Vikas, Anjoo Elix. Corros. Dye, 97, 2016; 42060.
40. Elayyachy Hammouti B, El Idrissi A, Appl. Surf. Sci, 249, 2005; 176.
41. Haruyama S, Tsuru T, Gijutsu B, Jpn J. Soc. Corros. Eng, 27, 1978; 573.
42. Gopiraman M, Selvakumaran N, Kesavan D, Karvembu R. ∗ Progress in Organic Coatings 73, 2012; 104.
43. Hegazy MA, Corros. Sci, 51, 2009; 2610.
44. Quartarone G, Bonaldo L, Tortato C, Appl. Surf. Sci. 252, 2006; 8251.
45. Chauhan LR, Gunasekaran G, Corros. Sci. 49, 2007; 1143.
46. Hegazy MA, Corros. Sci. 51, 2009; 2610.
47. Ferreira ES, Giancomelli C, Giacomelli F. C, Spinelli A, Mater. Chem. Phys, 83, 2004; 129.
48. Mu G.N., Li X.H., Qu Q., Zhou J., Corros. Sci. 48, 2006; 445.
49. Kertit S, Hammouti B, Appl. Surf. Sci. 93, 1996; 59.
50. Kardas G, Solmaz R, Corros. Rev. 24, 2006; 151.
51. Bayol E, Gürten AA, Dursun M, Kayakırılmaz K, Acta Phys. Chim. Sin., 24, 2008; 2236.
52. Avci G, Mater. Chem. Phys. 112, 2008; 234.
53. Umoren SA, Obot IB, Ebenso EE, Obi-Egbedi N.O, Desalination 247, 2009; 561.
54. Bahrami MJ, Hosseini SMA, Pilvar P, Corros. Sci. 52, 2010; 2793.
55. Özcan M, Karadag F. Dehri I, Acta Phys. Chim. Sin. 24, 2008; 1387.
56. Özcan M, Solmaz R, Kardas G, Dehri I,Colloids Surf, A 325, 2008; 57.
57. Obi-Egbedi NO, Obot IB, Corros. Sci. 53, 2011; 263.
58. Wang X, Yang H, Wang F, , Corros. Sci. 53, 2011; 113.
59. Negm NA, Elkholy YM, Zahran MK, Tawfik SM, Corros. Sci. 52, 2010; 3523.