

Corrosion Inhibition for Mild Steel in Acidic Medium by Using Hexadecylamine as Corrosion Inhibitor

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Abstract: The corrosion study of mild steel in 1.0 M HCl solution at 298, 308 and 318 K using various concentrations of hexadecylamine as corrosion inhibitor for different immersion time were carried out by weight loss technique and other different techniques *i.e.* Potentiodynamic polarization, Electrochemical impedance spectroscopy (EIS) at 298 K and SEM techniques. The adsorption of this molecule leads to the formation of a protective layer on mild steel. From the weight loss measurement the maximum percentage corrosion inhibition efficiency 96.26% was observed for 1000 ppm concentration of inhibitor at 298 K. By electrochemical impedance study it observed that charge transfer resistance (R_{ct}) value increases and double layer capacitance (C_{dl}) value decreases with increasing the inhibitor concentration hence inhibition efficiency increases which related to the charge transfer resistance. From potentiodynamic polarization study it was observed that hexadecylamine behave as mixed type corrosion inhibitor. Adsorption of inhibitor on the mild steel surface is in agreement with the Langmuir adsorption isotherm. From the surface study it can be seen that on increasing the inhibitor concentration there is formation of protective layer on the surface of mild steel to protect the surface against corrosion and surface become smooth and more clean and clear. All above techniques study shows that hexadecylamine is a good corrosion inhibitor for mild steel in 1.0 M HCl solution.

Keywords: Mild steel, Hexadecylamine, HCl, Potentiodynamic polarization, Electrochemical impedance spectroscopy, SEM

Introduction

Mild steel used mainly in industries and daily life uses due to its various properties like mechanical stress, easily availability and low cost price *etc.* It has been also used in formation of households, reaction vessel and storage tank¹⁻². Different type of acidic solutions mainly hydrochloric acid are widely used in industries in chemical cleaning, descaling and pickling, which lead to corrosive attack on such type steel³⁻⁶. Metals corroded usually in presence of oxygen and moisture and it involves two electrochemical processes *i.e.* oxidation occurs at anode and reduction at cathode. Corrosion can be controlled by

suitable modification of the environment which in turn stifle, retard or completely stop the anodic or cathodic reactions or both type reactions. In the field of corrosion scientists play main role in control of corrosion of metals and alloys. Various methods are applied in protection of metals and alloy against corrosion. But the corrosion control by inhibitors were found one of the most common, effective and economic methods to protect metals against corrosion in acid medium. Therefore, the consumption of inhibitors to reduce corrosion has increased in recent years⁷. Corrosion inhibitors when added in small amount are more effective in corrosive medium to protect the metal against corrosion. The inhibition of corrosion in acid medium can be affected by a variety of organic, inorganic compounds and pharmaceutical drugs *etc.* Such Compounds those having N, O and S have vast application as corrosion inhibitors⁸⁻¹⁶. The organic inhibitors are preferred over inorganic inhibitor as they contains electronegative group, π electron in multiple bonds and aromatic ring in their structure, which act as the main adsorption centers¹⁷⁻¹⁹. The effectiveness of organic inhibitor also depends on electron density of donor sites, molecular weight of molecules, size and structure of inhibitor *etc.*,²⁰⁻²³. Adsorption of inhibitors on mild steel surface is effective in cathodic and anodic processes and both type process. The first stage in the action mechanism of these compounds in acid media is their adsorption on the metal surface²⁴. The Adsorption capacity of different substances constitutes an important feature to form a protective layer on metal surfaces and thus, these may be promoted as corrosion inhibitors for metals and alloys in various aggressive media²⁵⁻³¹.

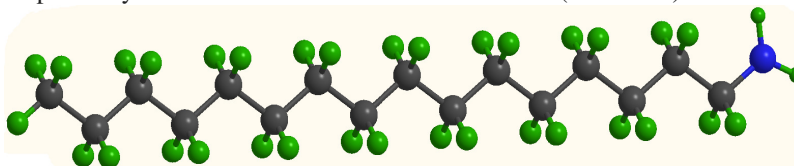
In continuation and literature survey to our earlier study³²⁻³⁷ show that amines and their derivative are effective corrosion inhibitors³⁸⁻⁴³. In the present study our aim to study the corrosion study of hexadecylamine for mild steel in 1.0 M HCl solution with different concentrations at different temperature for different time were analyzed by different techniques such as weight loss study, electrochemical impedance spectroscopy, potentiodynamic polarization technique, adsorption isotherm study and SEM (Scanning electron microscopy)

Experimental

Mild steel used for study having composition; C 0.054, Mn 0.26, Cr 0.056, Cu 0.010, Ti 0.002, S 0.017, P 0.019, Mo 0.018, Si 0.015, Ni 0.009 and remained iron. First of all the specimen were cut into 1x3 cm² dimensions for weight loss study and 1x5 cm² for electrochemical measurements and then polished with different grades of (100-1000) emery papers. Then specimens were rinsed with double distilled water, degreased with acetone and dried with help of hot air dryer and then used for the study.

Inhibitor

Hexadecylamine purchased from Sigma-Aldrich (99%) was used as corrosion inhibitor for study. The molecular mass and molecular formula of hexadecylamine is C₁₆H₃₅N and 241.463 g/mol respectively. Structure of inhibitor is shown below (Scheme 1).



Scheme 1. Structure of Hexadecylamine

Preparation of solutions

The corrosive medium *i.e.* acidic solution of 1.0 M HCl was prepared by dilution of conc. HCl analytical grade 37% with double distilled water. The inhibitor solution were made up by dilution of 0.5 mL hexadecylamine with 500 mL of 1.0 M HCl solution to make 1000 ppm solution (stock solution). The corrosion inhibitor used without any further purification. The concentrations range was used for experimentation from 0 ppm to 1000 ppm with a difference of 200 ppm. The desired concentrations of hexadecylamine were made from stock solution of 1000 ppm.

Weight loss measurement

The gravimetric method (weight loss measurement) is probably the most widely used method of inhibition assessment. The simplicity and reliability of the measurement offered by the weight loss method are such that the technique forms the baseline method of measurement in many corrosion monitoring programmers. The weight loss study has been carried out in 1.0 M HCl solution. First of all mild steel samples were cut in to 1x3 cm² then abraded with emery paper of different grade (100-1000) and rinsed with double distilled water, cleaned with acetone and finally dried between filter paper then weighed. The weight loss study carried out at on previously weighed sample in 30 mL of 1.0 M HCl solution filled in 50 mL beaker in presence and absence of various concentrations of inhibitor for 12, 18 and 24 h at different temperature ranges *i.e.* 298, 308 and 318 K in test solution and then sample put out side from the test solution after completion of time and cleaned with double distilled water followed by acetone, dried then weighed again. This weight loss study was performed in triplicate and then average weight loss was recorded by this weight loss study. Percentage corrosion inhibition efficiency and surface coverage was calculated by following equations.

$$\eta_w \% = \frac{w_o - w_i}{w_o} \times 100 \quad (1)$$

$$\theta = \frac{w_o - w_i}{w_o} \quad (2)$$

Where, w_o and w_i are the weight loss value of mild steel in absence and presence of inhibitor respectively. The corrosion rate of mild steel was calculated by using equation (3)

$$C_R (\text{mmy}^{-1}) = \frac{87.6 \times w}{AtD} \quad (3)$$

Where w is weight loss of mild steel in mg, A is area of sample (cm²), t is exposure time (hours) and D is density of mild steel (g cm⁻³).

Electrochemical measurement

Mild steel samples size of 1x5 cm² dimensions were used for electrochemical study. The mild steel samples were rubbed with (100-1000) grades of emery papers, cleaned with double distilled water followed by acetone and dried put into desiccators then used for experimental study. The sample surface area 1.0x1.0 cm² has been selected for the electrochemical study. Electrochemical impedance and potentiodynamic polarization were carried out by AUTOLAB salatron model 1280B potentiostat. Electrochemical process were carried out with help of three electrodes, one of them is mild steel as working electrode, platinum as counter electrode and saturated calomel electrode as reference electrode were suspended in 50 mL beaker with different concentrations (200-1000 ppm) of hexadecylamine prepared by 1.0 M HCl solution. Before starting each experiments first of all the electrodes were

immersed in test solution at open circuit potential (OCP) for 30 minutes at 298 K temperature to attain a stabilized value of OCP and then proceeded the measurement.

Electrochemical impedance spectroscopy

The impedance measurements were carried out in frequency range of 10 kHz to 0.01Hz with signal amplitude of 10 mV at the corrosion potential ($-E_{\text{corr}}$). The experiments were performed with different concentrations of inhibitor which were previously used in weight loss experiments. All impedance measurements were automatically controlled by Z-view software and the impedance diagrams were given in the Nyquist representation. Electrochemical impedance parameters such as charge transfer resistance (R_{ct}) and double layer capacitance (C_{dl}) were calculated from EIS data⁴⁴.

Potentiodynamic polarization

The electrochemical corrosion behavior of mild steel sample in presence and absence of different concentrations of inhibitor in 1.0 M HCl solution at 298 K was carried out by the potentiodynamic polarization curves. The polarization study was taken after impedance measurement at same cell setup and potential range were taken -200 mV to +200 mV with respect to open circuit potential, at a scan rate of 1.0 mV/s. From the polarization curves, the corrosion parameters such as corrosion potential ($-E_{\text{corr}}$), corrosion current density (I_{corr}), cathodic (β_c) and anodic (β_a) Tafel constant were obtained.

SEM analysis

After immersion of mild steel samples in 1.0 M HCl in the absence and presence of hexadecylamine at different temperatures for 24 h, the surface morphology of samples were performed on a ZEISS scanning electronic microscope (AIIMS, DELHI).

Results and Discussion

Weight loss study

Corrosion inhibition performance of hexadecylamine as corrosion inhibitors can be evaluated by using weight loss study of mild steel which was determined at various interval of time in absence and presence of different concentrations of inhibitor. Weight loss provides more reliable results than electrochemical techniques for the determination of corrosion inhibition efficiency.

Effect of immersion time

The experiments carried out in 1.0 M HCl solution with different concentration of hexadecylamine at different temperatures for different time *i.e.* 12, 18 and 24 h. The variations of inhibition efficiency and corrosion rate with immersion time at different temperatures are shown in Figures 1a-c and 2a-c. It can be observed from the figures that with increasing the immersion time the inhibition efficiency increased and corrosion rates decreased at same temperature. This is because of increased the adsorption process on mild steel surface at higher immersion time.

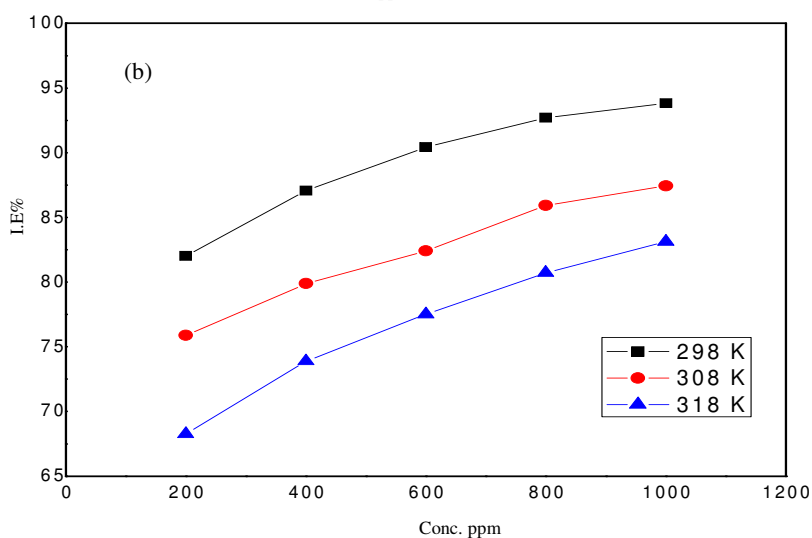
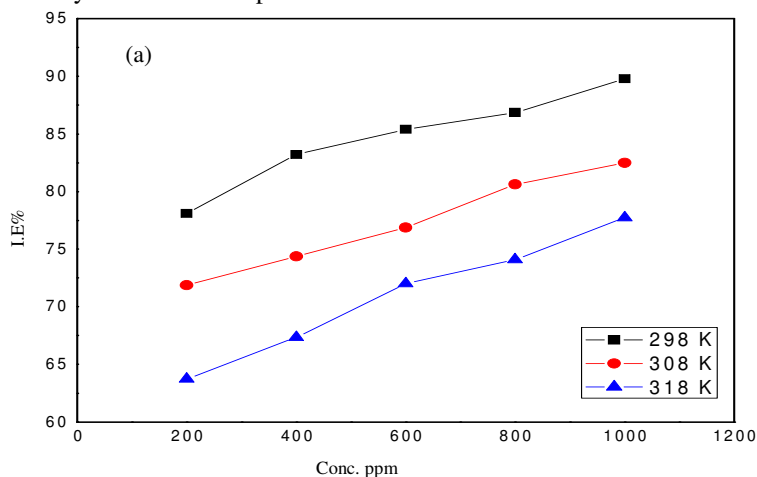
Effect of concentration

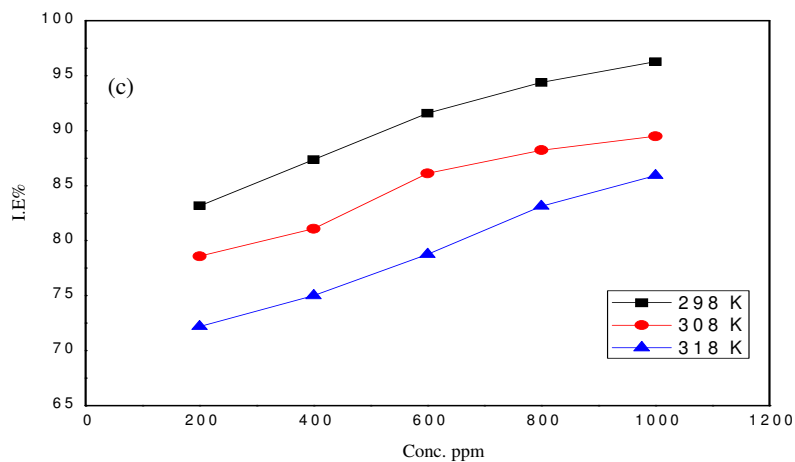
The values of inhibition efficiency and corrosion rate with different concentrations of inhibitor in acidic solution at different temperatures after various immersion times are summarized in Tables 1, 2 and 3. Data from tables revealed that the percentage inhibition efficiency increased and corrosion rates decreased with increasing the concentration of inhibitor.

The maximum inhibition efficiency was found to be 96.26% for higher concentration of inhibitor (1000 ppm) at 298 K temperature for 24 h. It might be due to increasing adsorption of hexadecylamine on the mild steel surface with concentration.

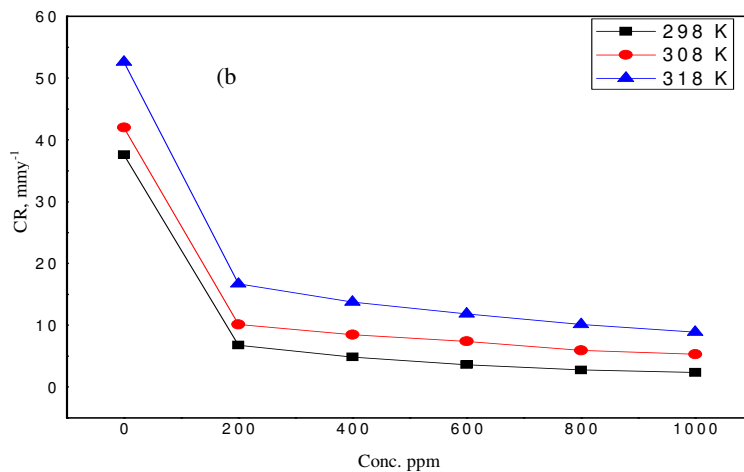
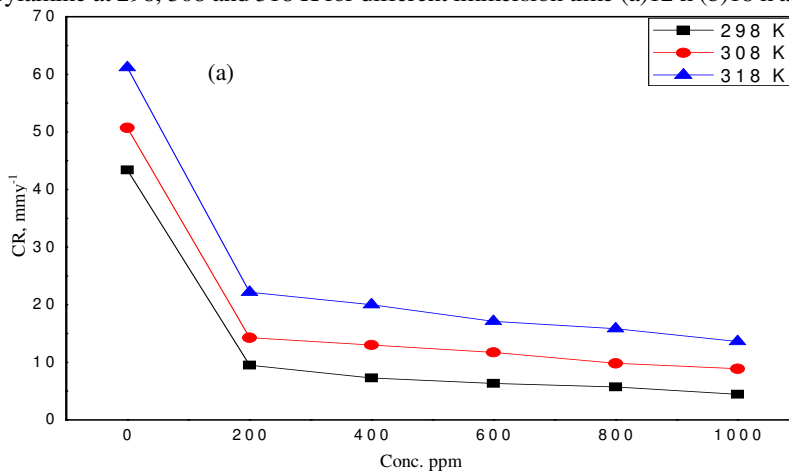
Effect of temperature

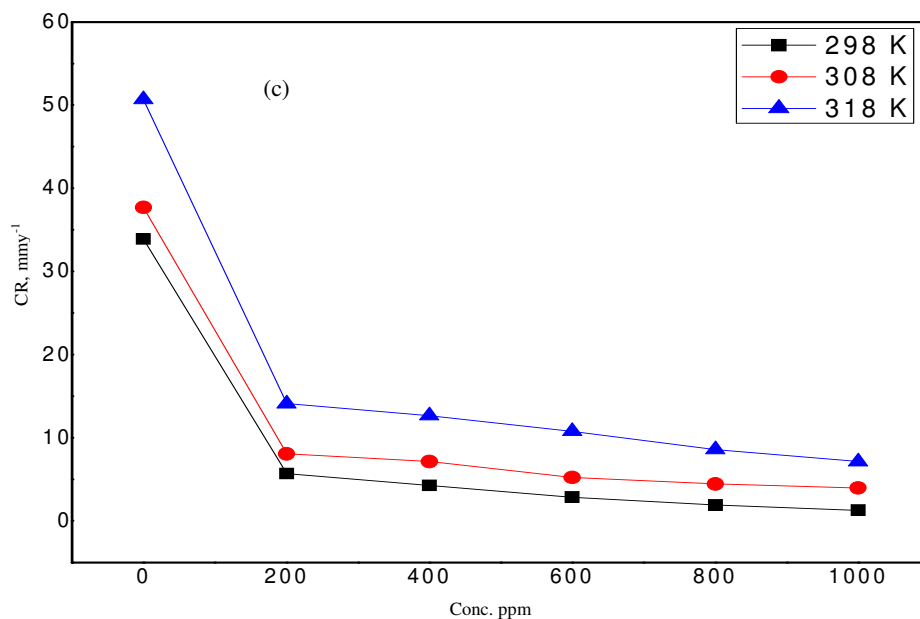
From the inspection of tables and figures it was observed that with rise in temperature from 298 K to 318 K the weight loss of mild steel increased hence the inhibition efficiency value decreased but corrosion rates value increased at same concentration of inhibitor. According to Oguzie *et al.*⁴⁵, a decrease of inhibition efficiency with rise in temperature suggests that inhibitor molecules are physically adsorbed on the metal surface, while the reverse behavior suggests the molecules adsorbed surface by the action of chemisorptions. Thus, the results signify that the adsorption of hexadecylamine is mainly due to the physical adsorption. The increase in temperature usually accelerates the evolution of hydrogen, which results in a higher dissolution rate of the mild steel. The decrease in inhibition efficiency with temperature may be due to desorption of the inhibitor molecule.





Figures 1a-c. Inhibition efficiency graph for mild steel with various concentrations of hexadecylamine at 298, 308 and 318 K for different immersion time (a) 12 h (b) 18 h and (c) 24 h





Figures 2a-c. Corrosion graph for mild steel with various concentrations of hexadecylamine at 298, 308 and 318 K for different immersion time (a) 12 h (b) 18 h and (c) 24 h

Table 1. Inhibition efficiency values for the corrosion of mild steel in acid solution of 1.0 M HCl in the absence and in the presence of different concentrations of hexadecylamine from weight loss measurements at 298 K for 12, 18 and 24 h of immersion time

Inhibitor name	Concentration, ppm	Weight Before, g	Weight After, g	Weight loss, g	Corrosion Rate mmy ⁻¹	Inhibition efficiency, ηw%
Hexa decylamine (12 h)	0	1.109	0.972	0.137	43.40	-
	200	1.114	1.084	0.030	9.50	78.10
	400	1.099	1.076	0.023	7.28	83.21
	600	1.101	1.081	0.020	6.33	85.40
	800	1.113	1.095	0.018	5.70	86.86
	1000	1.117	1.103	0.014	4.43	89.78
(18 h)	0	1.127	0.949	0.178	37.59	-
	200	1.093	1.061	0.032	6.75	82.02
	400	1.120	1.097	0.023	4.85	87.07
	600	1.080	1.063	0.017	3.59	90.44
	800	1.111	1.098	0.013	2.74	92.69
	1000	1.126	1.115	0.011	2.32	93.82
(24 h)	0	1.117	0.903	0.214	33.90	-
	200	1.110	1.074	0.036	5.70	83.17
	400	1.113	1.086	0.027	4.27	87.38
	600	1.106	1.088	0.018	2.85	91.58
	800	1.108	1.096	0.012	1.90	94.39
	1000	1.122	1.114	0.008	1.26	96.26

Table 2. Inhibition efficiency values for the corrosion of mild steel in acid solution of 1.0 M HCl solution in the absence and in the presence of different concentrations of hexadecylamine from weight loss measurements at 308 K for 12, 18 and 24 h of immersion time

Inhibitor name	Concentration, ppm	Weight before, g	Weight after, g	Weight loss, g	Corrosion rate, mm^{-1}	Inhibition efficiency, $\eta_{\text{w}}\%$
Hexa decylamine (12 h)	0	1.137	0.977	0.160	50.69	-
	200	1.115	1.070	0.045	14.25	71.87
	400	1.165	1.124	0.041	12.99	74.37
	600	1.097	1.060	0.037	11.72	76.87
	800	1.134	1.103	0.031	9.82	80.62
(18 h)	1000	1.127	1.099	0.028	8.87	82.50
	0	1.120	0.921	0.199	42.03	-
	200	1.109	1.060	0.048	10.13	75.87
	400	1.126	1.086	0.040	8.44	79.89
	600	1.096	1.061	0.035	7.39	82.41
(24 h)	800	1.124	1.096	0.028	5.91	85.93
	1000	1.118	1.093	0.025	5.28	87.43
	0	1.137	0.899	0.238	37.70	-
	200	1.147	1.096	0.051	80.7	78.57
	400	1.125	1.080	0.045	7.12	81.09
(24 h)	600	1.118	1.085	0.033	5.22	86.13
	800	1.129	1.101	0.028	4.43	88.23
	1000	1.121	1.096	0.025	3.96	89.49

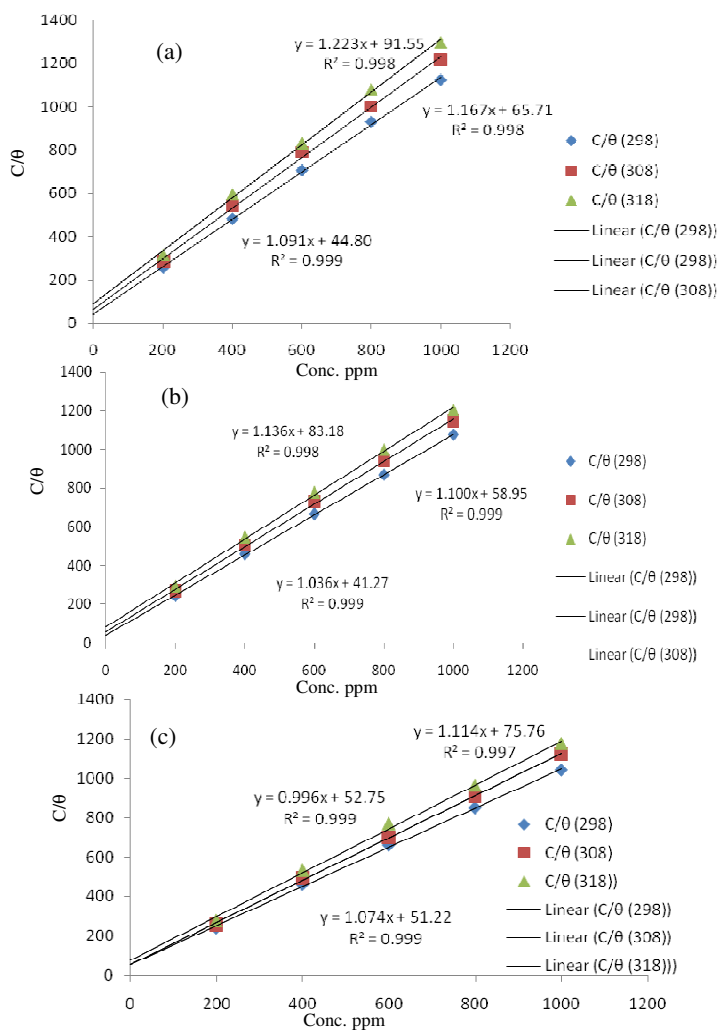
Table 3. Inhibition efficiency values for the corrosion of mild steel in acid solution of 1.0 M HCl in the absence and in the presence of different concentrations of hexadecylamine from weight loss measurements at 318 K for 12, 18 and 24 h of immersion time

Inhibitor name	Concentration, ppm	Weight Before, g	Weight After, g	Weight loss, g	Corrosion rate, mm^{-1}	Inhibition efficiency, $\eta_{\text{w}}\%$
Hexa decylamine (12 h)	0	1.140	0.957	0.193	61.15	-
	200	1.128	1.058	0.070	22.17	63.73
	400	1.120	1.057	0.063	19.96	67.35
	600	1.100	1.046	0.054	17.10	72.02
	800	1.140	1.090	0.050	15.84	74.09
(18 h)	1000	1.114	1.071	0.043	13.62	77.72
	0	1.087	0.838	0.249	52.59	-
	200	1.120	1.041	0.079	16.68	68.27
	400	1.100	1.035	0.065	13.72	73.89
	600	1.097	1.041	0.056	11.82	77.51
(24 h)	800	1.117	1.069	0.048	10.13	80.72
	1000	1.125	1.083	0.042	8.87	83.13
	0	1.148	0.828	0.320	50.69	-
	200	1.108	1.019	0.089	14.09	72.18
	400	1.101	1.021	0.080	12.67	75.00
(24 h)	600	1.152	1.084	0.068	10.77	78.75
	800	1.155	1.101	0.054	8.55	83.12
	1000	1.129	1.084	0.045	7.12	85.93

Adsorption isotherm

To understand the effect of inhibitor on mild steel surface, the study of adsorption isotherm is very important aspect. Several isotherm can be used to analyze the adsorption behavior of inhibitor on the surface *i.e.*, Temkin, Frumkin, Freundlich, Flory – Huggins and Langmuir isotherm *etc.* But among them the studied experimental data was found to be fitted by Langmuir's adsorption isotherm.

A straight line curve with strong correlation coefficient nearly equal to 1.0 was obtained on plotting C_{inh}/θ against C_{inh} as shown in Figures 3a-c also suggesting that adsorption of the compound on the mild steel surface followed Langmuir adsorption isotherm model. The relation between surface coverage θ and the inhibitor concentration is given by Langmuir's adsorption isotherm⁴⁶⁻⁴⁷.



Figures 3(a-c). Langmuir adsorption isotherm plot for the mild steel in 1.0 M HCl solution with different concentration of hexadecylamine at different temperatures for immersion time (a)12 h (b)18 h and (c) 24 h

$$\frac{C_{inh}}{\theta} = \frac{1}{K_{ads}} + C \quad (4)$$

Where, C_{inh} is the concentration of inhibitor, θ is the surface coverage which is obtained from the weight loss by using equation $\theta = \frac{W_o - W_i}{W_o}$ and K_{ads} could be calculated from the intercepts of the straight lines on the $\frac{C_{inh}}{\theta}$ axis; the equilibrium constant of the adsorption relation to the standard free adsorption energy is calculated from the equilibrium constant using following equation:

$$\Delta G_{ads}^0 = -RT(\ln 55.5 K_{ads}) \quad (5)$$

Where, R is the universal gas constant (8.314 J mol⁻¹ K⁻¹), T is absolute temperature and 55.5 is the concentration of water⁴⁸⁻⁴⁹ in solution (mol/L). The linear correlation coefficient adsorption parameters K_{ads} and ΔG_{ads}^0 values are illustrate in Table 4. It reveals that with increasing temperature the K_{ads} decreases gradually, which indicates that the inhibitor strongly adsorbed on to the steel surface at a lower temperature. But when the temperature is high, the adsorbed inhibitor tends to desorbed from the steel surface. Generally, the absolute value of ΔG_{ads}^0 is -20 kJ/mol lower than -20 kJ/mol, they are consistent with the electrostatic interaction between the charged molecules and the charged metal called physical adsorption (physisorption); when those that are -40 kJ/mol or more negative than -40 kJ/mol, which involve sharing or transfer of electrons from the inhibitor molecules to the metal surface to form a coordinate bond called chemical adsorption (chemisorption)⁵⁰⁻⁵². Here, the calculated value of ΔG_{ads}^0 for hexadecylamine from table are found to be ranged from -25.40 to -26.08 kJ mol⁻¹ for different immersion time which indicate that the adsorption process of inhibitor on metal surface is mixed physical and chemical adsorption called physiochemical adsorption⁵³⁻⁵⁵. Also the negative values of ΔG_{ads}^0 revealed that the adsorption of inhibitor on to the mild steel is a spontaneous process usually shows the strong interaction on the surface.

Table 4. Thermodynamic adsorption parameters for mild steel in 1.0 M HCl in the presence of various concentration of hexadecylamine at different temperatures

Inhibitor name	Temp., k	Log55.5 K_{ads}	ΔG_{ads}^0 , kJ mol ⁻¹
Hexadecylamine 12 h	298	4.482	-25.574
	308	4.315	-25.451
	318	4.171	-25.401
18 h	298	4.517	-25.777
	308	4.362	-25.729
	318	4.213	-25.654
24 h	298	4.411	-25.169
	308	4.424	-26.089
	318	4.254	-25.901

Electrochemical impedance spectroscopy measurement

Through the impedance spectroscopy study the results obtained are presented in the form of nyquist plot for mild steel in 1.0 M HCl in the presence and absence of different concentrations

of inhibitor is shown in Figure 4. The Nyquist plot are semicircle in nature and it can be seen from the diagram that diameter of semicircle increases with increasing the inhibitor concentration in 1.0 M HCl solution. It shows that the impedance of mild steel is increased with increasing in concentration of inhibitor and also shows adsorption of inhibitor on surface of mild steel. The impedance spectra show the one single capacitive loop which suggest that the corrosion of mild steel surface is mainly controlled by the charge transfer process and generally related to charge transfer and double layer behavior⁵⁶⁻⁵⁷.

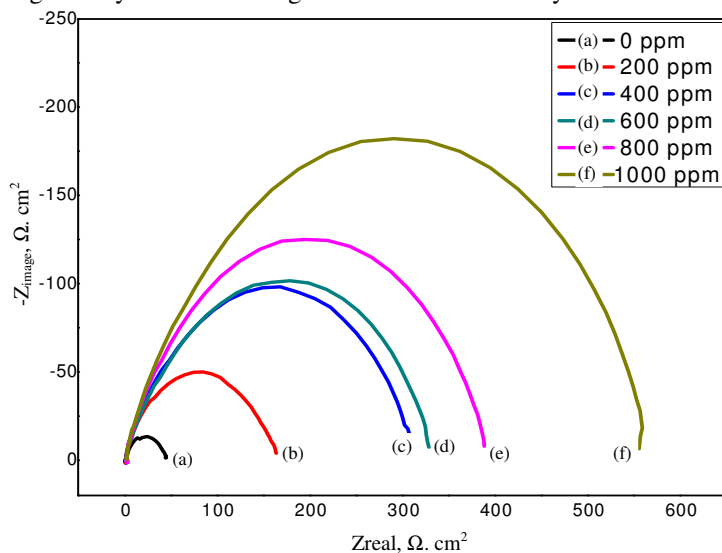


Figure 4. Nyquist plot for mild steel in 1.0 M HCl in different concentration of hexadecylamine as corrosion inhibitor

All the impedance parameters that are obtained from impedance such as charge transfer resistance (R_{ct}), double layer capacitance (C_{dl}) and inhibition efficiency are shown in Table 5. The value obtained for charge transfer resistance (R_{ct}) was calculated from the difference in impedance (Z_{real}) lower and higher frequencies. From the Table it has shown that the charge transfer resistance (R_{ct}) value increased with increasing the concentration of inhibitor in the solution. The decrease in C_{dl} (double layer capacitance) with increasing the concentration of inhibitor indicating that increase the thickness of electrical double layer which denote the inhibitor molecule function by adsorption at the metal/ solution interface⁵⁸. The value of double layer capacitance are calculated from the frequency at which the imaginary component of impedance is ($-Z_{max}$) maximal and R_{ct} value by using following equation^{59,37}.

$$C_{dl} = \frac{1}{2\pi f_{max} R_{ct}} \quad (6)$$

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

The R_{ct} value is used to calculate the percentage inhibition efficiency (IE_R %) of hexadecylamine according to following expression:

$$IE_R \% = \frac{R_{ct(inh)} - R_{ct}^0}{R_{ct(inh)}} \times 100 \quad (7)$$

Where, R_{ct} and $R_{ct(inh)}$ are the charge transfer resistance in absence and presence of different concentrations of inhibitor. The percentage inhibition efficiency ($IE_R \%$) increases with increasing inhibitor concentrations and maximum value is 92.11% at 1000 ppm. Thus it indicates that hexadecylamine perform as good corrosion inhibitor for mild steel in 1.0 M HCl medium.

Table 5. Impedance parameters and their corresponding inhibition efficiency in presence and absence of different concentrations of inhibitor at 298 K temperature

Inhibitor name	Conc., ppm	$R_{ct}, \Omega.cm^2$	$C_{dl}, \mu F.cm^{-2}$	$IE_R \%$
Hexadecylamine	0	43.64	321.20	-
	200	162.64	86.18	73.16
	400	310.17	45.19	85.93
	600	327.30	42.82	86.16
	800	386.30	36.28	88.70
	1000	553.18	25.33	92.11

Potentiodynamic polarization

Potentiodynamic polarization curves for mild steel in 1.0 M HCl solution in absence and presence of different concentrations of hexadecylamine as corrosion inhibitor are shown in Figure 5. It can be seen from the figure that inhibitor effect both cathodic and anodic polarization curves or the inhibitor shifted the both cathodic and anodic branches of Tafel curve to lower value of current density. The inhibitor first adsorbed on mild steel surface then reduced the anodic dissolution and also retarded the hydrogen evolution reaction at cathodic side hence shows that hexadecylamine act as mixed type inhibitor. The polarization parameters values such as corrosion potential ($-E_{corr}$), anodic (β_a) and cathodic (β_c) Tafel constant, polarization resistance (R_p) (that obtained from extrapolation of Tafel slope of curve), corrosion current density (I_{corr}) and inhibition efficiency ($IE_P \%$) are illustrated in Table 6.

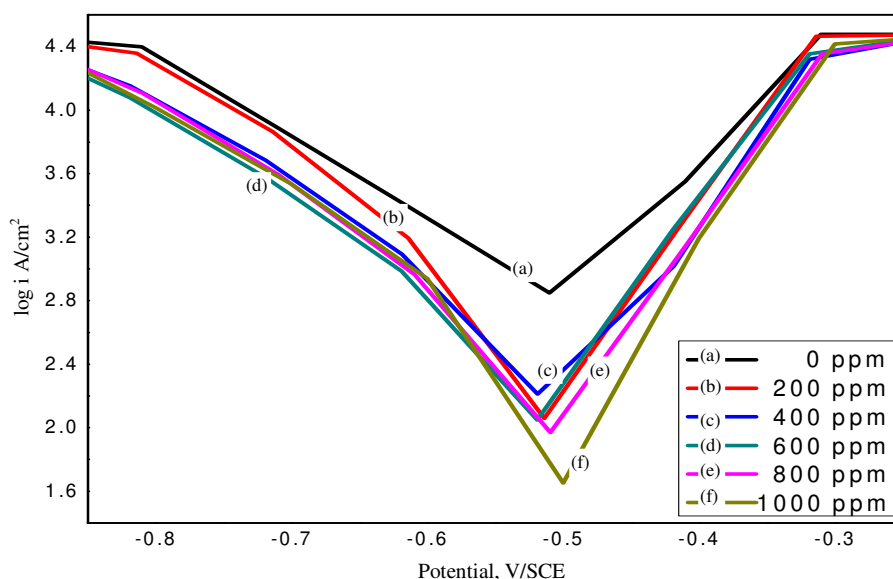


Figure 5. Tafel polarization curve for mild steel in 1.0 M HCl with presence or absence different concentration of hexadecylamine at 298 K

The values of corrosion current density (I_{corr}) calculated by using following equation (Stern-Geary equation). The values of polarization resistance, cathodic and anodic Tafel constant are used to calculate the corrosion current (I_{corr}).

$$I_{\text{corr}} = \frac{\beta_a \times \beta_c}{2.303(\beta_a + \beta_c)} \times \frac{1}{R_p} \quad (8)$$

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

Table 6. Potentiodynamic polarization measurement for mild steel samples in 1.0 M HCl solution with and without different concentrations of inhibitor at 298 K temperature

Inhibitor name	Conc., ppm	β_a , mV dec ⁻¹	β_c , mV dec ⁻¹	R_p , $\Omega \cdot \text{cm}^2$	E_{corr} , mV v.s. SCE	I_{corr} , $\mu\text{A cm}^{-2}$	IE_p %
	0	582	1376	11.2	-0.480	15.9	-
	200	516	1227	59.3	-0.476	2.65	83.33
Hexadecylamine	400	490	1268	62.2	-0.499	2.46	84.52
	600	496	1207	69.7	-0.477	2.19	86.22
	800	499	1162	75.5	-0.492	2.00	87.42
	1000	442	1142	89.5	-0.503	1.54	90.31

Through the inspection of table it is found that the cathodic (β_a), anodic (β_c) Tafel constant values slightly change and polarization resistance (R_p), inhibition efficiency values increases and corrosion current density (I_{corr}) decreases with increasing inhibitor concentration that confirm there is formation a protective thin layer film which reduced the corrosion process. This effect is also due to the inhibitor adsorb more strongly on steel surface as concentration of inhibitor high and which reduced both cathodic and anodic reaction on mild steel surface. The inhibition efficiency (IE_p %) for each concentrations of inhibitor are calculated by using following equation:

$$IE_p \% = \left(1 - \frac{I_{\text{corr}}^i}{I_{\text{corr}}^o}\right) \times 100 \quad (9)$$

Where, I_{corr}^o and I_{corr}^i are the corrosion current density without and with different concentrations of inhibitor, respectively. The maximum inhibition efficiency value of hexadecylamine found to be 90.31% and maximum reduction of corrosion current density (I_{corr}) found 1.54 μAcm^{-2} at higher concentration of inhibitor (1000 ppm).

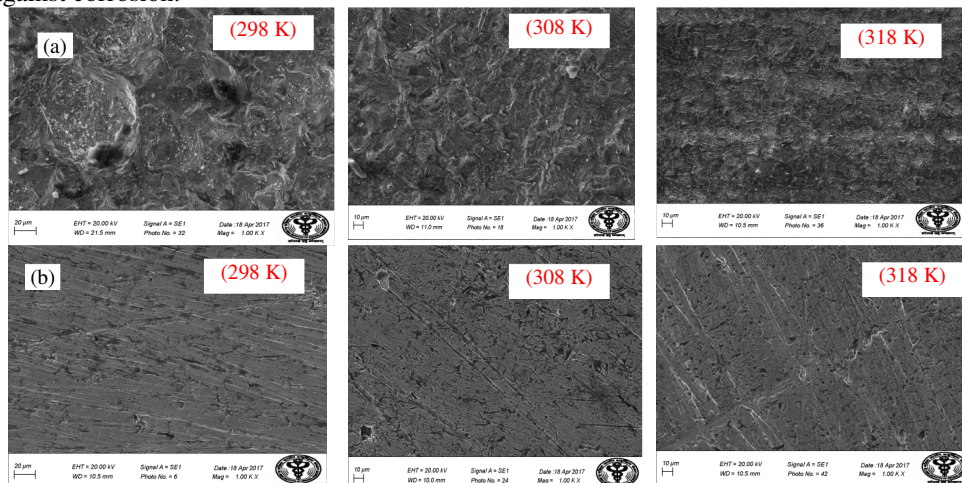
According to Ferreira⁶⁰ (a) if the value of displacement in ($-E_{\text{corr}}$) is higher than 85 mV with respect to ($-E_{\text{corr}}$), the inhibitor can be seen as anodic or cathodic type inhibitor and (b) if value of displacement in ($-E_{\text{corr}}$) is lower than 85 mV, the inhibitor can be acts as mixed type inhibitor (both cathodic and anodic type). In present study the maximum displacement in ($-E_{\text{corr}}$) is 23 mV, which clearly indicates that hexadecylamine act as mixed type inhibitor⁶¹⁻⁶³.

Inhibition efficiencies obtained from weight loss measurement (η_w %) electrochemical; impedance spectroscopy (IE_R %) potentiodynamic polarization measurement (IE_p %) are in near about good reasonably agreement.

Scanning electron microscope

Surface study for corrosion of mild steel samples in 1.0 M HCl solution for immersion period of 24 hours at 298, 308 and 318 K temperatures in absence and presence of hexadecylamine are shown in Figures 6a,b.

Figures show that in absence of inhibitor the surface of sample was completely damaged and in presence of inhibitor sample surface was almost unaffected by corrosion. It exhibit that there is a formation of thin protective film on mild steel surface which protect against corrosion.



Figures 6a,b. SEM images of mild steel surface at different temperatures (a) immersed for 24 h in blank 1.0 M HCl and (b) with 1000 ppm concentrations of hexadecylamine

Conclusion

Weight loss study shows that the inhibition efficiency of hexadecylamine increases with increasing concentration. From the electrochemical impedance measurement it can be seen that when inhibitor concentration increasing charge transfer resistance increases and double layer capacitance decreases. Hence percentage inhibition efficiency increases. By potentiodynamic polarization it showed that hexadecylamine is a mixed type corrosion inhibitor. Surface study show that there is formation of protective layer of inhibitor on mild steel surface

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