



3, 3'-Diaminodipropylamine (DADPA) as corrosion inhibitor for carbon steel in dilute hydrochloric acid solutions

Manju Kumari

Department of Chemistry, Govt. College Mahendergarh, Haryana, India

Abstract

3, 3' Diaminodipropylamine is investigated as corrosion inhibitor for Carbon steel in different concentrations of Hydrochloric Acid medium and at temperatures 25, 30, 35°C. Corrosion rate and Percentage Corrosion Inhibition Efficiency (PCIE) was calculated by weight loss method, Electrochemical polarization experiments and Impedance spectroscopy techniques. Surface study of corroded and blank specimens was carried out by SEM and Metallurgical research Microscopy techniques. Different concentrations of (100, 200, 400, 600, 800 and 1000 ppm) 3, 3'diaminodipropylamine was tested in different concentration of HCl solution i.e. 2.0, 1.0 and 0.1 N. Observed results show that percentage corrosion inhibition efficiency increases with increase in concentration of corrosion inhibitor. Effect of temperature on percentage corrosion inhibition efficiency was also studied. As the temperature increases percentage corrosion inhibition efficiency decreases. It is also observed that percentage corrosion inhibition efficiency decreases with dilution of HCl. DADPA acts as a very good inhibitor for Carbon Steel in different hydrochloric acid medium.

Keywords: carbon steel, weight loss, polarization, impedance, DADPA, corrosion

Introduction

In modern research work, protection of different metals and their alloys from corrosion in acidic solution is the most demanding work due to the large number of applications in the fields like acid usage and oil recovery industry, petrochemical related industry, etc. Carbon steel is one of the industrially important metals and is expected to expose its surface to the different industrial environments during use. Carbon steel pipelines are normally used in the transportation of oil and gas also. Carbon steel piping and equipments are subjected to corrosion caused by the presence of water and acidic gases like carbon dioxide (CO₂), hydrogen sulfide (H₂S) and acids like acetic acid (CH₃COOH). Carbon steel decomposed to different degree depending on the ferociousness of the medium or the nearby environment. In general the service life of steel is improved by using a variety of corrosion measuring techniques. The majority of the easily presented methods for decreasing corrosion are based on modifying either the surface of the metal or changing environmental circumstances. In this type of cases the corrosion of steel is successfully prevented using proper inhibitors. Most of the acid corrosion inhibitors are organic compounds which contain hetero atoms like N, S, O and aromatic ring. [1-5]. It is found that most of corrosion inhibitor, which contains N and S has been found to be successful corrosion inhibitors. Nearly all of the organic inhibitors work by adsorption on the surface of metal. The corrosion resisting properties of metals can distinctly change by the forming a protective later of inhibitors at interface of the metal/ solution. This process of protection of corroding surfaces of metals and equipments prevents the misuse of both materials and wealth. The surfactant inhibitors are used due to high inhibition efficiency, low price, low toxicity and easy

production the adsorption of the surfactant on the metal surface can distinctly alter the corrosion resisting property of the metal ^[6] and so the study of the relationship between the adsorption and corrosion inhibition is of great value. As are preventative type of these organic inhibitors, quaternary ammonium compounds have been demonstrated to be highly cost-effective and widely used in various industrial processing for preventing corrosion of iron and steel in acidic media ^[7, 9]. Many mechanisms have been proposed for the inhibition of metal corrosion by organic inhibitors. However, the exact mechanism of inhibition is still not understood completely. In continuation to our earlier study ^[10, 16], in the present work, the corrosion inhibition efficiency of the surfactant i.e. 3,3'Diaminodipropylamine (DADPA) on the acid dissolution of carbon steel was evaluated using weight loss, Electrochemical Polarization, Impedance spectroscopy and surface study by metallurgical research microscopy and SEM techniques.

Materials and Methods

Weight loss measurement

Carbon steel was used for various measurement having composition C = 0.54%, P = 0.05%, Mn =0.32%, S = 0.05%, Si = 0.05%, P=0.20, Ni=0.03, Cu=0.01, Cr=0.01 and iron is the remainder portion. Samples of size (3.0 cm × 1.5 cm) were used for weight loss measurements. Strips were mechanically polished with different grades of emry papers and washed with acetone before use. A sheet cut of the same composition having size (1 cm ×1 cm) was used for electrochemical polarization and impedance experiments. The electrode was polished using different grades of emery papers and degreased with acetone. HCl was used for preparing solutions was of AR grade. The inhibitor DADPA used was Spectrochem made.

Double distilled water is used in making all solution. Corrosion rate and percentage corrosion inhibition efficiencies (PCIEs) for different concentrations of the inhibitor were calculated from weight loss experiments in the absence and presence of the inhibitor at three different temperature of 25.0, 30.0, and 35.0°C with the help of formula (1) & (2).

$$\text{Corrosion Rate (mpy)} = \frac{534+W}{DAT} \quad (1)$$

Where, W = weight loss (in mg), D = density of carbon steel (in g/cm³), A = area of sample (in sq. inch), T = exposure time (in hour).

$$\text{Percentage Corrosion Inhibition Efficiency (PCIE)} = \frac{(CR_o - CR)100}{CR_o} \quad (2)$$

Where, CR_o = corrosion rate in absence of inhibitor and CR = corrosion rate in presence of inhibitor.

The effect of temperature on the performance of the inhibitor and the effectiveness of the inhibitor at higher acid strength were also studied.

Electrochemical Polarization Measurements

An electrochemical cell assembly containing three electrodes based was used for electrochemical polarization experiments. Mechanically polished Carbon steel coupons itself act as working electrode. Ag/AgCl electrode was used as a reference electrode and a platinum electrode was used as an auxiliary counter electrode. Mechanical polishing of the Carbon steel coupons was successively done with different grade empty papers i.e. 150, 250, 350, 600 μ. The surface of mechanically polished surfaces Carbon steel coupons were degreased with acetone in order to remove grease or oil from Carbon Steel surface and then washed with abundance of double distilled water before performing the corrosion experiments. The surface area of exposure of working electrode for performing experiments was 1.0 cm² and rest of area was covered with epoxy resin. The electrochemical polarization experiments were performed on electrochemical workstation PGSTAT 128N Metrohm Autolab. Ltd., Netherland. Before starting the electrochemical polarization experiments, the working electrode i.e. Carbon Steel was kept into the acidic solution as a corrosion medium for 2.0 hrs. to gain the constant value of equilibrium potential. Electrochemical polarization experiments were carried out at temperatures of 298.0, 303.0, 308.0 K constantly flowing water from thermostat maintained at a constant temperature. The same process is repeated in different concentration of corroding medium i.e. 2.0, 1.0, 0.1 N HCl. Electrochemical polarization experiments were performed from -1.2 to 2.0 V at a scan rate of 0.01 (V/s). The corrosion rate (CR) and PCIE was found out by the use of following equations:

The corrosion rate was observed by the Stern-Gerry equation

given in equation (3) as below:

$$\text{Corrosion rate (C.R.) (mpy)} = \frac{0.1288 \cdot I_{corr} \cdot Eq.wt.}{D} \quad (3)$$

Where, Eq. Wt. is the gram eq. wt. of CS, D is the density of CS in gm/cm³ and I_{corr} is the corrosion current density in (μA/cm²).

$$\text{PCIE} = \frac{(CR_o - CR)100}{CR_o} \quad (4)$$

Electrochemical impedance spectroscopy

The electrochemical impedance spectroscopy measurements were carried out using class one handheld electrochemical work station Netherland under static conditions. Three electrode based double walled glass cell was used. The reference electrode was a saturated calomel electrode (SCE). A platinum electrode was used as auxiliary electrode of a surface area of 0.094 cm². The working electrode was carbon steel. All potentials given in this study were referred to this reference electrode. The working electrode was immersed in the test solution for 3 min, to establish a steady state open circuit potential (E_{ocp}). After measuring the E_{ocp}, the electrochemical measurements were performed. Nyquist plots were plotted with the help of which R_{ct} (charge transfer resistance) calculated. Percentage inhibition was calculated efficiency by the use of charge transfer resistance using this formula

$$I.E. \% = \frac{(R_{ct} - R_{ct}^*)}{R_{ct}} \times 100$$

Where R_{ct} and R_{ct}* are the charge-transfer resistances with and without the inhibitors

Surface Study

The test specimens of carbon steel after weight loss method in absence and presence of the DADPA in 2.0 N HCl solutions at 298.0 K temperature were used for SEM. These coupons were washed with double distilled water and then with acetone. Finally metal coupons were treated for the surface study by SEM model JEOL JSM 6150 and Metallurgical research microscope.

Result & Discussion

Weight loss technique

In weight loss method, PCIE increases as we increase the conc. of inhibitor from 100ppm to 1000ppm. It acts as a good inhibitor even at low concentration of inhibitor in different acidic medium. Highest PCIE is observed in 2.0N HCl at 1000 ppm. Results of Weight loss method are shown in table

Table 1: Corrosion rate and Percentage Corrosion Inhibition Efficiency (PCIE) of DADPA using different concentrations by weight loss method at 25.0, 30.0, 35.0°C temperatures in 2.0, 1.0, 0.1N HCl media.

Conc. of DADPA	Conc. of HCl	CR at 25.0 °C	PCIE at 25.0 °C	CR at 30.0 °C	PCIE at 30.0 °C	CR at 35.0 °C	PCIE at 35.0°C
blank	2.0 N	1065.96	--	1147.45	--	1269.01	--
	1.0 N	837.54		897.54		964.64	
	0.1 N	456.84		502.40		558.36	
100	2.0 N	295.17	72.67	396.07	65.67	913.68	28.56
200		262.09	75.34	376.45	67.45	862.92	32.34
400		235.06	77.67	312.16	72.08	710.64	44.23
600		198.66	81.23	308.22	73.56	761.40	40.56
800		165.08	84.80	262.14	77.34	634.50	50.21
1000		148.90	86.43	212.36	81.24	602.78	52.78
100	1.0 N	328.16	60.21	447.30	49.74	837.54	13.09
200		289.08	65.13	413.45	53.45	786.78	18.34
400		264.80	68.56	376.04	56.67	736.02	23.76
600		254.46	69.21	350.16	60.42	685.26	28.89
800		238.42	71.09	306.01	65.78	662.34	31.54
1000		213.84	74.43	288.19	67.56	643.87	33.56
100	0.1 N	282.10	38.43	339.80	32.89	532.98	09.89
200		262.80	42.56	317.34	36.45	507.60	04.45
400		238.92	47.78	292.60	41.23	532.98	04.09
600		213.04	53.56	264.03	47.08	406.08	27.05
800		169.59	62.90	224.64	55.67	329.94	40.65
1000		137.81	69.56	214.98	57.78	304.56	45.56

Effect of inhibitor dose and temperature on inhibition efficiency

The order of the inhibition efficiencies obtained from the weight loss with different concentrations of inhibitor in 0.1, 1.0 and 2.0 N HCl concentration media at different temperatures (25.0, 30.0, and 35.0 °C) are shown in Table 1. The results show that percentage corrosion inhibition efficiency increases as the concentration of inhibitor increases from 100 to 1000 ppm at 25.0, 30.0 and 35.0 °C. The maximum inhibition efficiency for DADPA inhibitor was observed to be about 86.0% in 2.0 N HCl solution. The inhibition was estimated to be 72% at 25.0°C even at low concentrations (100 ppm), and at 400 ppm its protection was more than 75% (25.0°C). This trend may result from the fact that the amount of adsorption and the surface coverage of DADPA on the Carbon-steel increase with the inhibitor concentration, thus the Carbon-steel surface is efficiently separated from the medium. Effect of temperature also studied which show that the inhibition efficiency decreases with an increase in corrosion temperature at the same inhibitor concentration revealing that the high temperature might result in desorption of the inhibitor molecules from the Carbon-steel

surface.

Electrochemical polarization technique

Table-2, 3, 4 shows electrochemical polarization data for CS in 2.0, 1.0, 0.1 N HCl solutions in presence and absence of DADPA at 25.0, 30.0, 35.0 °C temperature. The values of OCP, R_p , β_a , β_c and I_{corr} and PCIE are tabulated in table 2, 3 &4.

It is observed that the increase in concentration. Of DADPA to the acid solution as a corroding medium increases both i.e. anodic and cathodic over-potentials but corrosion current density ($I_{Corr.}$) decreases. The values of anodic and cathodic Tafel slopes (β_a and β_c) confirm the adsorption of DADPA on the surface of Carbon Steel. It is clear from the Table-2 that cathodic hydrogen evolution and anodic metal dissolution reactions are inhibited to the almost equal extent and the magnitude of corrosion inhibition of Carbon Steel increases as the concentration of corrosion inhibitor increases in corrosive acid media. No definite trend was observed in $E_{corr.}$ values in presence of different concentrations of DADPA in 2.0 N HCl solution. This result indicates that DADPA may be regarded as mixed type of corrosion inhibitor.

Table 2: OCP, Corrosion Current Density (I_{corr}), anodic Tafel slope (β_a), cathodic Tafel slope (β_c), resistance polarization (R_p),corrosion rate and PCIE of DADPA at different concentrations by electrochemical polarization method at 25.0 °C temperature in 2.0, 1.0, 0.1 N HCl solution

Conc. of HCl	Conc. of inhibitor (ppm)	OCP	I_{corr} ($\mu A/cm^2$)	β_a , (V/dec)	β_c (V/dec)	R_p	CR (mpy)	PCIE
2.0 N	Blank	-0.530	5.23	2.453	3.567	8.51×10^4	2.31	-
1.0 N		-0.534	4.03	3.407	2.342	9.79×10^4	1.78	
0.1 N		-0.524	3.58	2.345	4.897	7.15×10^5	1.58	
2.0N	100	-0.573	1.54	1.360	1.375	9.51×10^4	0.68	70.56
	400	-0.569	1.38	1.234	1.346	7.79×10^4	0.60	74.02
	1000	-0.587	1.14	1.331	1.431	2.15×10^5	0.50	78.35

1.0N	100	-0.567	1.56	1.841	1.705	1.20×10 ⁵	0.68	61.79
	400	-0.586	1.47	0.537	1.837	5.03×10 ⁴	0.64	64.04
	1000	-0.557	1.41	0.476	1.263	4.02×10 ⁴	0.62	65.16
0.1N	100	-0.686	1.78	0.340	1.621	3.17×10 ⁴	0.78	50.63
	400	-0.676	1.66	0.527	1.732	5.23×10 ⁴	0.73	53.79
	1000	-0.555	1.44	1.632	1.938	1.35×10 ⁵	0.63	60.12

Table 3: OCP, Corrosion Current Density (*I*_{corr}), anodic Tafel slope (β_a), cathodic Tafel slope (β_c), resistance polarization (*R*_p), corrosion rate and PCIE of DADPA at different concentrations by electrochemical polarization method at 30.0 °C temperature in 2.0, 1.0, 0.1 N HCl solution.

Conc. of HCl	Conc. of inhibitor (ppm)	OCP	<i>I</i> _{corr} (μA/cm ²)	<i>b</i> _a (V/dec)	<i>b</i> _c (V/dec)	<i>R</i> _p	CR (mpy)	PCIE
2.0 N	Blank	-0.530	6.13	2.456	3.786	4.27×10 ⁴	2.70	
1.0 N		-0.527	4.98	3.987	2.675	5.23×10 ⁵	2.20	
0.1 N		-0.524	3.76	3.234	4.987	3.25×10 ⁴	1.66	
2.0 N	100	-0.580	2.45	1.456	2.056	2.27×10 ⁴	1.08	60.00
	400	-0.577	2.24	1.987	1.867	4.03×10 ⁵	0.98	63.70
	1000	-0.564	1.87	1.234	1.730	4.15×10 ⁴	0.82	69.25
1.0 N	100	-0.570	2.14	1.456	0.456	4.17×10 ⁵	0.94	57.27
	400	-0.567	1.99	0.967	2.787	5.03×10 ⁴	0.88	60.00
	1000	-0.554	1.86	1.234	2.234	3.20×10 ⁵	0.82	62.72
0.1 N	100	-0.580	1.96	1.506	0.416	2.27 ×10 ⁵	0.86	48.19
	400	-0.567	1.87	1.867	1.067	4.03×10 ⁴	0.82	50.60
	1000	-0.554	1.61	1.024	1.234	2.15 ×10 ⁵	0.70	57.83

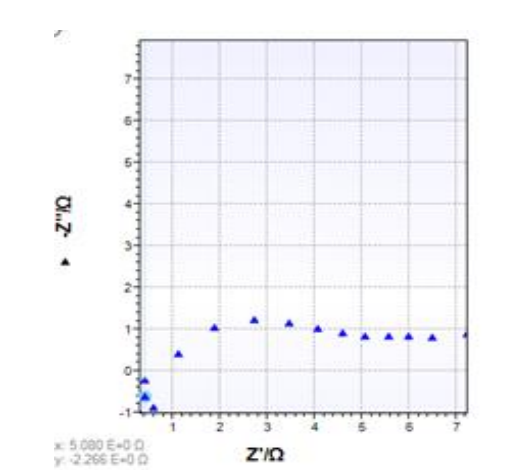
Table 4: OCP, Corrosion Current Density (*I*_{corr}), anodic Tafel slope (β_a), cathodic Tafel slope (β_c), resistance polarization (*R*_p), corrosion rate and PCIE of DADPA at different concentrations by electrochemical polarization method at 35.0 °C temperature in 2.0, 1.0, 0.1 N HCl solution.

Conc. of HCl	Conc. of inhibitor (ppm)	OCP	<i>I</i> _{corr} (μA/cm ²)	<i>b</i> _a (V/dec)	<i>b</i> _c (V/dec)	<i>R</i> _p	CR (mpy)	PCIE
blank		-0.524	6.86	3.671	4.784	9.01×10 ⁴	3.03	-
		-0.484	5.23	2.562	5.675	6.79×10 ⁴	2.31	
		-0.512	4.76.	4.567	3.654	1.05×10 ⁵	2.10	
2.0N	100	-0.556	2.76	1.350	1.465	7.51×10 ⁵	1.21	60.06
	400	-0.569	2.58	1.144	1.346	8.69×10 ⁴	1.14	62.37
	1000	-0.572	2.24	1.231	1.291	1.25×10 ⁵	0.98	67.65
1.0N	100	-0.567	2.71	1.841	1.805	1.20×10 ⁵	1.19	48.48
	400	-0.676	2.57	0.837	1.737	5.33×10 ⁴	1.13	51.08
	1000	-0.567	2.43	0.486	1.253	5.12×10 ⁴	1.07	53.67
0.1N	100	-0.776	2.56	0.744	1.621	3.17×10 ⁴	1.13	46.19
	400	-0.676	2.15	0.637	1.932	5.23×10 ⁴	1.19	48.09
	1000	-0.555	2.08	1.732	1.138	1.35×10 ⁵	0.91	56.66

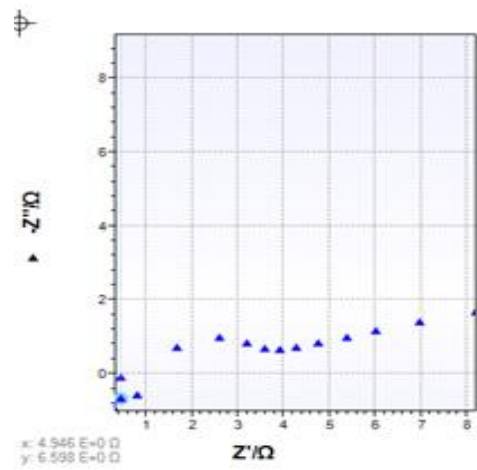
Electrochemical impedance spectroscopy

Impedance spectroscopy technique was used to study corrosion processes occurring on the surface of Carbon steel in presence and absence of Corrosion inhibitor. For considerate the phenomenon, electronic structure of electrified interface formed at the surface of working electrode and surface processes, EIS experiments were performed at equilibrium potential in frequency range i.e. 10,000 to 0.1 Hz at 298.0 K, 303.0 K, 308.0 K. Figure 3 shows EIS plots for Carbon Steel coupons dipped in 2.0 N, 1.0 N, 0.1N HCl medium at 298.0 K with and without corrosion inhibitor at the OCP. It is also

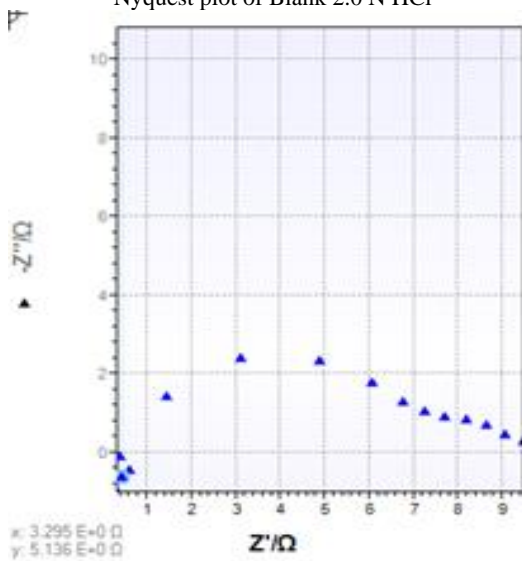
observed from Nyquist plots that the diameter of the semicircle augment with the augment in concentration of DADPA in the corroding medium, which indicates an increase in resistance to corrosion. It is observed from electrochemical impedance data presented in the Table-5. Table data indicates that both *R*_{CT} and PCIE were found to increase with increase in the concentration. The present behavior can be attributed due to either decrease in the dielectric constant value or may be due to increase in the width of the electrical double layer of the electrified interface, represents good corrosion inhibitor.



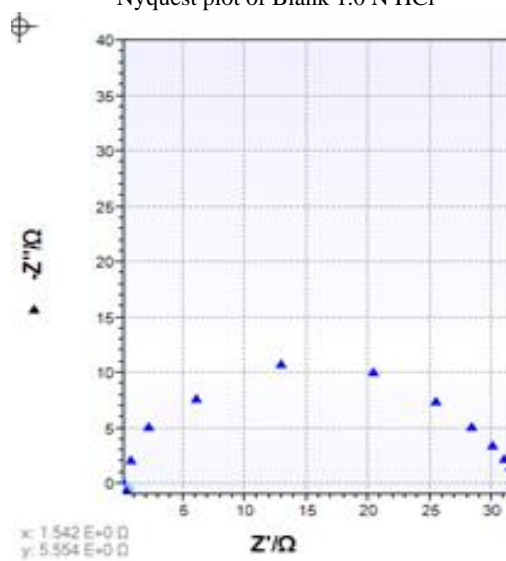
Nyquist plot of Blank 2.0 N HCl



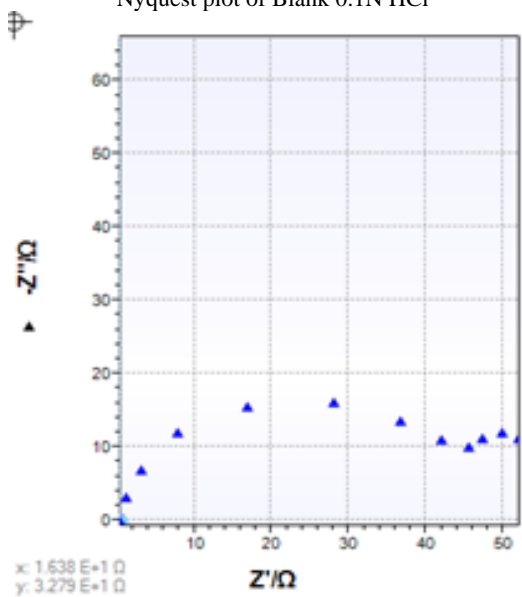
Nyquist plot of Blank 1.0 N HCl



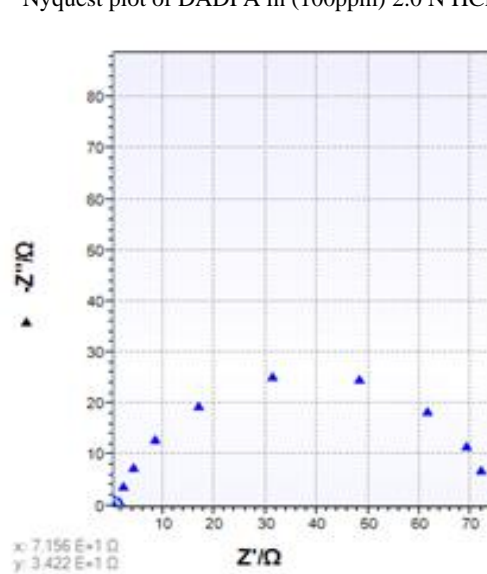
Nyquist plot of Blank 0.1N HCl



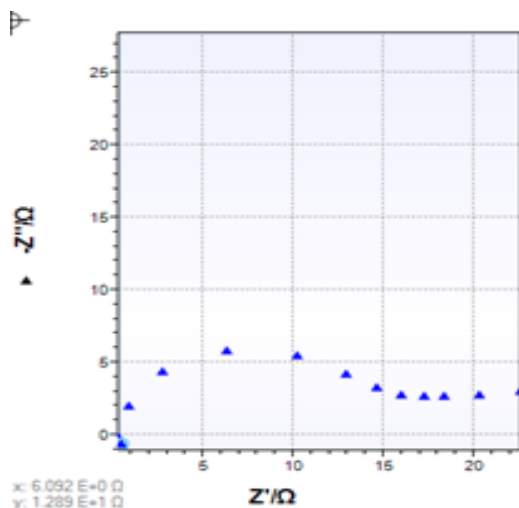
Nyquist plot of DADPA in (100ppm) 2.0 N HCl



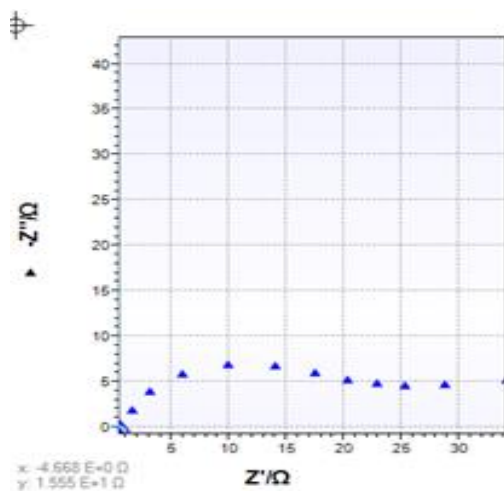
Nyquist plot of DADPA(400ppm) in 2.0 N HCl



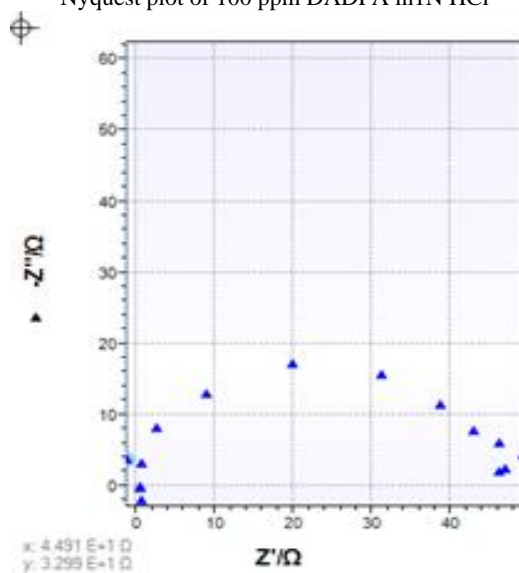
Nyquist plot of DADPA(1000 ppm) in 2.0 N HCl



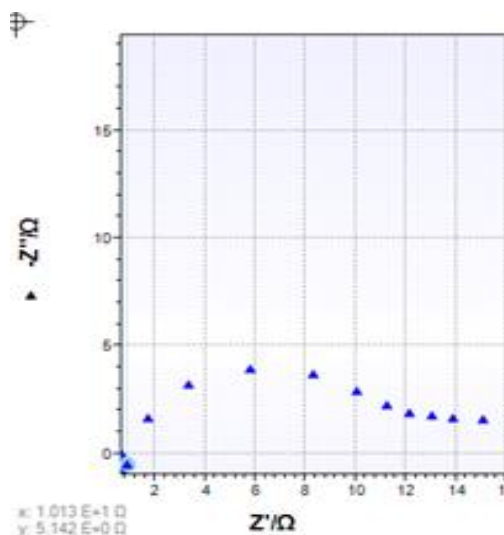
Nyquist plot of 100 ppm DADPA in 1N HCl



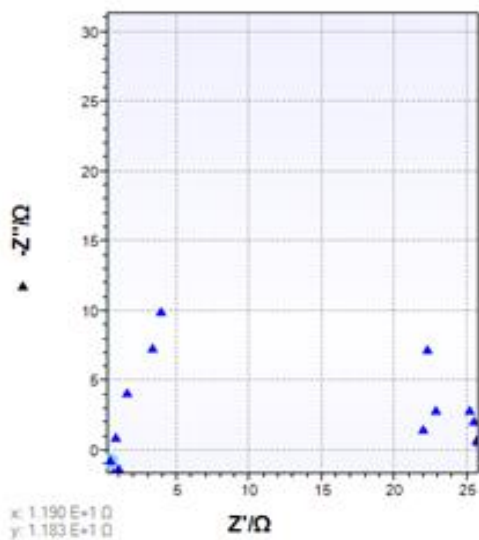
Nyquist plot of 400 ppm DADPA in 1N HCl



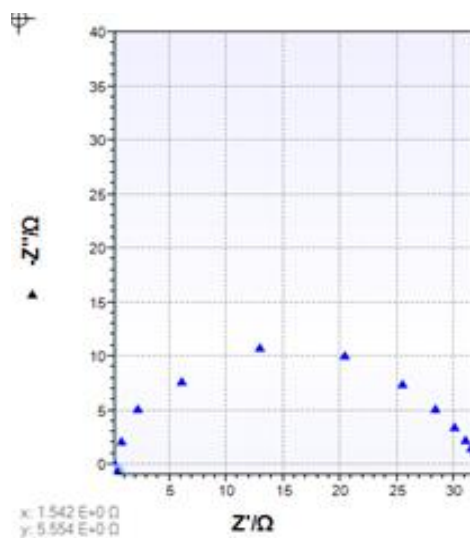
Nyquist plot of DADPA(1000 ppm) in 1N HCl



Nyquist plot of DADPA(100ppm) in 0.1N HCl



Nyquist plot of DADPA(400ppm) in 0.1N HCl



Nyquist plot of DADPA(1000ppm) in 0.1N HCl

Fig 1: Nyquist plots (EIS) of Carbon steel immersed in 2.0, 1.0, 0.1 N HCl in absence and presence of different concentrations of *DADPA* at 298.0 K temperature

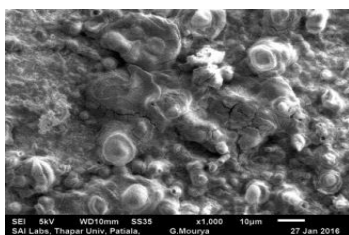
Table 5: Electrochemical impedance parameters for Carbon steel samples in 2.0, 1.0, 0.1 N HCl solution in absence and presence of different concentrations of DADPA at 25.0, 30.0, 35.0 °C temperature

Conc. of inhibitor	Conc. of HCl	Rct at 25°C	% I.E. at 25°C	Rct at 30°C	% I.E. at 30°C	Rct at 35°C	% I.E. at 35°C
Blank	2.0 N	7.8	-	7.2	-	6.9	-
	1.0 N	9.2		8.8		8.2	
	0.1 N	10.5		10.2		9.8	
100	2.0 N	31.90	75.54	20.13	64.23	12.14	43.16
400		52.07	85.02	32.52	81.50	20.13	65.72
1000		74.75	89.56	43.83	85.25	32.78	82.20
100	1.0 N	22.20	58.55	13.03	32.46	10.01	18.08
400		37.51	75.47	29.56	70.23	18.45	55.55
1000		46.32	80.13	36.53	75.91	28.01	70.72
100	0.1 N	16.42	36.05	12.15	16.04	9.65	0
400		25.81	59.31	18.07	43.55	12.20	25.75
1000		31.90	67.08	22.82	55.30	18.78	37.89

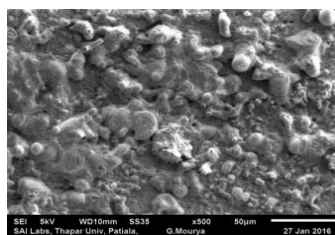
SEM

Surface study of the Carbon steel coupons was studied by scanning electron microscopy (SEM) using scanning electron microscope. This technique provides the evidences in support of the inhibition data obtained by different techniques for different corrosion inhibitor in different environment and for the mechanism of inhibition. In this technique, the coupons, after treating with the weight loss test, were studied at different resolutions on the different spots on the carbon steel

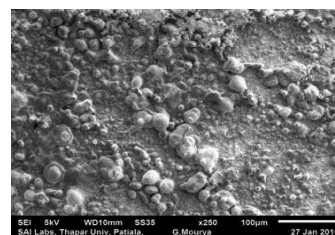
coupons for complete detail about the inhibition mechanism. SEM of the blank Carbon steel coupons were also taken for the comparative study of metal specimens which are shown in Fig 2 SEM of the blank coupons clearly provides the evidence of the more extent of corrosion in corroding medium. Pits and brown rust particles are clearly shown in blank Carbon steel coupons dipped in 2.0 N HCl solution at 1000 and 500 magnification. Roughness of Carbon steel surface becomes lesser with increase in concentration.



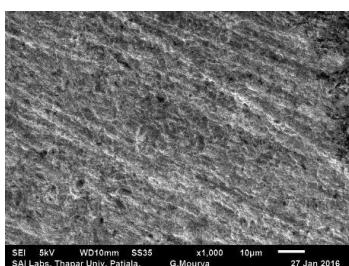
Blank 2.0 N HCl at 1000 magnification



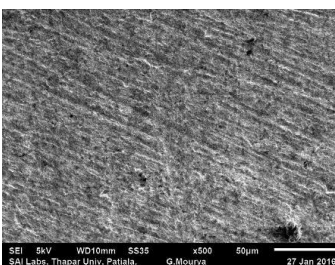
Blank 2 N HCl at 500 magnification



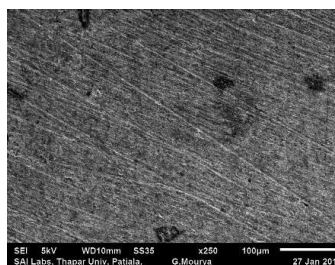
Blank 2 N HCl at 250 magnification



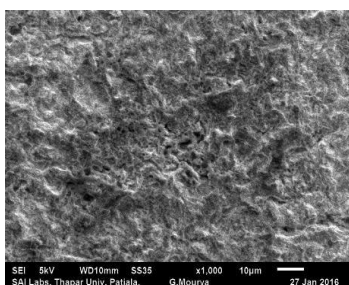
DADPA (1000ppm) at 1000 magnification



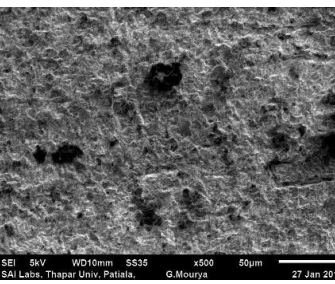
DADPA (1000ppm) at 500 magnification



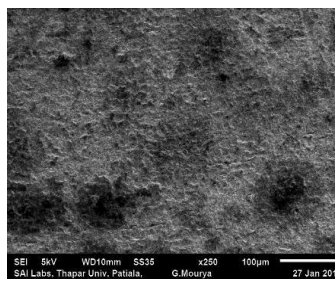
DADPA(1000ppm) at 250 magnification



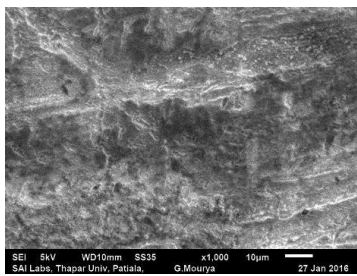
DADPA (400ppm) at 1000 magnification



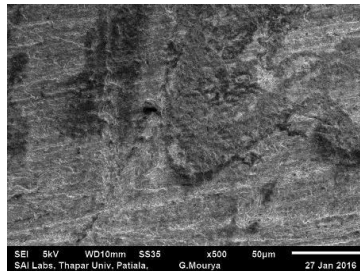
DADPA (400ppm) at 500 magnification



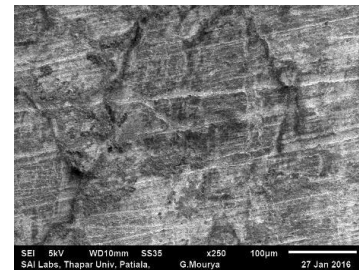
DADPA (400ppm) at 250 magnification



DADPA (100ppm) at 1000 magnification



DADPA (100ppm) at 500 magnification



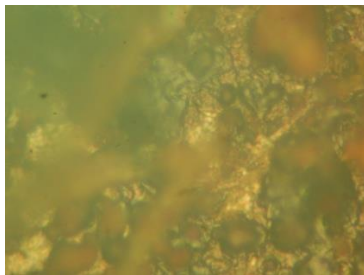
DADPA(100ppm) at 250 magnification

Fig 2: SEM images of Carbon steel samples with and without DADPA at different concentrations.

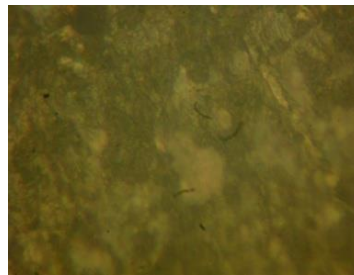
Metallurgical research microscopy technique

This test was carried out in order to know about the nature and extent of corrosion using Trinocular inverted metallurgical research microscope. To explain the corrosion inhibition efficiency of DADPA, micrographs of the corroded coupons treated with DADPA were subjected to porosity study, Coating thickness, length of pores and morphology of surface. By the obtained results of porosity and surface morphology, the information about the size of pores, percentage porosity and area covered by the pores on the surface of sample after the weight loss test was calculated. Percentage porosity (PP) shows the roughness of surface. While maximum perimeter and maximum area covered provide the information about the

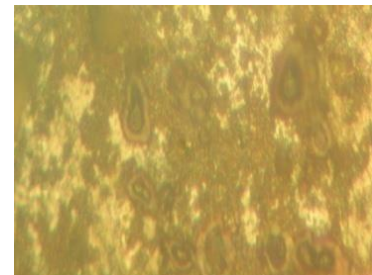
size and depth of the pores on the surface of Carbon steel. Micrographs of blank corroded coupons were taken after exposure of different concentration of HCl for 2 hours are shown in figure 3 and data obtained from metallurgical research microscopy of blank Carbon steel sample after weight loss experiments are reported in table 6 from which it is clear that after weight loss test in different conc. of acidic medium due to uniform corrosion in humid environment surface become porous after exposing specimen in corroding medium.. As the conc. of DADPA increases, porosity of surface decreases. Coating thickness also measured which increases with increase in conc. of DADPA.



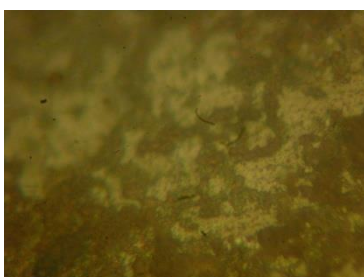
Blank in 2.0 N HCl



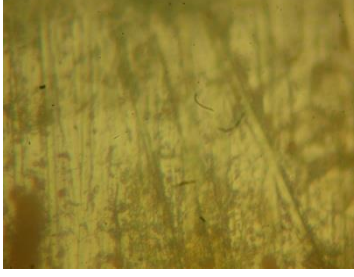
Blank in 1.0 N HCl



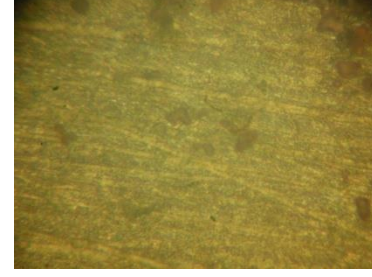
Blank in 0.1 N HCl



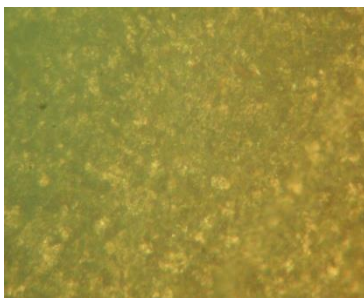
100 PPM DADA in 2.0 N HCl



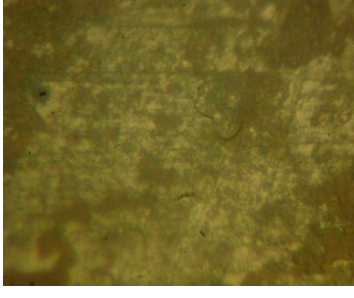
400 PPM DADA in 2.0 N HCl



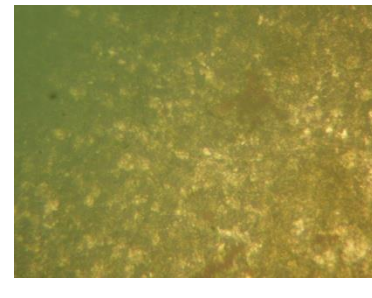
1000 PPM DADA in 2.0 N HCl



100 PPM DADA in 1.0 N HCl



400 PPM DADA in 1.0 N HCl



1000 PPM DADA in 1.0 N HCl

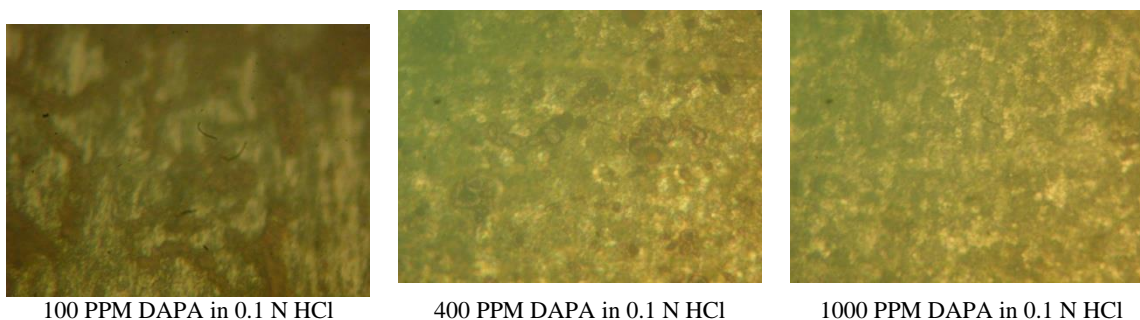


Fig 3: Trinocular Inverted Metallurgical Research Micrographs of different Carbon steel samples with and without DADPA at different concentration.

Table 6: Coating thickness, percentage porosity and pore length of Carbon steel coupons with and without corrosion inhibitor

Conc. of inhibitor (ppm)	Conc. Of HCl	Max. perimeter (Micron)	Max. Area covered	%age porosity	Coating thickness (micron)	Length of pore (micron)
Blank	2.0 N	6543.67	26785.64	89.67	32.56	590.45
	1.0 N	5887.64	24567.98	84.45	28.45	394.67
	0.1 N	4321.91	23145.89	72.23	24.67	298.56
100	2.0 N	2105.6426	17512.7878	14.32	143.78	291.72
400		3219.7847	15516.6775	11.54	134.65	845.82
1000		4428.7642	12506.4532	8.76	103.53	1768.53
100	1.0 N	1951.7505	19528.906	16.90	153.31	135.75
400		9815.8979	15526.546	13.78	142.67	514.34
1000		2477.6537	12777.893	10.23	109.54	1548.34
100	0.1 N	1578.6595	21789.879	20.21	162.45	89.24
400		2105.7626	18527.656	17.45	150.78	316.45
1000		2105.8926	16590.345	12.23	123.54	1305.23

Mechanism of Inhibition

Analysis of the results reveals that proposed mechanism of inhibiting action of investigated corrosion inhibitor contains following features: 1. Due to presence of lone pair on donar N atom and specific active functional groups by which it can be easily adhere on the surface of Carbon steel due to acid base nature of steel and corrosion inhibitor respectively. 2. Presence of Diamino and Dipropyl group attached with the lone pair donar atoms increase the basic strength of DADPA molecule which it can be neutralized the acidic environment around the Carbon Steel.

Conclusion

DADPA acts as very good inhibitor for the corrosion of C-steel in 2.0 N, 1.0 N and 0.1 N HCl solutions, and the maximum corrosion inhibition efficiency is about 86% in 2.0 N HCl solution. The inhibition efficiency values increase with the increase in inhibitor conc., but decrease with the increase in temperature. The corrosion rate of C-steel in the presence and absence of DADPA acts as a function of inhibitor conc. Increase in the conc. resulted in increasing the inhibition efficiency. The weight loss and the electrochemical polarization studies are in good agreement. DADPA acts as a mixed-type inhibitor in 2.0, 1.0 and 0.1 N HCl. The inhibitive mechanism was proposed. When DADPA introduced into 2.0, 1.0 and 0.1 N HCl solutions a film formed on the C-steel surface, causes the decrease of the C-steel roughness and effectively protect the C-steel from corrosion. Results obtained from SEM & metallurgical research microscopy techniques further supports the weight loss and

electrochemical experiments.

References

1. Fouda AS, Shalabi K, Ezzat R. Evaluation of some thiazazole derivatives as acid corrosion inhibitors for carbon steel in aqueous solutions, *J. Mater. Environ. Sci.* 2015; 6(4):1022-1039.
2. Fouda AS, Abdallah YM, Nabill D. Dimethyl Pyrimidine Derivatives as Corrosion Inhibitors for Carbon Steel in Hydrochloric Acid Solutions, *International Journal of Innovative Research in Science, Engineering and Technology*, 2014; 3(5).
3. Anejjar R, Salghi A, Zarrouk O, Benali H, Zarrok B, Hammouti *et al.* Inhibition of carbon steel corrosion in 1 M HCl medium by potassium thiocyanate, *J. Ass. Arab Uni. Basic & Appl. Sci.*, 2005; 10:446-456.
4. Abd SA, El-Maksoud, Fouda AS. pyridine derivatives as corrosion inhibitors for carbon steel in acidic medium, *Mat. Chem. & Phys.*, 2005; 93:84-90.
5. Bentiss FM, Traisnel L, Gengembre, Lagrenée M. A new triazole derivative as inhibitor of the acid corrosion of mild steel: electrochemical studies, weight loss determination, SEM and XPS. *Appl. surf. sci.*, 1999; 152(3):237-249.
6. Li L, Gao J, Wang Y. Evaluation of cyto-toxicity and corrosion behavior of alkali-heat-treated magnesium in simulated body fluid, *Surf. & Coat. Tech.* 2004; 185(1):92-98.
7. Mansfeld F, Kendig MW, Tsai S. Recording and analysis of AC impedance data for corrosion studies, *Corr.* 1982;

- 38(11):570-580.
8. Amin MA, SSA El-Rehim, EEF El-Sherbini, Bayoumi RS. The inhibition of low carbon steel corrosion in hydrochloric acid solutions by succinic acid: Part I. Weight loss, polarization, EIS, PZC, EDX and SEM studies, *Electrochim. Acta.* 2007; 52(11):3588-3600.
 9. Song G, Atrens A, Dargusch M. Influence of microstructure on the corrosion of diecast AZ91D *Corr. Sci.* 1998; 41(2):249-273.
 10. Kumar H, Saini V, Yadav V. Study of Vapour Phase Corrosion inhibitors for Mild Steel under different Atmospheric Conditions, *Int. J. Engg. & Innovative Tech.* 2013; 3(3):206-211.
 11. Kumar H, Yadav V. Corrosion Characteristics of Mild Steel under different Atmospheric Conditions by Vapour Phase Corrosion Inhibitors, *Am. J. of Materials Sci. & Engg.* 2013; 1(3):34-39.
 12. Kumar H, Yadav S, Chaudhary RS, Kumar D. Synergistic effect of some antiscalants as Corrosion inhibitor for Industrial Cooling Water System, *J. of Applied Electrochem.* 2009; 39(3):313-465.
 13. Harish Kumar, Vikas Yadav. Citrus sinensis peels as a Green Corrosion Inhibitor for Mild Steel in 5.0 MHydrochloric Acid Solution, *Research Journal of Chemical Sciences.* 2016; 6(1):53-60.
 14. Saini v, kumar H, NNNN-Tetramethylethylenediamine and 1,3-Diaminopropane as vapour phase corrosion inhibitor for mild steel under atmospheric conditions, *Research journal of chemical sciences.* 2014; 4(6):45-53.
 15. Saini V, Kumar H, DAA 1-BIZ, 5-ATZ as Vapour Phase Corrosion Inhibitors for Mild Steel under Different Aggressive Atmospheric Conditions at High Temperature, *Int. Letters of Chem., Phys. & Astronomy.* 2014; 17(2):174-192.
 16. Saini V, Kumar H. Synergistic Effect of CTAB as VPCI for Mild Steel, *Intern. J. of Chemical & Physical Sci.* 2014; 3(5):52-69.