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Use of hexamine as corrosion inhibitor for carbon steel in hydrochloric acid

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Abstract
Hexamine is used as corrosion inhibitor for Carbon steel in different concentrations of Hydrochloric Acid medium at three different temperatures 25, 30, 35^{0}C. Corrosion rate and Percentage Corrosion Inhibition Efficiency (PCIE) in presence and absence of inhibitor 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) 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. Hexamine acts as a very good inhibitor for Carbon Steel in different hydrochloric acid medium.

Keywords: carbon steel, weight loss, polarization, impedance, hexamine, 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 (CO_2), hydrogen sulfide (H_2S) and acids like acetic acid (CH_3COOH). 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. 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. Hexamine 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 Hexamine 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^{0}C with the help of formula (1) & (2).

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

Where, W = weight loss (in mg), D = density of carbon steel (in g/cm^3), A = area of sample (in sq. inch), T = exposure time (in hour).

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

Where, CRo = 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 empry 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 cm^2 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:

$$\text{Corrosion rate (C.R.) (mpy)} = \frac{0.1288*Icorr*Eq.wt.}{D} \qquad (3)$$

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

$$\text{PCIE} = \frac{(CRo-CR)100}{CRo} \qquad (4)$$

Electrochemical impedance spectroscopy

The electrochemical impedance spectroscopy measurements were carried out using class one handhold 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 (Eocp). After measuring the Eocp, the electrochemical measurements were performed. Nyquist plots were plotted with the help of which Rct (charge transfer resistance) calculated. Percentage inhibition was calculated efficiency by the use of charge transfer resistance using this formula

$$I.E.\% = \frac{(Rct - Rct^*)}{Rct} X\ 100$$

Where Rct and Rct* 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 HEXAMINE 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 for Carbon steel samples in 2.0 N HCl solution in absence and presence of different concentrations of HA at 25.0, 30.0 and 35.0^{0}C for two hours

Conc. of corrosion inhibitors (ppm)	C R at 25.0 ^{0}C (mpy)	PCIE at 25.0 ^{0}C	CR at 30.0 ^{0}C (mpy)	PCIE at 30.0 ^{0}C	CR at 35.0 ^{0}C (mpy)	PCIE at 35.0 ^{0}C
Blank	1065.96	--	1147.45	--	1269.01	--
100	315.17	70.13	390.97	65.07	659.88	48.13
200	282.09	73.31	380.45	66.13	634.50	50.01
400	245.06	77.23	335.09	70.14	635.50	50.23
600	218.66	79.09	300.22	73.07	583.74	54.03
800	175.08	83.31	282.34	75.02	527.60	58.05
1000	158.90	85.13	236.46	79.00	482.22	62.11

Table 2: Corrosion rate and Percentage corrosion inhibition efficiency for Carbon steel samples in 1.0 N HCl solution in absence and presence of different concentrations of HA at 25.0, 30.0 and 35.0^{0}C for two hours.

Conc. of corrosion inhibitors (ppm)	C R at 25.0^{0}C (mpy)	PCIE at 25.0 ^{0}C	CR at 30.0^{0}C (mpy)	PCIE at 30.0^{0}C	CR at 35.0^{0}C (mpy)	PCIE at 35.0^{0}C
Blank	837.54	--	897.54	--	964.64	--
100	328.16	60.12	459.30	48.65	558.365	42.09
200	295.08	64.09	423.45	52.05	532.98	44.43
400	264.80	68.01	386.04	56.34	512.98	46.06
600	254.46	69.00	350.16	60.78	507.60	47.14
800	239.42	71.02	316.01	64.65	470.30	50.00
1000	213.84	74.21	278.19	69.08	380.70	60.34

Table 3: Corrosion rate and Percentage corrosion inhibition efficiency for Carbon steel samples in 0.1 N HCl solution in absence and presence of different concentrations of HA at 25.0, 30.0 and 35.0^{0}C for two hours

Conc. of corrosion inhibitors (ppm)	C R at 25.0^{0}C (mpy)	PCIE at 25.0 ^{0}C	CR at 30.0^{0}C (mpy)	PCIE at 30.0^{0}C	CR at 35.0^{0}C (mpy)	PCIE at 35.0^{0}C
Blank	456.84	--	502.40	--	558.36	--
100	292.10	36.06	445.80	11.20	532.98	04.98
200	272.80	40.28	407.34	18.92	482.22	13.23
400	248.92	45.51	371.60	26.03	456.84	18.56
600	213.04	53.36	356.13	29.11	380.70	31.32
800	169.59	62.87	325.04	35.30	355.32	36.21
1000	137.81	69.83	204.08	59.37	329.94	40.45

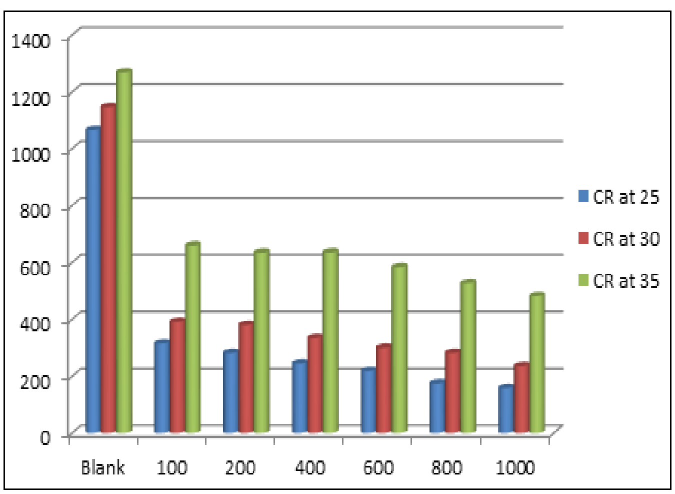


Fig 1: Corrosion rate at different concentrations of HA at three different temperatures

Analysis of weight loss results of HA for Carbon steel

Inhibition efficiency increases with increase in concentration of corrosion inhibitor. This occurs due to more adsorption of corrosion inhibitor on the interface if metal and HA. A thin film was observed on the surface of the metal in the SEM images. Weight loss was seen very less in the presence of inhibitor which indicates that no rust or scale could be seen on the surface of the specimen. As the temperature increases then desorption or removal of inhibitor takes place due to which inhibition efficiency decreases. In 2.0 N HCl maximum inhibition efficiency observed as compared to 1.0N, 0.1 N HCl which shows that the inhibitor acts as a rust preventing corrosion inhibitor.

From above the three Tables 1,2,3, it is clear that Percentage corrosion inhibition efficiency decreases with the dilution of medium. i.e. from 2.0 N HCl to 0.1 N HCl.

Results of potentiodynamic polarization technique

Table 4: OCP, Corrosion Current Density (Icorr), anodic Tafel slope (β_a), cathodic Tafel slope (β_c), resistance polarization (Rp),corrosion rate and PCIE of HA at different concentrations by electrochemical polarization method at 25.0^{0}C temperatures in 2.0, 1.0 and 0.1 N HCl solution

Conc. of HCl	Conc. of inhibitor (ppm)	OCP	Icorr (µA/cm2)	(β_a), (V/dec)	(β_c) (V/dec)	Rp	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	-0.556	1.54	1.150	1.255	7.41×10^4	0.68	70.56
	400	-0.579	1.45	1.104	1.336	8.59×10^4	0.64	72.29
	1000	-0.582	1.31	1.231	1.214	1.25×10^5	0.57	75.32
1.0N	100	-0.577	1.62	1.631	1.605	1.30×10^5	0.71	60.11
	400	-0.626	1.54	0.517	1.807	4.03×10^4	0.68	61.43
	1000	-0.587	1.48	0.356	1.343	5.02×10^4	0.65	63.48
0.1 N	100	-0.773	1.73	0.350	1.231	3.37×10^4	0.75	52.53
	400	-0.646	1.51	0.427	1.842	4.13×10^4	0.66	58.22
	1000	-0.523	1.34	1.302	1.038	1.05×10^5	0.59	62.65

Table 5: OCP, Corrosion Current Density (Icorr), anodic Tafel slope (β_a), cathodic Tafel slope (β_c), resistance polarization (Rp),corrosion rate and PCIE of HA at different concentrations by electrochemical polarization method at 30.0^{0}C temperature in 2.0, 1.0 and 0.1 N HCl solution

Conc. of HCl	Conc. of inhibitor (ppm)	OCP	Icorr (µA/cm2)	ba (V/dec)	bc (V/dec)	Rp	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	0.575	2.56	1.424	2.036	3.17×10^4	1.13	58.14
	400	0.587	2.38	1.877	1.877	5.13×10^5	1.05	61.11
	1000	0.574	1.94	1.214	1.634	4.05×10^4	0.85	68.51
1.0 N	100	0.572	2.31	1.251	0.443	3.07×10^5	1.02	53.63
	400	0.577	2.06	0.847	2.677	5.15×10^4	0.91	58.63
	1000	0.569	1.93	1.324	2.024	3.05×10^5	0.85	61.36
0.1 N	100	0.570	2.01	1.306	0.406	2.27×10^5	0.88	46.98
	400	0.567	1.84	1.947	1.057	4.15×10^4	0.81	51.22
	1000	0.554	1.68	1.014	1.114	2.05×10^5	0.74	55.42

Table 6: OCP, Corrosion Current Density (Icorr), anodic Tafel slope (β_a), cathodic Tafel slope (β_c), resistance polarization (Rp), corrosion rate and PCIE of HA at different concentrations by electrochemical polarization method at 35.0^{0}C temperatures in 2.0, 1.0 and 0.1 N HCl solution

Conc. of HCl	Conc. of inhibitor (ppm)	OCP	Icorr (µA/cm2)	ba (V/dec)	bc (V/dec)	Rp	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	
2.0 N	100	0.566	2.93	1.360	1.355	9.01×10^5	1.29	57.42
	400	0.579	2.78	1.144	1.306	7.49×10^4	1.22	58.34
	1000	0.602	2.31	1.231	1.431	1.02×10^5	1.02	66.33
1.0 N	100	0.549	2.64	1.851	1.705	2.20×10^5	1.16	49.78
	400	0.666	2.50	0.427	1.707	5.03×10^4	1.10	52.38
	1000	0.657	2.31	0.476	1.343	4.02×10^4	1.02	55.84
0.1 N	100	0.756	2.56	0.350	1.521	3.17×10^4	1.13	46.19
	400	0.686	2.22	0.557	1.532	5.03×10^4	0.98	53.33
	1000	0.575	2.15	1.622	2.122	2.25×10^5	0.95	54.76

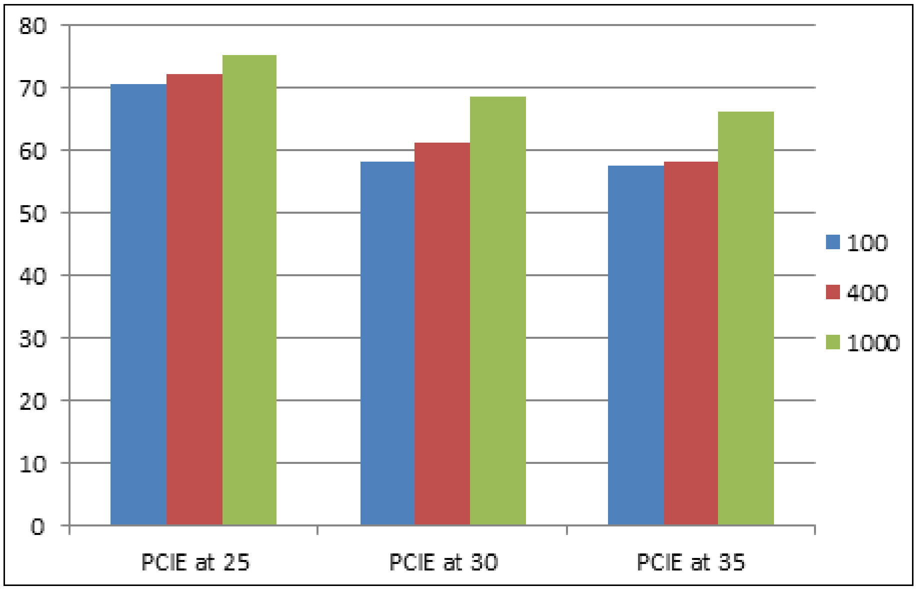


Fig 2: PCIE at different temperature i.e.25 to 35.0^{0}C using different concentrations of HA

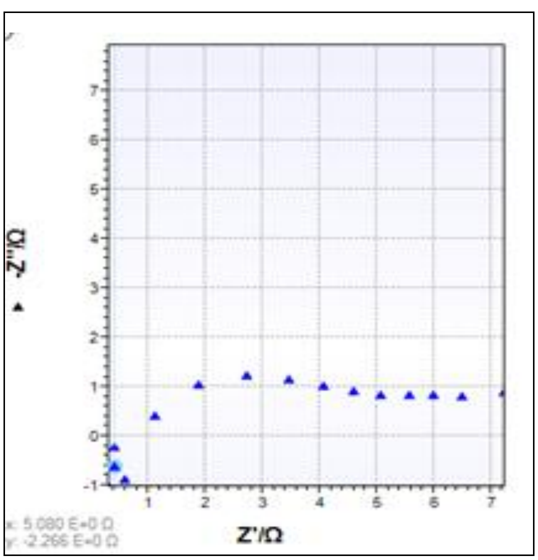
Analysis of the results of potentiodynamic polarization study for HA

The corrosion parameters of carbon steel immersed in HA solutions obtained by polarization study are given in Tables 4,5,6 of temperature 25, 30, 35.0^{0}C. When carbon steel is immersed in different concentrations of HA the value of OCP changes. The shift is very small at each conc.. Hence it behaves as a mixed type inhibitor. Shifting of OCP towards less negative side indicates anodic control in the presence of inhibitor which indicates that this inhibitor is acting on anodic sites. The decrease in corrosion current density indicates that the rate of anodic reaction decreases i.e. rate of corrosion reaction at anode is reduced which results into the increased corrosion inhibition efficiency of the inhibitor. Hence the metal surface was protected by the formation of protective inhibitor layer cover the surface of Carbon steel.

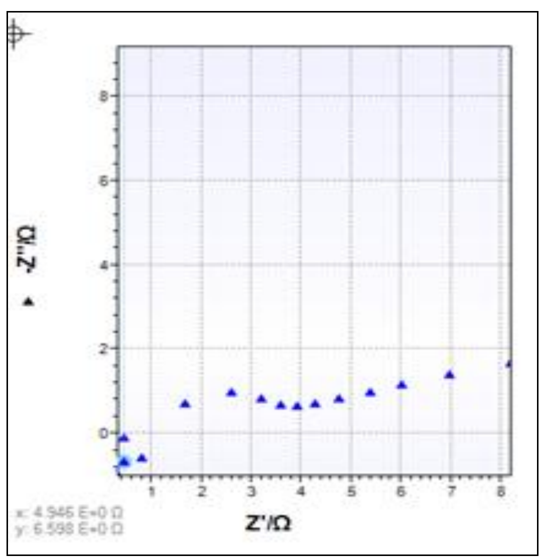
The major decrease in the value of corrosion current for high conc. inhibitor observed which indicates that more adsorption of the inhibitors and high inhibition efficiency. The shift in the value of both the β_c and β_a value indicate a mixed type of corrosion inhibitor. This result suggests that a protective film is formed on the surface of metal. This layer or film protects the metal from corrosion.

Results of electrochemical impedance spectroscopic technique

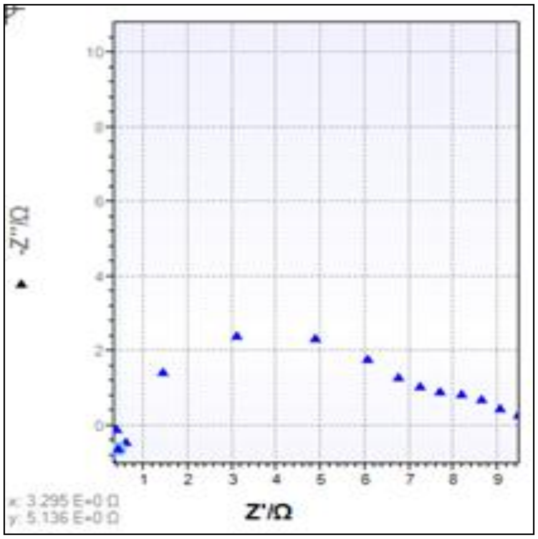
Figure 3 shows Nyquist plots of Carbon steel in different concentrations of HCl with and without the presence of HA. From the Figure It is clear that Charge transfer resistance increases with the use of inhibitor. In absence of inhibitor charge transfer value is less i.e 2.0N, 1.0 N,0.1 N HCl.it is observed that from Figure 4.45 that film resistance i.e. impedance increase in concentration of HA i.e. from 100 to 1000 ppm.



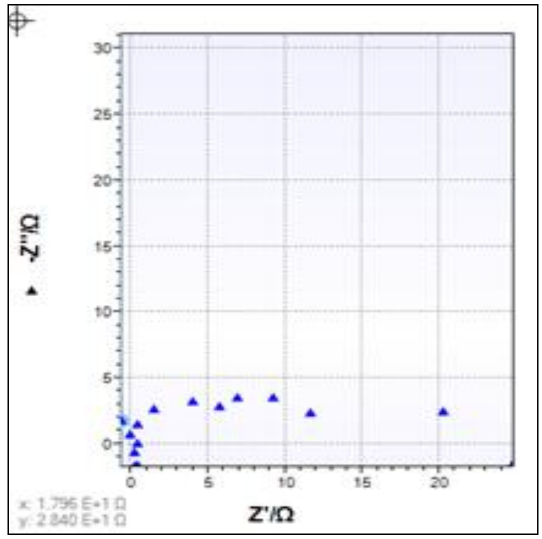
Nyquest plot of Blank 2.0 N HCl



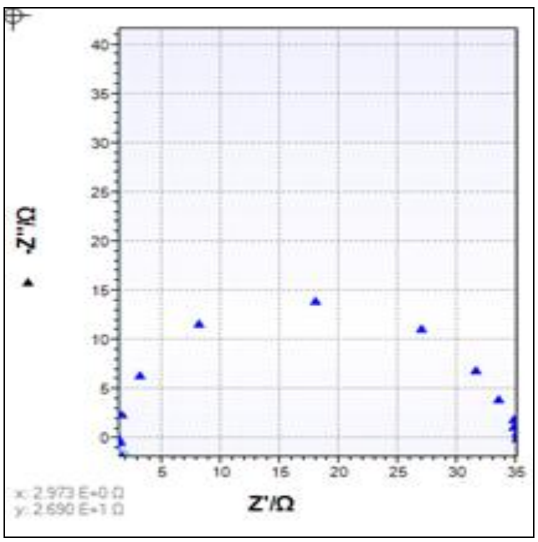
Nyquest plot of Blank 1.0 N HCl



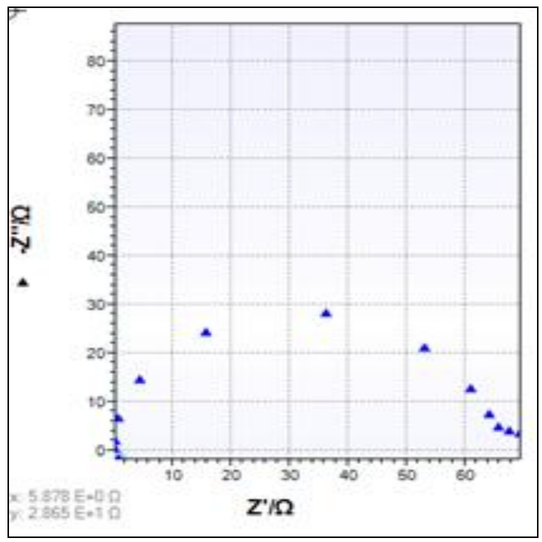
Nyquest plot of Blank 0.1 N HCl



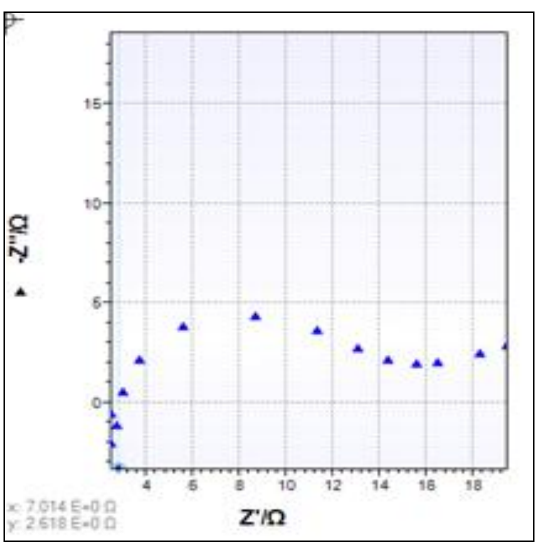
Nyquest plot of 1000 ppm HA in 2.0 N HCl



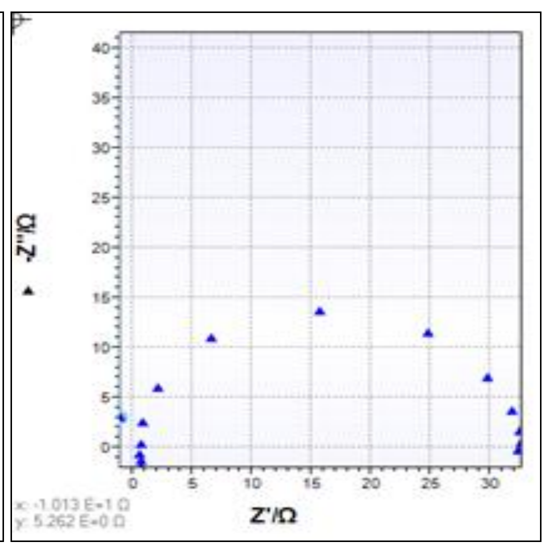
Nyquest plot of HA(400 ppm) in 2.0 N HCl



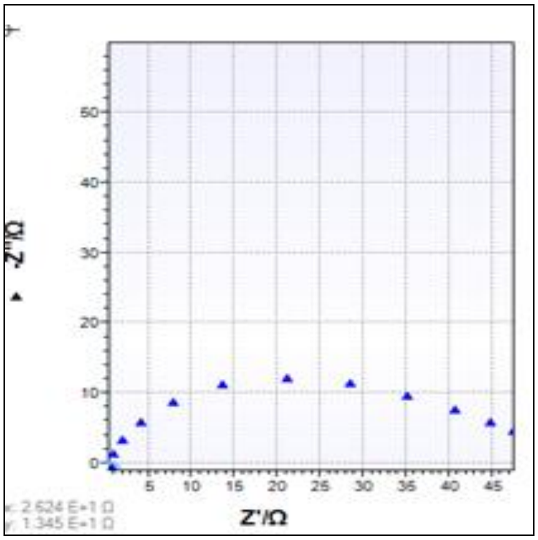
Nyquest plot of HA(1000 ppm)in 2.0 N HCl



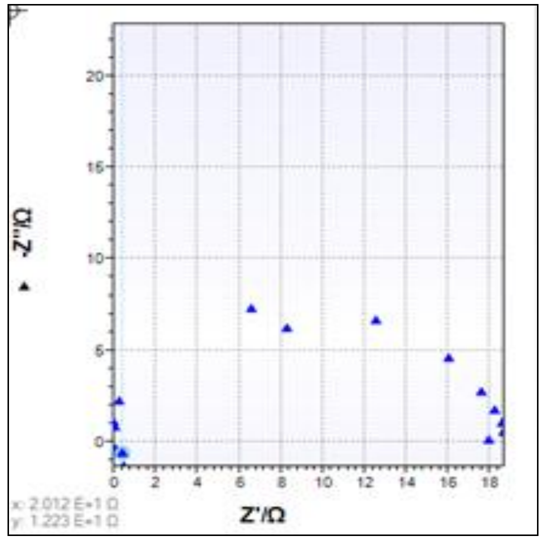
Nyquest plot of 100 ppm HA in1.0 N HC



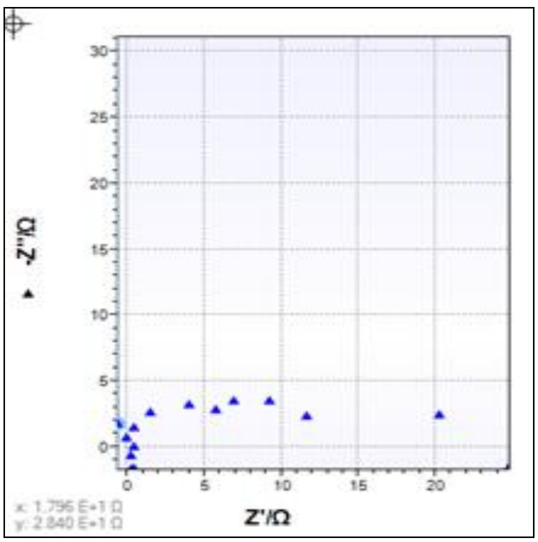
Nyquest plot of 400 ppm HA in1.0 N HCl



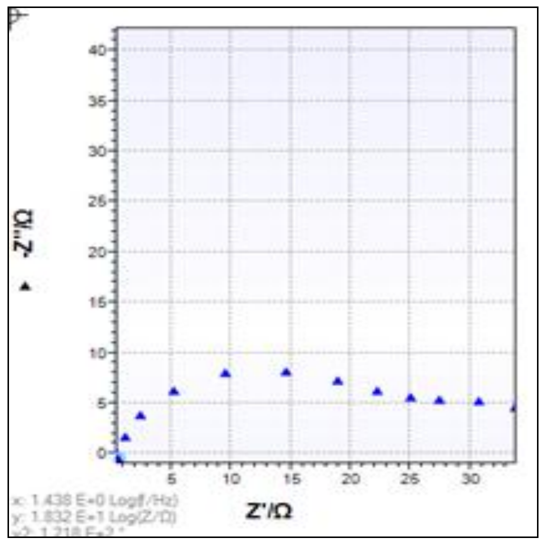
Nyquest plot of 1000 ppm HA in 1.0 N HCl



Nyquest plot of 100 ppm HA in 0.1 N HCl



Nyquest plot of 400 ppm HA in 0.1 N HCl



Nyquest plot of1000 ppm HA in 0.1 N HCl

Fig 3: Nyquist plots (EIS) of Carbon steel immersed in 2.0, 1.0 and 0.1 N HCl in absence and presence of different concentrations of HA at 298.0 K temperature

Table 7: Electrochemical impedance parameters for Carbon steel samples in 2.0, 1.0 and 0.1 N HCl solution in absence and presence of different concentrations of HA at 25.0^{0}C temperature

Conc. of inhibitor	Conc. of HCl	C_{dl} (F cm^2)	Rct(Ω cm^2) at 25.0^{0}C	% I.E. at 25.0^{0}C
Blank	2.0 N	1.7×10^{-2}	7.8	-
	1.0 N	9.6×10^{-3}	9.2	
	0.1 N	6.8×10^{-3}	10.5	
100	2.0 N	1.4×10^{-3}	24.51	68.17
400		3.0×10^{-4}	35.06	77.75
1000		7.6×10^{-5}	69.60	88.79
100	1.0 N	1.3×10^{-3}	19.46	52.72
400		3.2×10^{-4}	32.41	71.61
1000		2.7×10^{4}	47.67	80.83
100	0.1 N	1.2×10^{-3}	17.83	41.11
400		1.1×10^{-3}	24.45	57.05
1000		5.2×10^{-4}	33.84	68.97

Table 8: Electrochemical impedance parameters for Carbon steel samples in 2.0, 1.0 and 0.1 N HCl solution in absence and presence of different concentrations of HA at 30.0^0C temperature

Conc. of inhibitor	Conc. of HCl	C_{dl} (F cm^2)	Rct(Ω cm^2) at 30.0^0C	% I.E. at 30.0^0C
Blank	2.0 N	2.0×10^{-2}	7.2	-
	1.0 N	9.9×10^{-3}	8.8	
	0.1 N	6.9×10^{-3}	10.2	
100	2.0 N	1.9×10^{-3}	18.03	60.06
400		3.4×10^{-4}	22.52	68.02
1000		7.9×10^{-5}	43.83	85.25
100	1.0 N	1.6×10^{-3}	12.32	28.57
400		3.6×10^{-4}	23.03	61.80
1000		3.1×10^{-4}	40.56	77.17
100	0.1 N	1.5×10^{-3}	10.15	0
400		1.3×10^{-3}	18.56	45.04
1000		5.5×10^{-4}	28.67	64.42

Table 9: Electrochemical impedance parameters for Carbon steel samples in 2.0, 1.0 and 0.1 N HCl solution in absence and presence of different concentrations of HA at 35.0^0C temperature

Conc. of inhibitor	Conc. of HCl	C_{dl} (F cm^2)	Rct(Ω cm^2) at 35.0^0C	% I.E. at 35.0^0C
Blank	2.0 N	2.4×10^{-2}	6.9	-
	1.0 N	10.4×10^{-3}	8.2	
	0.1 N	7.3×10^{-3}	9.8	
100	2.0 N	2.3×10^{-3}	10.04	31.27
400		3.9×10^{-4}	14.13	51.16
1000		8.2×10^{-5}	32.78	82.20
100	1.0 N	1.9×10^{-3}	8.01	0
400		3.9×10^{-4}	15.67	47.67
1000		3.5×10^{-4}	23.45	65.03
100	0.1 N	1.9×10^{-3}	6.20	0
400		1.6×10^{-3}	10.54	7.02
1000		5.9×10^{-4}	18.78	37.89

Analysis of the results of Electrochemical impedance spectra of HA

Adsorption of a protective inhibitor HA on the carbon steel surface leads to increase in the impedance of the corrosion system, thereby increasing in the resistance to charge transfer process. Therefore the corrosion inhibition efficiency of an inhibitor can be determined by the measuring impedance of the corrosion system. The extent of the corrosion inhibition can be measured by comparing the impedance spectra obtained with the presence and absence of the inhibitor. The Electrochemical impedance method is used to determine the charge-transfer resistance by measurement of the electrical components in Nyquist plot. In the same way to the effect seen on the corrosion potential, the impedance of the steel corrosion system was changed by the presence of inhibitors. The Nyquist plots for the corrosion behaviour of carbon steel in the absence and presence of HA are shown in Figure the impedance parameters, the charge transfer resistance ($_{Rct}$) and the double layer capacitance (C_{dl}) are given in Tables at different temperatures and different concentrations of inhibitor in different HCl medium. When carbon steel is immersed in different HCl solution in absence of inhibitor the Rct value was less as compared to solution in which inhibitor is used and the C_{dl} value decreases in presence of inhibitor.

The increased Rct value and decreased double layer capacitance value obtained from impedance spectra explain the good performance of HA. This results shows that the film formed acts as a barrier to the corrosion reaction.

Results of metallurgical research microscopy technique

Surface morphology of corroded and uncorroded Carbon steel samples is studied with the help of trinocular inverted microscope. Coating thickness, Length of pores, percentage porosity, Maximum perimeter of pores, and Maximum area covered are studied in this technique. Carbon steel Samples used in weight loss test are used for this study. The data obtained from surface study shown in Table which are shown below. Micrographs obtained from surface study are shown in Figure.

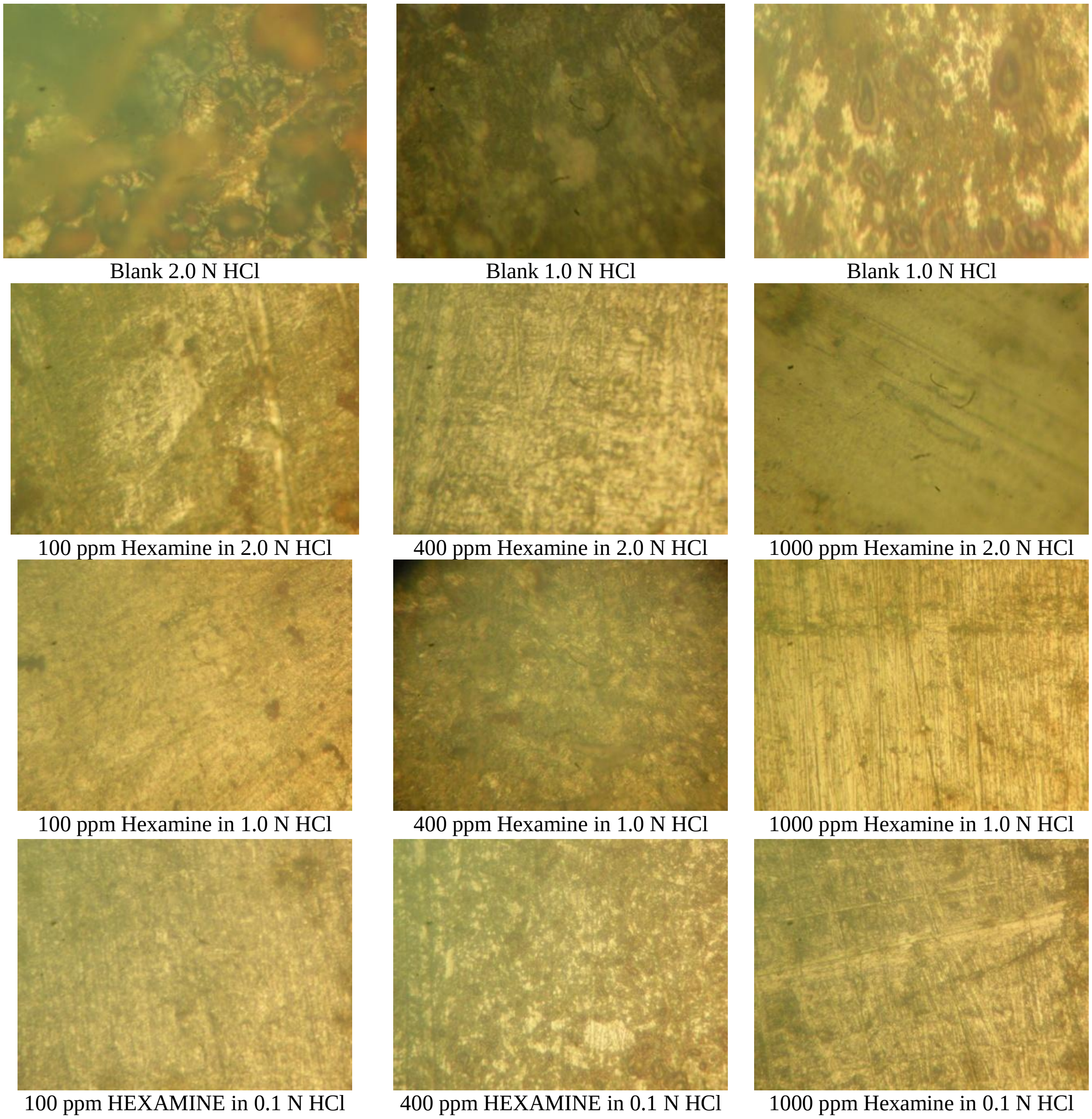


Fig 4: Trinocular inverted metallurgical research micrographs of different carbon steel samples with and without use of HA at different temperatures

Table 10: Maximum perimeter, maximum area covered and percentage porosity of carbon steel coupons with and without use of HA

Conc. of inhibitor (ppm)	Conc. of HCl	Max. perimeter (Micron)	Max. Area covered	% porosity
Blank	2.0 N	6543.67	26785.64	89.67
	1.0 N	5887.64	24567.98	84.45
	0.1 N	4321.91	23145.89	72.23
100	2.0 N	2477.3709	16569.087	20.03
400		2477.3765	19567.098	15.56
1000		2693.5416	20526.564	13.67
100	1.0 N	5543.6809	18526.4532	24.90
400		2477.9037	20526.7896	20.56
1000		21052.5436	22526.8907	15.78
100	0.1 N	8529.5950	10506.8976	26.02
400		1881.2780	10516.7654	22.09
1000		2477.7837	10526.3214	18.01

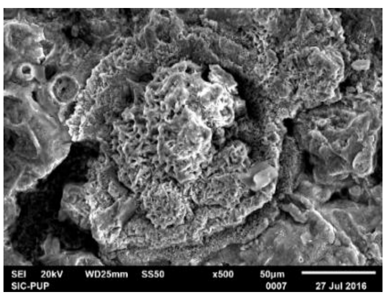
Table 11: Coating thickness and pore length of carbon steel coupons with and without use of HA

Conc. of HCl	Conc. of Corrosion inhibitor	Coating Thickness	Length of Pores
2.0 N	Blank	90.45	342.56
1.0 N		94.67	298.45
0.1 N		98.56	254.67
2.0 N	100	156.67	223.45
	400	143.34	1050.67
	1000	102.34	2363.89
1.0 N	100	167.56	123.56
	400	153.24	409.34
	1000	115.67	1768.23
0.1 N	100	175.34	87.34
	400	160.32	356.47
	1000	121.68	1540.45

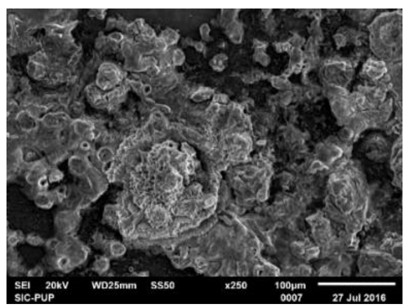
SEM Analysis for HA inhibitor

SEM images of Carbon Steel coupons in presence and absence of HA are shown in Figure which clearly indicates that HA is a good corrosion inhibitor. To understand the nature of the surface film in the absence and presence of inhibitor and the extent of corrosion of carbon steel, the SEM micrographs are very useful. For surface study of carbon steel specimens which are immersed in different corroding media the absence and presence of inhibitor, SEM images are taken at different magnification power and shown in Figure.

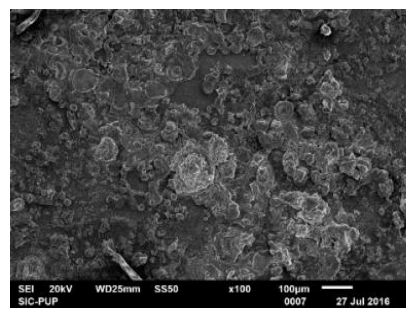
Figure shows that roughness of Carbon steel surface decreases with the use of inhibitor which shows the absence of any corrosion products formed on the metal surface. In presence of inhibitor no pit and corrosion products are shown however at very high resolution some roughness is observed.



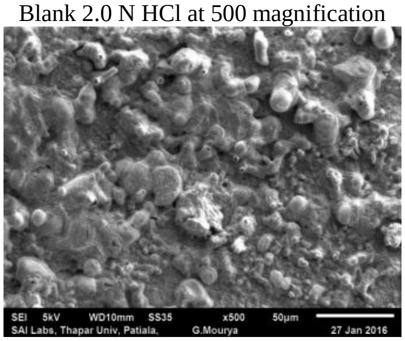
Blank 2.0 N HCl at 500 magnification



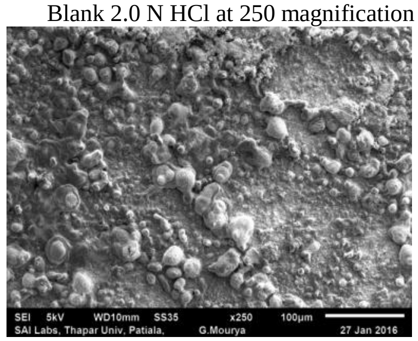
Blank 2.0 N HCl at 250 magnification



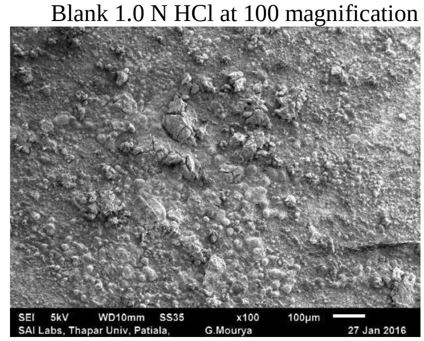
Blank 1.0 N HCl at 100 magnification



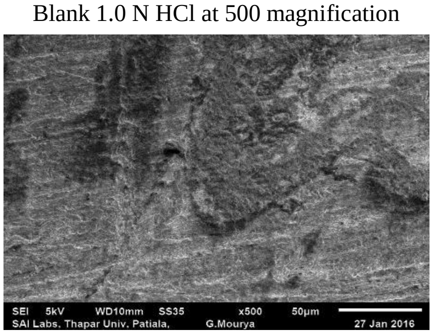
Blank 1.0 N HCl at 500 magnification



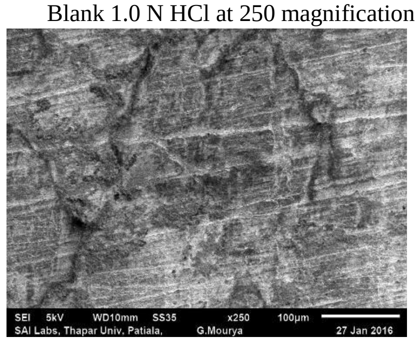
Blank 1.0 N HCl at 250 magnification



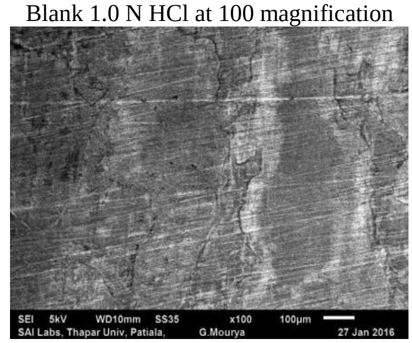
Blank 1.0 N HCl at 100 magnification



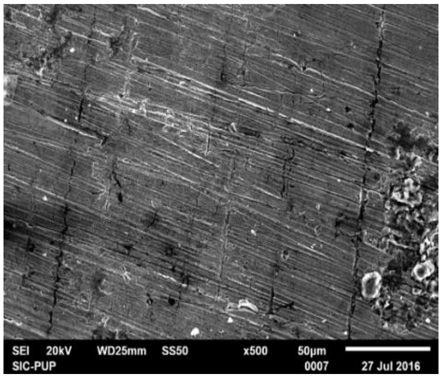
Blank 0.1 N HCl at 500 magnification



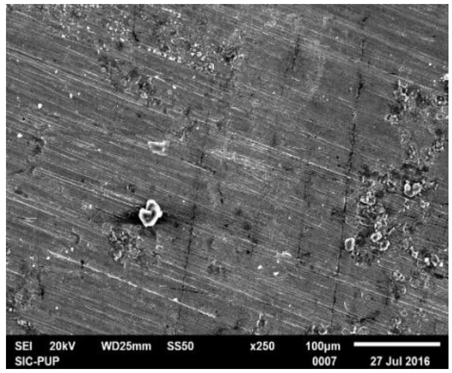
Blank 0.1 N HCl at 250 magnification



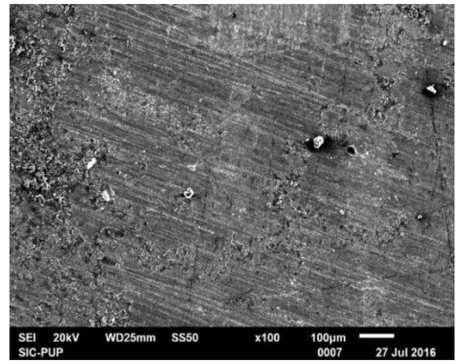
Blank 0.1 N HCl at 100 magnification



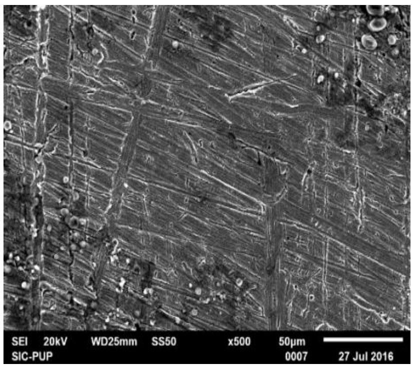
HA(1000 ppm) at 500 magnification in 2.0 N HCl



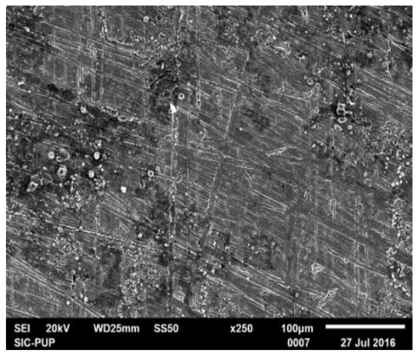
HA (1000 ppm)at 250 magnification in 2.0 N HCl



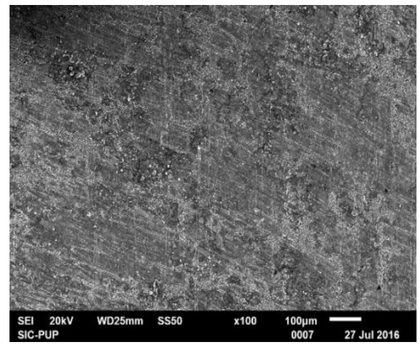
HA (1000 ppm) at 100 magnification in 2.0 N HCl



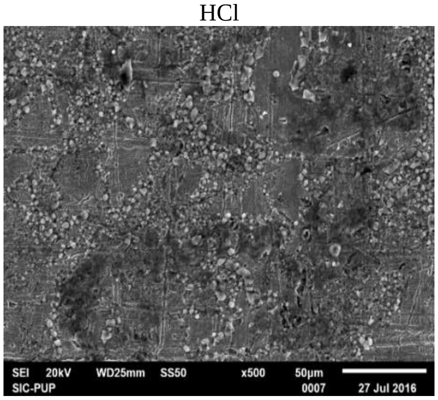
HA(400 ppm)at 500 magnification in 2.0 N HCl



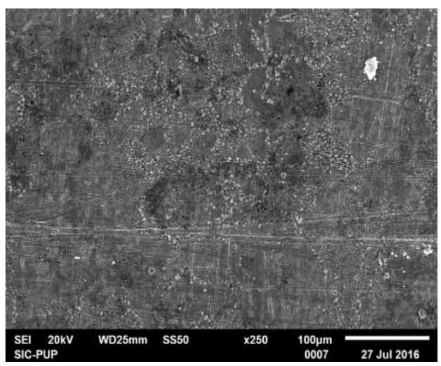
HA (400 ppm)at 250 magnification in 2.0 N HCl



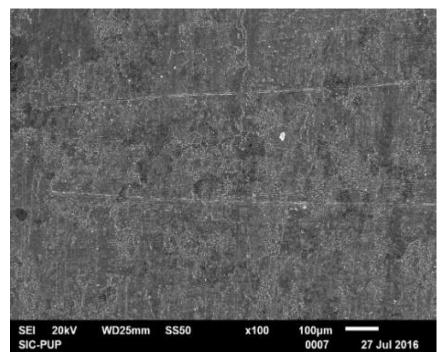
HA (400 ppm)at 100 magnification in 2.0 N HCl



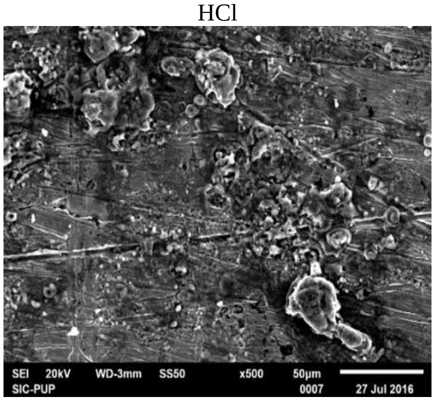
HA (100 ppm) at 500 magnification in 2.0 N HCl



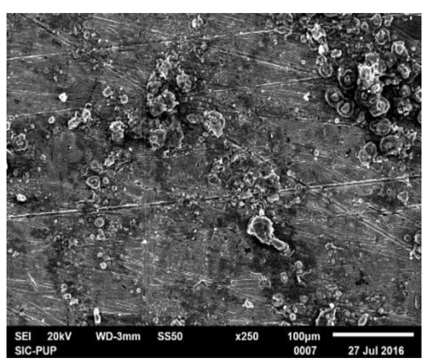
HA (100 ppm) at 250 magnification in 2.0 N HCl



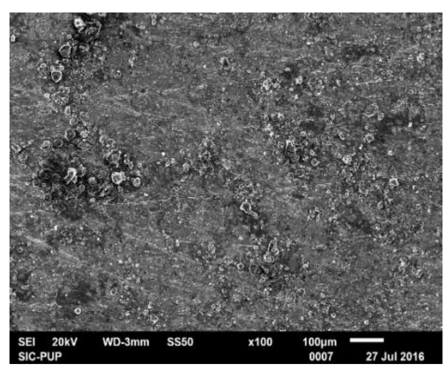
HA (100 ppm) at 100 magnification in 2.0 N HCl



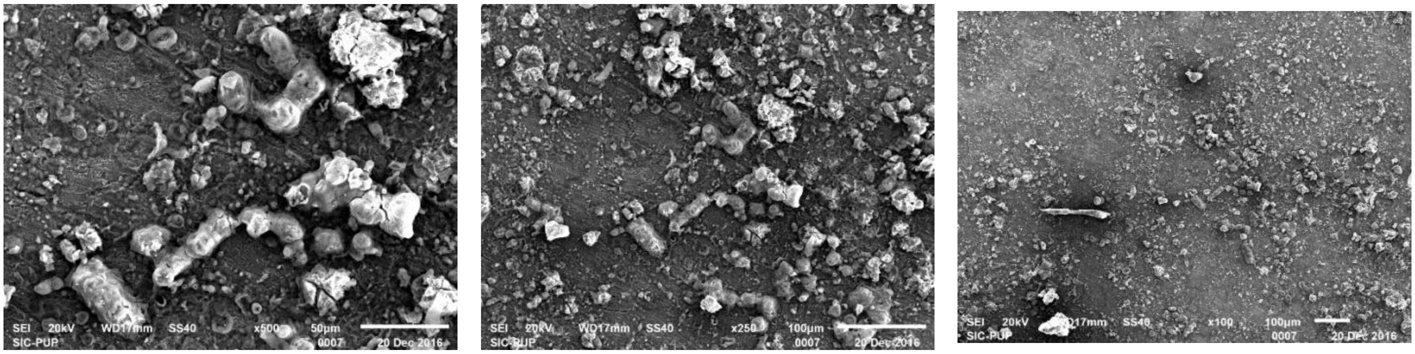
HA (1000 ppm) at 500 magnification in 1.0 N HCl



HA (1000 ppm) at 250 magnification in 1.0 N HCl



HA (1000 ppm) at 100 magnification in 1.0 N HCl



HA (1000 ppm) at 500 magnification in 0.1 N HCl

HA (1000 ppm) at 250 magnification in 0.1 N HCl

HA (1000 ppm) at 100 magnification in 0.1 N HCl

Fig 5: SEM micrographs of Carbon steel samples with and without the use of inhibitor HA

Mechanism of corrosion inhibition

The probable mechanism of inhibition action of 1-HA contain following features:

a. Presence of four amine groups having lone pair, donar nitrogen atoms in the molecule of-HA which provide the capability to adsorb on the surface of Carbon steel to protect it from corrosive environment.
b. Presence of methylene group near the lone pair donar atom enhances the electron density of N atom and basic strength of HA by inductive effect

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