



# Corrosion Characteristics of Cetyl Trimethyl Ammonium Bromide for Carbon Steel in Hydrochloric Acid Solutions

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## ABSTRACT

Cetyl trimethyl ammonium bromide (CTAB) is tested as corrosion inhibitor for carbon steel in different concentration of hydrochloric acid medium and at different temperature. Corrosion rate and Percentage Corrosion Inhibition Efficiency (PCIE) was measured by weight loss method, electrochemical polarization and Impedance spectroscopy techniques. Surface study of corroded and blank specimens was carried out by SEM and Metallurgical Research Microscopy techniques. 100, 200, 400, 600, 800 and 1000 ppm of Cetyl trimethyl ammonium bromide was tested in different concentration of HCl solution i.e. 2.0, 1.0 and 0.1 N. It was observed that percentage corrosion inhibition efficiency increases with increase in concentration of corrosion inhibitor. Effect of temperature on percentage corrosion inhibition efficiency was also investigated. As the temperature increases percentage corrosion inhibition efficiency decreases. It is observed that percentage corrosion inhibition efficiency decreases with dilution of HCl. CTAB acts as a very good inhibitor for Carbon Steel in different hydrochloric acid medium.

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## Introduction

Corrosion and corrosion inhibition of iron and its alloys like steel have received a great attention in different media acidic and basic with the use of different corrosion inhibitors [1-4]. Hydrochloric acid solutions are used for pickling, chemical and electrochemical etching of metals, acidization of oil wells and in cleaning of scales because it is more economical, efficient and trouble-free, compared to other mineral acids like nitric acid and sulphuric acid [5-8]. It is very important to add corrosion inhibitors to prevent metal dissolution and minimize acid consumption [9-12]. Most of corrosion inhibitors are organic compounds containing nitrogen, sulfur and oxygen atoms. The inhibiting action exercised by organic compounds on the dissolution of metallic species is normally related to interactions by adsorption between the inhibitors and the metal surface. This process is considered as interface inhibition, according to Fischer's classification [13-16]. The surfactant inhibitor has many advantages such as high inhibition efficiency, low price, low toxicity and easy production [16-21]. The adsorption of the surfactant on the metal surface can markedly change the corrosion resisting property of the metal [22-23], and so the study of the relationship between the adsorption and corrosion inhibition is of great importance. 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 [24-26]. 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 [27-34], in the present work, the corrosion inhibition efficiency of the surfactant i.e. cetyl trimethyl ammonium bromide (CTAB) 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

Carbon steel was used for the weight loss measurement contains 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, of size (3.0 cm × 1.5 cm) were used. Strips were mechanically polished with different grades of emery papers and washed with acetone before use. A sheet cut of the same composition having size (1.0 cm × 1.0 cm) was used for electrochemical polarization experiments. The electrode was polished using different grades of emery papers and washed. HCl was used for preparing solutions was of AR grade. The inhibitor CTAB used was CDH made. All solutions were prepared using double distilled water. 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).

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

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

$$\text{Percentage Corrosion Inhibition Efficiency (PCIE)} = \frac{(CR_0 - CR)100}{CR_0} \quad (2)$$

Where, CR<sub>0</sub> = 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 using three electrodes

based was used for electrochemical polarization experiments. Mechanically polished Carbon steel coupons itself act as working electrode. As a reference electrode, Ag/AgCl electrode was used and a platinum electrode was used as an auxiliary counter electrode. Mechanical polishing of the Carbon steel coupons was successively done with 150, 250, 350, 600  $\mu$  grade emery papers. The surface of mechanically polished surfaces Carbon steel coupons were washed with acetone in order to remove grease or oil from CS surface and then washed with plenty of double distilled water before performing the corrosion experiments. The surface area of exposure of working electrode for performing experiments was 1.0 cm<sup>2</sup> and rest of area was coated 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. CS 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 under temperature 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:

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

Where, *Eq. Wt.* is the gram eq. wt. of CS, *D* is the density of CS in gm/cm<sup>3</sup> and *i<sub>corr</sub>* is the corrosion current density in ( $\mu\text{A}/\text{cm}^2$ ).

$$\text{PCIE} = \frac{(\text{CR}_0 - \text{CR})100}{\text{CR}_0} \quad (4)$$

#### Electrochemical impedance spectroscopy

The electrochemical impedance spectroscopy measurements were carried out using Class1 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 cm<sup>2</sup>. 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<sub>ocp</sub>). After measuring the E<sub>ocp</sub>, 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

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

Where Rct and Rct\* are the charge-transfer resistances with and without the inhibitors

#### Surface Study

The test coupons of carbon steel after weight loss method in absence and presence of the CTAB 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, Kyowa Getner, Japan.

**Table 1. Weight loss, Corrosion rate and Percentage Corrosion Inhibition Efficiency (PCIE) of CTAB at different concentration by weight loss technique at 25, 30 and 35.0°C temperature in 2.0, 1.0, 0.1 N HCl solution.**

Conc. of CTAB	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	
100 200 400 600 800 1000	2.0 N	279.67	73.75	385.67	66.38	482.22	62.00
		242.89	77.20	368.45	67.88	452.34	64.35
		205.56	80.71	321.16	72.01	422.08	66.73
		177.66	83.33	298.22	74.01	406.08	68.00
		152.28	85.71	252.34	78.00	355.32	72.00
		126.90	88.09	206.46	82.00	329.94	74.00
100 200 400 600 800 1000	1.0 N	318.26	62.00	448.50	50.03	558.36	42.11
		279.18	66.66	403.65	55.02	507.60	47.37
		253.80	69.69	376.54	58.04	470.30	51.24
		255.45	69.49	340.86	62.02	431.46	55.27
		228.42	72.72	296.01	67.01	380.70	60.53
		203.04	75.75	269.10	70.01	350.10	63.70
100 200 400 600 800 1000	0.1 N	274.10	40.00	332.80	33.75	482.22	13.63
		253.80	44.44	307.34	38.82	431.46	22..72
		228.42	50.00	281.60	43.94	406.08	27.27
		203.04	55.55	256.13	49.01	397.48	28.81
		159.89	65.00	215.04	57.19	355.32	36.36
		127.91	72.00	204.08	59.37	228.42	59.09

## Result & Discussion

### Weight Loss Technique

In weight loss method, PCIE increases as we increase the concentration of inhibitor from 100 ppm to 1000 ppm. It acts as a good inhibitor even at low concentration of 100 ppm in different acidic medium. High PCIE is observed in 2.0 N HCl at 1000 ppm. Results of Weight loss method are shown in Table 1.

### Effect of inhibitor dose and temperature on inhibition efficiency

The trend of the inhibition efficiencies obtained from the weight loss with different inhibitor concentrations in 0.1, 1.0 and 2.0 N HCl concentration media at different temperatures (25, 30, and 35 °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, 30 and 35 °C. The maximum inhibition efficiency for CTAB inhibitor was found to be about 88.0% in 2.0 N HCl solution. The inhibition was estimated to be 73% at 25°C even at low concentrations (100 ppm), and at 400 ppm its protection was more than 80% (25°C). This trend may result from the fact that the amount of adsorption and the surface coverage of CTAB on the Carbon-steel increase with the inhibitor concentration, thus the Carbon-steel surface is efficiently

separated from the medium [19, 20]. Also, the inhibition efficiency decreases with an increase in corrosion temperature at the same inhibitor concentration indicating that the high temperature might result in desorption of the inhibitor molecules from the carbon-steel surface [21].

### 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 CTAB at 25, 30, 35 °C temperature. The values of OCP,  $R_p$ ,  $\beta_a$ ,  $\beta_c$  and  $I_{corr}$  and PCIE are tabulated in Table 2, 3 and 4.

It is observed that the increase in conc. of CTAB 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 ( $\beta_a$  and  $\beta_c$ ) confirm the adsorption of CTAB on the surface of CS. It is clear from the Table-2 that cathodic hydrogen evolution and anodic metal dissolution reactions are inhibited to the same extent and the magnitude of corrosion inhibition of CS 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 CTAB in 2.0 N HCl solution. This result indicates that CTAB may be regarded as mixed type of corrosion inhibitor.

**Table 2. OCP, Corrosion Current Density ( $I_{corr}$ ), anodic Tafel slope ( $\beta_a$ ), cathodic Tafel slope ( $\beta_c$ ), resistance polarization ( $R_p$ ), corrosion rate and PCIE of CTAB 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	$I_{corr}$ ( $\mu A/cm^2$ )	( $\beta_a$ ), (V/dec)	( $\beta_c$ ) (V/dec)	$R_p$	CR (mpy)	PCIE
2.0 N	Blank	-0.530	5.23	2.453	3.567	$8.51 \times 10^4$	2.31	-
1.0 N		-0.534	4.03	3.407	2.342	$9.79 \times 10^4$	1.78	
0.1 N		-0.524	3.58	2.345	4.897	$7.15 \times 10^5$	1.58	
2.0N	100	-0.576	1.38	1.350	1.365	$9.51 \times 10^4$	0.60	74.02
	400	-0.579	1.24	1.144	1.336	$8.79 \times 10^4$	0.55	76.19
	1000	-0.602	0.95	1.231	1.331	$1.15 \times 10^5$	0.41	82.25
1.0N	100	-0.557	1.47	1.841	1.805	$1.20 \times 10^5$	0.64	64.04
	400	-0.686	1.41	0.537	1.837	$5.23 \times 10^4$	0.62	65.16
	1000	-0.557	1.13	0.476	1.253	$5.02 \times 10^4$	0.49	72.47
0.1N	100	-0.786	1.66	0.340	1.621	$3.27E \times 10^4$	0.73	53.79
	400	-0.686	1.44	0.537	1.832	$5.23E \times 10^4$	0.63	60.12
	1000	-0.545	1.27	1.732	2.138	$1.25E \times 10^5$	0.56	64.55

**Table 3. OCP, Corrosion Current Density ( $I_{corr}$ ), anodic Tafel slope ( $\beta_a$ ), cathodic Tafel slope ( $\beta_c$ ), resistance polarization ( $R_p$ ), corrosion rate and PCIE of CTAB 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	$I_{corr}$ ( $\mu A/cm^2$ )	$\beta_a$ (V/dec)	$\beta_c$ (V/dec)	$R_p$	CR (mpy)	PCIE
2.0 N	Blank	-0.530	6.13	2.456	3.786	$4.27 \times 10^4$	2.70	
1.0 N		-0.527	4.98	3.987	2.675	$5.23 \times 10^5$	2.20	
0.1 N		-0.524	3.76	3.234	4.987	$3.25 \times 10^4$	1.66	
2.0 N	100	-0.580	2.24	1.456	2.056	$3.27 \times 10^4$	0.98	63.70
	400	-0.577	1.87	1.987	1.987	$5.03 \times 10^5$	0.83	69.25
	1000	-0.564	1.65	1.234	1.834	$4.25 \times 10^4$	0.72	73.33
1.0 N	100	-0.580	1.99	1.456	0.456	$4.07 \times 10^5$	0.88	60.00
	400	-0.577	1.86	0.967	2.987	$5.23 \times 10^4$	0.82	62.72
	1000	-0.564	1.73	1.234	2.134	$3.25 \times 10^5$	0.76	65.45
0.1 N	100	-0.580	1.77	1.406	0.416	$2.27 \times 10^5$	0.78	53.01
	400	-0.577	1.61	1.967	1.087	$4.13 \times 10^4$	0.70	57.83
	1000	-0.564	1.45	1.034	1.134	$2.25 \times 10^5$	0.64	61.44

**Table 4. OCP, Corrosion Current Density ( $I_{corr}$ ), anodic Tafel slope ( $\beta_a$ ), cathodic Tafel slope ( $\beta_c$ ), resistance polarization ( $R_p$ ), corrosion rate and PCIE of CTAB 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	$I_{corr}$ ( $\mu A/cm^2$ )	$\beta_a$ (V/dec)	$\beta_c$ (V/dec)	$R_p$	CR (mpy)	PCIE
blank		-0.524 -0.484 -0.512	6.86 5.23 4.76	3.671 2.562 4.567	4.784 5.675 3.654	$9.01 \times 10^4$ $6.79 \times 10^4$ $1.05 \times 10^5$	3.03 2.31 2.10	—
2.0N	100 400 1000	-0.576 -0.579 -0.602	2.58 2.24 1.95	1.350 1.144 1.231	1.365 1.336 1.331	$9.51 \times 10^5$ $8.79 \times 10^4$ $1.15 \times 10^5$	1.14 0.98 0.86	62.37 67.65 71.61
1.0N	100 400 1000	-0.557 -0.686 -0.557	2.57 2.43 2.03	1.841 0.537 0.476	1.805 1.837 1.253	$1.20 \times 10^5$ $5.23 \times 10^4$ $5.02 \times 10^4$	1.13 1.07 0.89	51.08 53.67 61.47
0.1N	100 400 1000	-0.786 -0.686 -0.545	2.15 2.08 1.98	0.340 0.537 1.732	1.621 1.832 2.138	$3.27 \times 10^4$ $5.23 \times 10^4$ $1.25 \times 10^5$	1.19 0.91 0.84	48.09 56.66 60.00

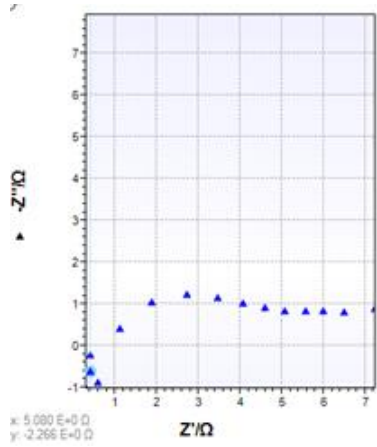
**Table 5. Electrochemical impedance parameters for carbon steel samples in 2.0, 1.0, 0.1 N HCl solution in absence and presence of different concentrations of CTAB at 25.0, 30.0 and 35.0 °C temperature.**

Concentration of inhibitor	Concentration of HCl	Rct at 25.0 °C	% I.E. at 25.0 °C	Rct at 30.0 °C	% I.E. at 30.0 °C	Rct at 35.0 °C	% I.E. at 35.0 °C
Blank	2.0 N 1.0 N 0.1 N	7.8 9.2 10.5	-	7.2 8.8 10.2	-	6.9 8.2 9.8	-
100 400 1000	2.0 N	47.59 66.60 119.83	83.61 87.68 93.40	39.52 48.83 67.60	81.50 85.25 89.30	34.23 38.78 48.83	79.80 82.20 85.80
100 400 1000	1.0 N	38.11 47.67 66.60	75.86 80.70 86.18	23.03 38.56 61.03	61.80 77.17 85.50	16.01 33.45 47.01	48.78 75.40 82.55
100 400 1000	0.1N	18.21 28.76 60.70	42.23 63.49 81.80	14.15 18.67 48.82	27.90 45.30 79.13	13.20 15.78 39.52	25.75 37.89 75.20

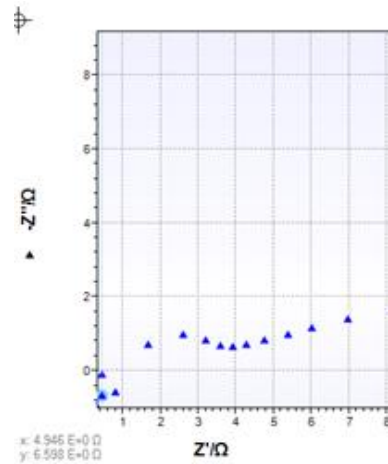
**Electrochemical Impedance Spectroscopy**

Impedance spectroscopy technique was used to study the electrode/electrolyte interface behavior of the electrode and corrosion processes occurring on the surface of Carbon steel in presence and absence of Corrosion inhibitor. For understanding the phenomenon, electronic structure of electrified interface formed at the surface of working electrode and surface processes, EIS experiments were carried out 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 CS coupons dipped in 2.0 N, 1.0 N, 0.1N HCl medium at 298.0 K

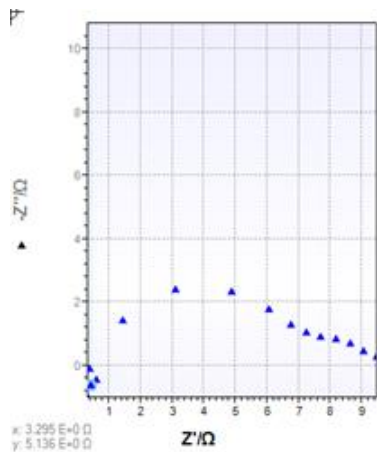
with and without corrosion inhibitor at the OCP. It is also observed from Nyquist plots that the diameter of the semicircle augment with the augment in concentration of CTAB in the corroding medium, which indicates an increase in resistance to corrosion. It is observed from electrochemical impedance data presented in the Table-5. Table data point out that both *RCT* and *PCIE* were found to increase with increase in the concentration. The present behavior can be accredited 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.



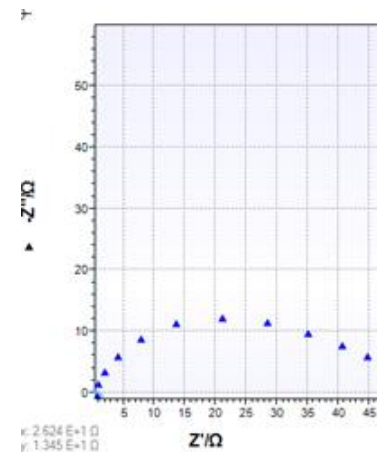
Nyquist plot of Blank 2.0 N HCl



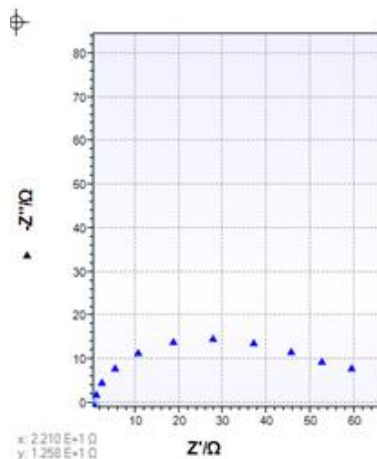
Nyquist plot of Blank 1.0 N HCl



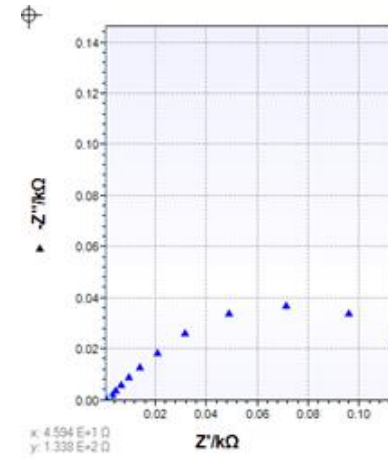
Nyquist plot of Blank 0.1N HCl



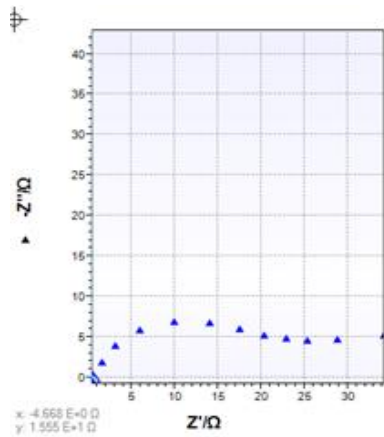
Nyquist plot of CTAB in (100ppm) 2N HCl



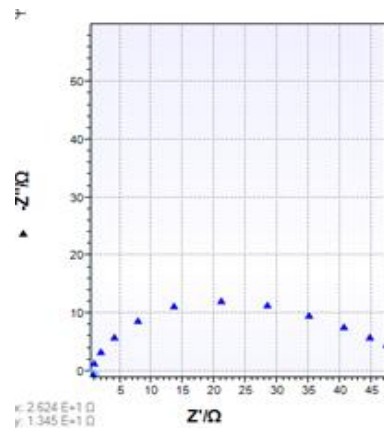
Nyquist plot of CTAB(400ppm) in 2N HCl



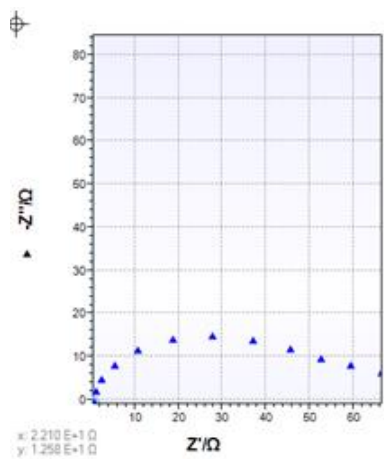
Nyquist plot of CTAB(1000 ppm) in 2N HCl



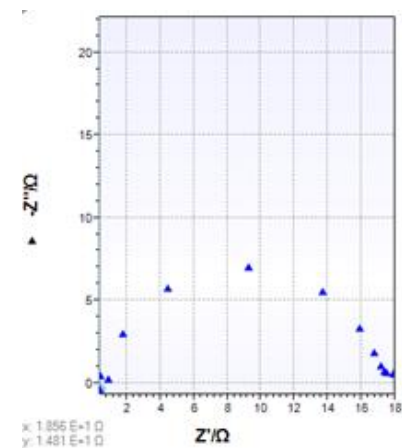
Nyquist plot of 100 ppm CTAB in 1N HCl



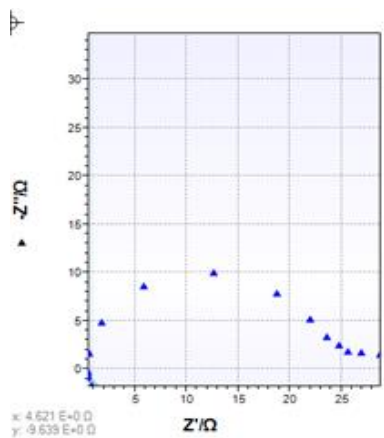
Nyquist plot of 400 ppm CTAB in 1N HCl



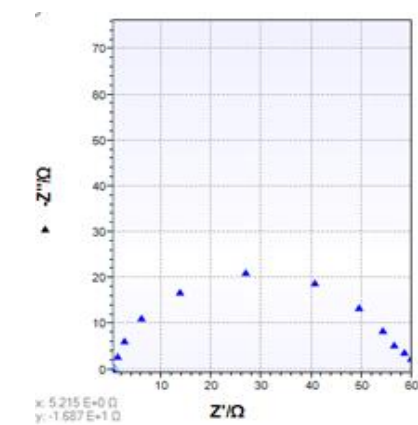
Nyquist plot of CTAB(1000 ppm) in 1N HCl



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



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



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

Figure 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 CTAB at 298.0 K temperature.



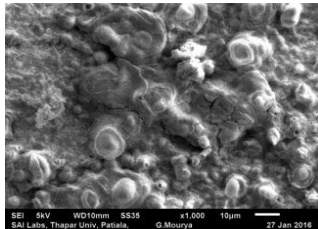
**SEM**

Morphology 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 of different corrosion inhibitor in different environment and for the mechanism of inhibition. In this technique, the samples, 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

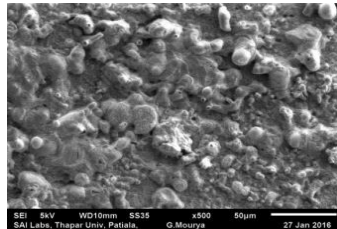
which are shown in Fig 2 SEM of the blank coupons clearly provides the evidence of the more extent of corrosion in corroding medium. Pits and brown rust particles are clearly visible in blank Carbon steel coupons dipped in 2.0 N HCl solution at 1000 and 500 magnification. Carbon steel surface becomes more and more smoother with increase in concentration of inhibitor.

**Metallurgical Research Microscopy Technique**

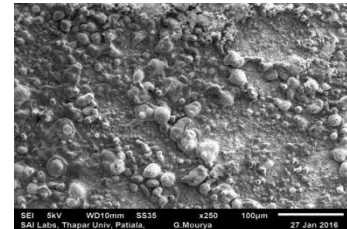
This test was carried out in order to know about the nature, type and extent of corrosion using Trinocular Inverted Metallurgical Research Microscope.



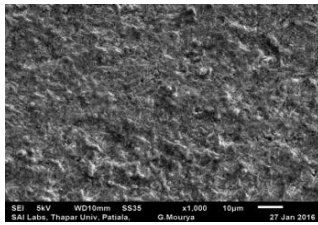
**Blank 2 N HCl at 1000 magnification**



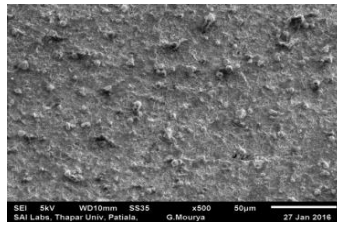
**Blank 2 N HCl at 500 magnification**



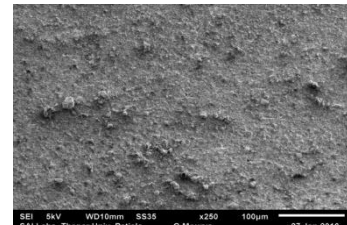
**Blank 2 N HCl at 250 Magnification**



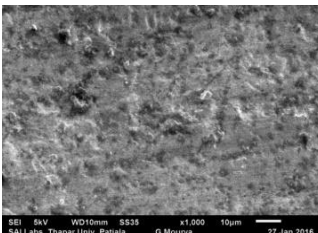
**CTAB(1000ppm) at 1000 magnification**



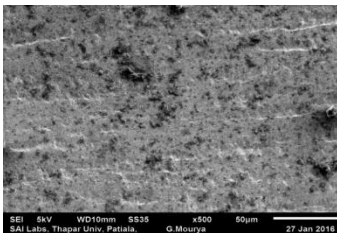
**CTAB(1000ppm) at 500 magnification**



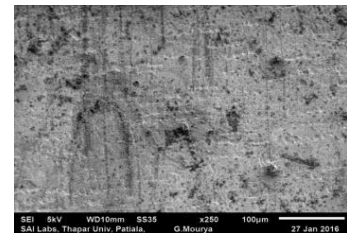
**CTAB(1000ppm) at 250 magnification**



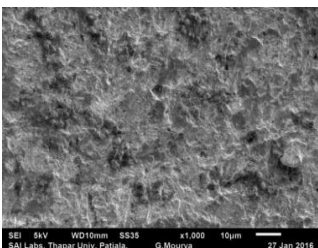
**CTAB(400ppm) at 1000 magnification**



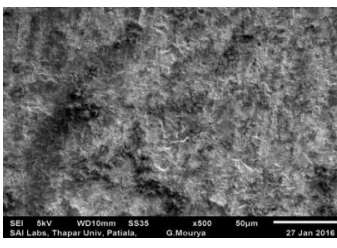
**CTAB(400ppm)at500 magnification**



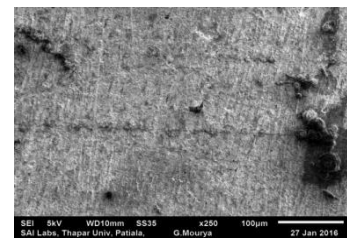
**CTAB (400ppm) at 250 magnification**



**CTAB (100ppm) at 1000 magnification**



**CTAB (100ppm) at 500 magnification**

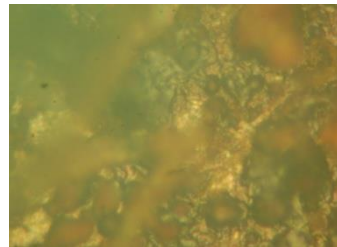


**CTAB (100ppm) at 250 magnification**

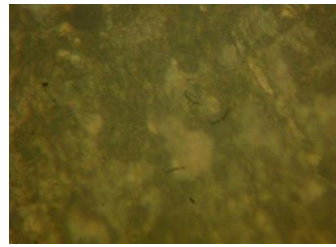
**Figure 2. SEM images of carbon steel samples with and without CTAB at different concentrations.**

To explain the mechanism of corrosion inhibition by CTAB, metallurgical research micrographs of the corroded coupons treated with CTAB were subjected to different test like porosity study, Coating thickness, length of pores and morphology of surface. Results of porosity and surface morphology provides 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. 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

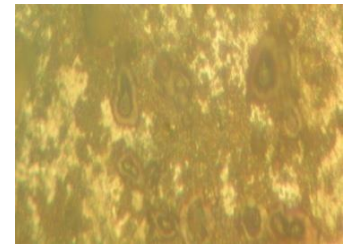
surface of carbon steel. Micrographs of blank corroded coupons were taken after exposure of different concentration of HCl for 2.0 hours are shown in Figure 3 and data obtained from metallurgical research microscopy of blank Carbon steel sample after weight loss experiments are reported in table 6 from 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 CTAB increases, porosity of surface decreases. Coating thickness also measured which increases with increase in conc. of CTAB.



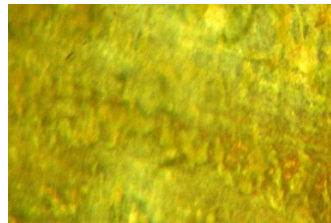
**Blank in 2.0 N HCl**



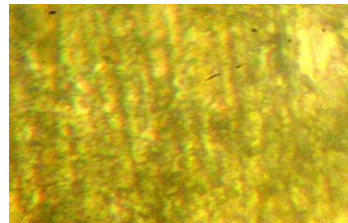
**Blank in 1.0 N HCl**



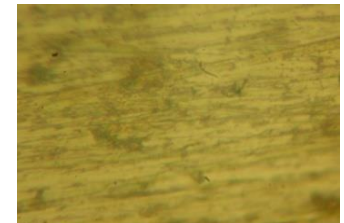
**Blank in 0.1 N HCl**



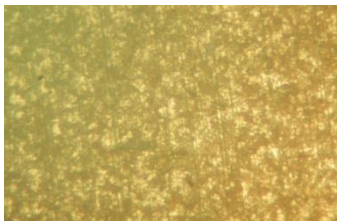
**CTAB (100 ppm) in 2.0 N HCl**



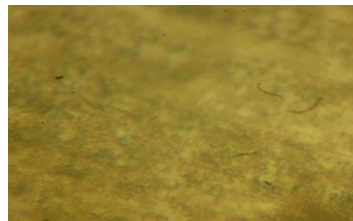
**CTAB (400 ppm) in 2.0 N HCl**



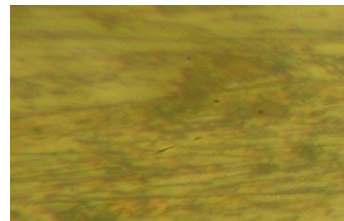
**CTAB (1000ppm) in 2.0 N HCl**



**CTAB (100ppm) in 1.0N HCl**



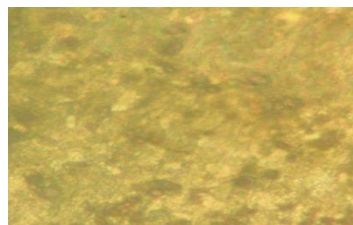
**CTAB (400ppm) in 1.0N HCl**



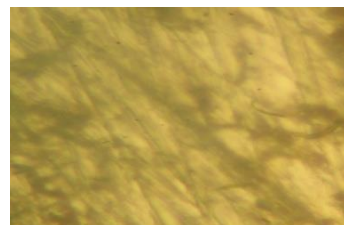
**CTAB (1000ppm) in 1.0N HCl**



**CTAB (100ppm) in 0.1 N HCl**



**CTAB (400ppm) in 0.1 N HCl**



**CTAB (1000ppm) in 0.1 N HCl**

**Figure 3. Trinocular Inverted Metallurgical Research Micrographs of different carbon steel samples with and without CTAB at different concentration.**



**Table 6. Coating thickness, percentage porosity and pore length of carbon steel coupons with and without corrosion inhibitor.**

Concentration of CTAB	Concentration of HCl	% age porosity	Max. Perimeter (micron)	Max. area (micron square)	Length of pore (micron)	Coating thickness (micron)
Blank	2.0 N	89.34	6543.67	26785.64	590.45	32.56
	1.0 N	84.53	5887.64	24567.98	394.67	28.45
	0.1 N	72.56	4321.91	23145.89	298.56	24.67
100 400 1000	2.0 N	8.90	2804.43	13453.67	121.32	96.48
		5.67	1278.39	11502.56	114.34	106.34
		3.78	1035.88	10512.43	72.45	231.45
100 400 1000	1.0 N	10.97	3064.49	15456.78	134.23	94.35
		8.67	2323.16	13123.43	123.45	97.46
		5.65	3724.38	11678.67	87.55	196.23
100 400 1000	0.1 N	11.78	7988.15	10124.78	142.34	82.27
		9.67	2105.26	11056.56	132.56	87.32
		7.83	1256.43	10589.98	98.56	126.15

### Mechanism of Inhibition

CTAB is a surfactant which adsorb on carbon steel surface and inhibits the corrosion rate. As we know the molecular weight of CTAB is large ( $C_{16}H_{33} - N^+(CH_3)_3Br^-$ ), therefore CTAB can relatively easily adsorb on the surface of carbon steel by Van der Waals forces. It has two parts, the main hydrophilic part -  $N^+(CH_3)_3$ , which may attack the C-steel surface while the main hydrophobic part ( -  $C_6H_{33}$ ), may extend to the solution face. Furthermore, CTAB may chemisorb at carbon steel or solution interface via chemical bond between positively charged nitrogen atoms and negatively charged carbon-steel surface which is: In acidic solution i.e. 2.0 N HCl, CTAB acts as a cationic surfactant, ionizes and carry a positive charge. As steel surface is positively charged in presence of acidic medium because of  $E_{corr} - E_q = 0$  (zero charge potential)  $> 0$ , while bromide ion is negatively charged. As a result, the adsorption of bromide ion occurs onto Carbon steel surface, ionized CTAB easily reaches Carbon steel surface, and the dipoles of the surface compound are oriented with their negative ends towards solution, preventing acid solution from attaching directly to Carbon steel surface. Thus, bromide ion acts as an adsorption mediator of an adsorption composite layer in which bromide ion are fitted between metal and positively charged part of the inhibitor. This layer acts as a barrier facing corrosion process. This mechanism explains percentage inhibition efficiency of CTAB in different solution of HCl. Also it was found that the inhibition efficiency decreases with increases the experimental temperature, which is due to desorption of CTAB from Carbon steel surface at higher temperature.

### Conclusion

CTAB acts as a very good inhibitor for the corrosion of carbon steel in 2.0 N, 1.0 N and 0.1 N HCl solutions, and the maximum corrosion inhibition efficiency is about 88.0 % in 2.0 N HCl solution. The inhibition efficiency values increase with the increase in inhibitor concentration, but decrease with the increase in temperature. The corrosion rate of Carbon steel in the presence and absence of CTAB acts as a function of inhibitor concentration. Increase in the concentration resulted in the increase the corrosion inhibition efficiency. The weight loss and the electrochemical polarization studies are in good

agreement to each other. CTAB acts as a mixed-type inhibitor in 2.0, 1.0 and 0.1 N HCl. The inhibitive mechanism was proposed. CTAB forms a continuous film on the Carbon steel surface, which results in the decrease of the carbon steel roughness and effectively protect the carbon steel from corrosion. Results obtained from SEM and Metallurgical Research Microscopy techniques further support the weight loss and electrochemical experiments.

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