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Inhibitory behavior of new ionic liquids against low carbon steel corrosion in a 1 M HCl solution

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Abstract

Two new imidazolium-based ionic liquids namely, 1-hexadecyl-3-(4-methylbenzyl)-1H-imidazol-3-ium chloride (IL-CH_3), and 1-hexadecyl-3-(4-nitrobenzyl)-1*H*-imidazol-3-ium chloride (IL-NO_2) were synthesized. The inhibitory activity of these compounds against the corrosion of low-carbon steel (LCS) in a 1 M HCl was examined by utilize multiple techniques such as polarization (PP) and electrochemical impedance spectroscopy (EIS). The outcome data displayed that the protection efficiency rises with improving the dose of IL'S (IL-CH_3, IL-NO_2). PP data confirm that they are mixed kind inhibitors. Best performances (i.e. 92.9% and 94.5%) were recorded at maximal IL-CH_3 (100 ppm) and IL-NO_2 (100 ppm) doses, respectively. These findings imply that the novel ionic liquids (IL-CH_3, IL-NO_2) are efficient corrosion inhibitors.

***Keywords*:** carbon steel; acid solution; ionic liquids; Corrosion inhibition

1- Introduction

Carbon steel is the primary metal utilized in the oil and gas manufacturing sectors. Steel corrosion is thus a highly problematic risk factor for developing significant economic and ecological concerns [1-5]. As a result, acid de-scaling and pickling operations are commonly employed in manufacturing processes to eliminate corrosion scales from metal surfaces under harsh conditions, such as strong acidic solutions and high temperatures. In order to prevent corrosion of the steel surface, a special action is therefore required. Varieties of organic molecules were employed in this situation as effective corrosion protections and inhibitors. [6-10]. Regrettably, due to high doses utilized, which could have toxic effects on the surroundings, the utilization of that kind agents is restricted. For minimizing the corrosion of several metallic materials, ionic liquids (ILs) had already lately been recommended as endorsing compounds in a wide range of applications [11, 12-14]. As shown in a literature review, numerous synthesized ILs were often choose as efficient steel corrosion inhibitors in a variety of electrolyte solutions [15-19]. The main innovation of this work is the layout of two novel ionic liquid additives, 1-hexadecyl-3-(4-methylbenzyl)-1H-imidazol-3-ium chloride and 1-hexadecyl-3-(4-nitrobenzyl)-1H-imidazol-3-ium chloride (IL-CH_3, IL-NO_2).

2- Experimental

2.1 Synthesis of IL-CH_3, IL-NO_2

Synthesis of ILs (IL-CH_3, IL-NO_2) was carried out according to Scheme 1.

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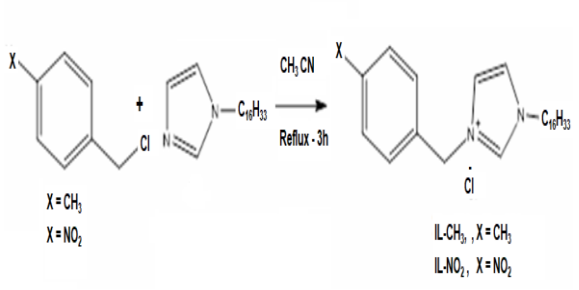

Scheme 1: Synthesis of (IL-CH_3, IL-NO_2).

The purity of prepared IL-CH_3, IL-NO_2 is 99.8%

2.2 Anticorrosion efficiency

LCS has been cut into sizes of 1 cm x 1 cm for the electrochemical experiment.

Table 1 lists the LCS's chemical components

chemical components	Mn	C	Si	P	Fe
(wt%)	0.349	0.209	0.0035	0.0242	remainder

Before each test, the LCS were abraded with a variety of emery papers ranging in grade from 200 to 1800, degreased with acetone, and cleaned with distilled water. A glass unit was used for electrochemical estimations using the Gamry G750 instrument, platinum (Pt), a saturated calomel electrode (SCE), and an LCS plate as the working anode (WE). Assessments of polarization (PP) were made by sweeping the potential at E_{OC} from –(500) to + (500) mV at a rate of 1.0 mV s^{-1}.

Surface cover (θ) and the inhibition efficacy (%IE) were derived using the relation (1)

$$\%IE = \theta \times 100 = (i_{corr(0)} - i_{corr} / i_{corr(0)}) \times 100 \quad (1)$$

$i_{corr(0)}$ = Corrosion current density for blank solution.

i_{corr} = Corrosion current density when ILs are present.

The EIS assays were made out with a perturbation of 10 mV and a frequency band of 0.2 Hz to 30 kHz.

Surface coverage (θ) and the%IE were derived from relation (2) [21]:

$$\%IE = \theta \times 100 = [(1 - (R^{\circ}_{ct} / R_{ct})] \times 100 \quad (2)$$

In which R°_{ct} and R_{ct} are, respectively, the resistance data prior to and after the addition of ILs.

3. Results and discussion

3.1 EIS Assessments

The Nyquist shapes for the corrosion activity of LCS in 1.0 M HCl containing and not containing varying amounts of ILs (IL-CH_3, IL-NO_2) are shown in Figs. (1-2). Impedance spectrum revealed a single time constant connected to only one capacitive semi-circles, showing that charge transfer was primarily controlling the corrosion activity [22]. The formation of an ILs (IL-CH_3, IL-NO_2) adsorbed barrier on the top layer of the LCS causes the diameter of Nyquist curves to increase as the ILs (IL-CH_3, IL-NO_2) dosages rises. Tables (2 and 3) show the EIS, and %IE data. Charge transfer resistance, or R_{ct}, increases as the dose of ILs (IL-CH_3, IL-NO_2) is increased. As ILs (IL-CH_3, IL-NO_2) molecules replace water and create an inhibitive shield at the LCS, the qualities of C_{dl} (double layer capacitance) decline [23].

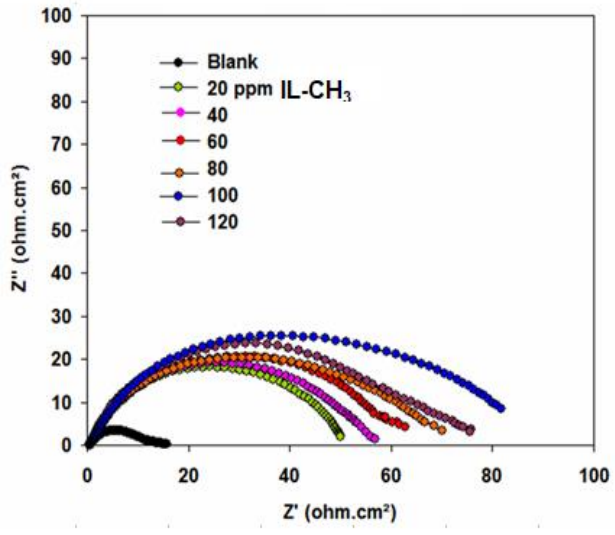

Fig. 1. Nyquist plots for LCS at 25 °C in 1 M HCl without and including IL-CH_3

Table 2: EIS parameters in 1 M HCl with and without IL-CH_3 at 25 °C for LCS

IL-CH_3 Conc. (ppm)	R_s ($\Omega.cm^2$)	R_{ct} ($\Omega.cm^2$)	C_{dl} $\mu F.\ cm^{-2}$	IE %
Blank	0.89	12.4	112.5	-
20	0.85	49.9	100.4	75.1
40	0.82	58.3	93.6	78.7
60	0.82	63.7	76.4	80.5
80	0.77	74.8	70.6	83.4
100	0.78	89.7	56.9	86.1
120	0.73	79.4	59.8	84.4

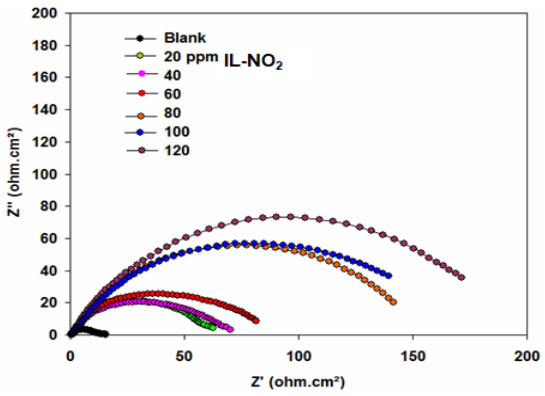

Fig. 2 Nyquist plots for LCS at 25 °C in 1 M HCl without and including IL-NO_2

Table 3 EIS parameters in 1 M HCl with and without IL-NO_2 at 25 °C for LCS.

IL-NO_2 Conc. (ppm)	R_s ($\Omega.cm^2$)	R_{ct} ($\Omega.cm^2$)	C_{dl} $\mu F.cm^{-2}$	IE %
Blank	0.89	12.4	112.5	-
20	0.87	56.3	97.9	78.5
40	0.87	61.8	78.9	83.9
60	0.83	72.2	72.8	86.2
80	0.83	77.6	60.5	88.9
100	0.89	152.2	54.8	92.9
120	0.82	149.8	59.9	90.6

The maximum efficiency (86.1% and 92.9 %) has been observed at optimum concentrations of IL-CH_3 (100 ppm) and IL-NO_2 (100 ppm), respectively.

3.2. PP Measurements

Figs. (3,4) show the PP graphs of LCS in 1.0 M HCl solution before and after varied IL amounts (IL-CH_3, IL-NO_2) were added. After having to add ILs (IL-CH_3, IL-NO_2), respectively cathodic and anodic sections started moving to the relatively low i_{corr} data, lowering the corrosion rate. The effects of IL concentration (IL-CH_3, IL-NO_2) on polarization data and (% IE) for LCS corrosion in 1 M HCl at 25°C are shown in Tables (4,5). Corrosion potential (E_{corr}) is shifted slightly toward less negative numbers when ILs (IL-CH_3, IL-NO_2) are added to 1 M HCl, indicating that these ILs (IL-CH_3, IL-NO_2) could really be regarded as mixed-type inhibitors [24]. Additionally, this adding doesn't really significantly alter (βa and βc), indicating that neither the mechanism for liberating hydrogen nor the method by which LCS dissolves are impacted [25]. The maximum efficiency (92.9% and 94.5%) has been observed at optimum concentrations of IL-CH_3 (100 ppm) and IL-NO_2 (100 ppm), respectively.

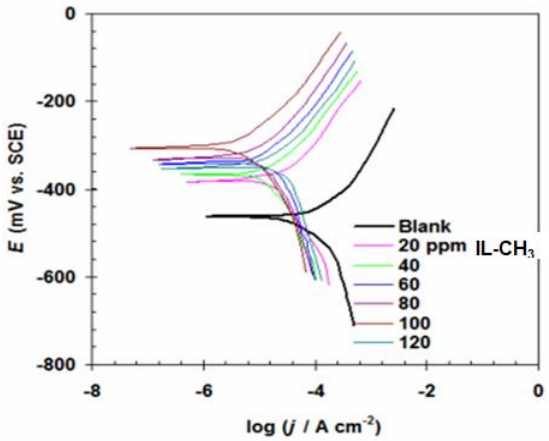

Fig. 3. PP curves for the corrosion of LCS in 1 M HCl solution without and with various concentrations of IL-CH_3 at 25°C.

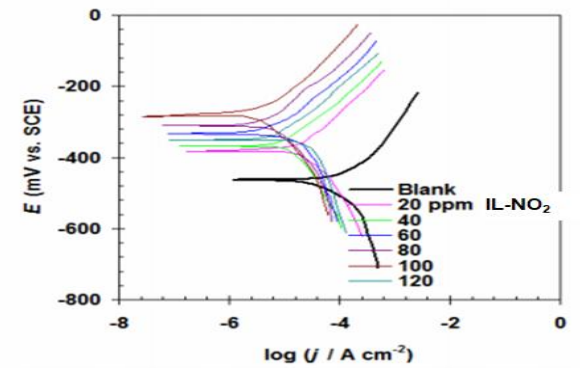

Fig. 4. PP curves for the corrosion of LCS in 1 M HCl solution without and with various concentrations of IL-NO_2 at 25˚C.

Table 4 Polarization parameters for LCS in 1 M HCl without and with IL-CH_3 at 25˚C

IL-CH_3 Conc. (ppm)	$E_{corr.}$ mV (SCE)	βa (mV. dec^{-1})	βc (mV. dec^{-1})	$I_{corr.}$ µA cm^{-2}	IE %
Blank	-463	69	108	125.8	-
20	-384	77	124	27.0	78.5
40	-366	72	114	20.2	83.9
60	-343	62	98	17.3	86.2
80	-332	58	102	13.9	88.9
100	-310	88	138	8.9	92.9
120	-352	87	122	11.7	90.6

Table 5 Polarization parameters for LCS in 1 M HCl without and with IL-NO_2 at 25˚C.

IL-NO_2 Conc. (ppm)	$E_{corr.}$ mV (SCE)	βa (mV. dec^{-1})	βc (mV. dec^{-1})	$I_{corr.}$ µA cm^{-2}	IE %
Blank	-463	69	108	125.8	-
20	-384	63	98	21.8	82.6
40	-366	84	99	15.9	87.3
60	-343	75	92	13.0	89.6
80	-332	83	112	7.6	93.9
100	-310	84	125	6.9	94.5
120	-352	85	120	10.6	91.5

Consequently, the main role of ionic liquids is to create a barrier between the LCS surface and the acidic surroundings [26–31]. By stifling both the hydrogen evolving and LCS solubilization responses, ionic liquids could indeed stop LCS corrosion from occurring. IL-CH_3 and IL-NO_3 can remove a considerable number of H_2O molecules from the LCS surface due to their significantly bigger molecular size and shapes. Adsorption of IL-CH_3 and IL-NO_3 by heteroatoms and π-electrons leading to the establishment of a barrier protection film.

4. Conclusions:

Two new imidazolium-based ionic liquids (IL-CH_3 and IL-NO_3) were synthesized in the current work. The anti-corrosion characteristics of the two ionic liquids (IL-CH_3 and IL-NO_3) produced was practical investigated. The inhibition optimization obtained from all measured data was in good agreement. Potentiodynamic polarization evaluations revealed that the ionic liquids were mixed suppressors. The EIS study found that by adding the IL-CH_3 and IL-NO_3, the double-layer capacitances decrease particularly in comparison to the control sample, and the largest charge transfer resistance of IL-CH_3 and IL-NO_3 is a factor of the formation of a dense interfacial film.

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