Effect of temperature and hydrodynamic conditions on corrosion inhibition of an azomethine compounds for mild steel in 1 M HCl solution

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ABSTRACT

This work studies the influence of temperature (25–55 °C) and hydrodynamic conditions (0–2000 rpm) on corrosion inhibition of a azomethine compounds: $PhN=N-C-(COCH_3)=NC_6H_4Y$ {$Y=OCH_3$ (SB_1), CH_3 (SB_2), H (SB_3), Br (SB_4) and $Y=Cl$ (SB_5)} on mild steel in a 1 M HCl. Potentiodynamic polarization and electrochemical impedance spectroscopy (EIS) techniques were employed. The results of electrochemical measurements show that the inhibition efficiency increased with increasing compound concentration and decreasing with temperature and hydrodynamic condition. The adsorption process on mild steel surface obeyed Langmuir isotherm. The associated activation parameters and thermodynamic data of adsorption were evaluated and discussed. The inhibition mechanism was determined by potential of zero charge (PZC) measurements. Corrosion attack morphologies were observed at stagnant and hydrodynamic conditions to verify qualitatively the results obtained by electrochemical methods.

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1. Introduction

Corrosion problem occurs in many industries, and can cause serious damages to metal and alloy in the system components causing economic consequences in terms of repair, replacement and product losses. Among various methods of corrosion of metals in acids, the use of inhibitors is the most effective, economical and practical method to prevent metals against electrochemical corrosion.

The use of organic compounds as corrosion inhibitors may be the main choice to decrease the corrosion rate of alloys in acidic media. By considering the practical applications of acidic solutions at various industrial processes such as acid pickling of steels, scale removal in metallurgy, acid cleaning of boilers and oil-well acidizing, the special importance of corrosion inhibitors is more pronounced [1–5]. The existing data show that most of the organic inhibitors act by adsorption on the metal surface. Majority of the efficient inhibitors used in industry are organic compounds, which mainly contain oxygen, sulfur, nitrogen atoms and multiple bonds. The inhibiting action of these inhibitors attributed to their interactions with the mild steel surface via adsorption. It has been observed that adsorption mainly depends on certain physicochemical properties of the inhibitors such as electron density at the donor atom, π-orbital character and the electronic structure of the molecule [6–8].

An arylazoheterocyclic ligand with an imine group (−C=N−) and azo group (−N=N−) such as 2-(arylazo) pyridine (aap) coordinates a metal ion as an azoimine bidentate ligand (−N=N−C=N−) [9,10]. This ligand is a stronger π-acceptor than 2, 2′-bipyridine and other N-donor heterocyclic ligands [11–14]. Also, the −N=N−C=N− group has been implanted into a coumarine backbone for the synthesis of a photoactive coumarinyl azoimine compounds. These compounds are used for the synthesis of photosensitive materials [15,16] and as organic fluorescent molecules [17,18]. In addition, the azoimine moiety is used as building block for the synthesis of nitrogen containing biological active heterocyclic compounds [19,20].

The hydrodynamic flow can be a vital environmental factor which influences on inhibitor performance by facilitating the molecular transport process from bulk solution to surface. Although numerous investigations on inhibitive behavior of organic compounds have been conducted in the static condition [1–5,21,22]. Several researchers have studied the effect of

$Y = OCH_3$ (SB$_1$), CH$_3$ (SB$_2$), H (SB$_3$),Br (SB$_4$), Cl (SB$_5$)
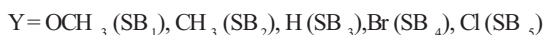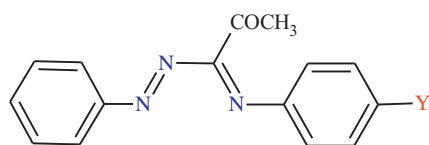
Scheme 1. The structures of the investigated azomethine compounds SB$_1$–SB$_5$.

hydrodynamic flow on inhibitors performance in diverse corrosive environments [23–30].

The aim of this research is to study the effect of temperature and hydrodynamic conditions on the corrosion inhibition of azomethine compounds, PhN=N–C (COCH$_3$) = NC$_6$H$_4$Y {Y = OCH$_3$(SB$_1$), CH$_3$ (SB$_2$), H (SB$_3$), Br (SB$_4$) and Y = Cl (SB$_5$)} [12], on mild steel in 1 M HCl solution (Scheme 1). In the begging, the inhibitive behavior of the compounds was examined using electrochemical methods including potentiodynamic polarization and EIS techniques in a stagnant condition. Then, the RDE was employed to investigate the effect of hydrodynamic flow on inhibitive performance of these azomethine derivatives. Finally, corrosion attack morphologies at various environmental conditions were used to qualitatively validate the results acquired by electrochemical techniques.

2. Experimental methods

2.1. Materials

The working electrode was selected from a mild steel rod with a chemical composition (in wt%) as follows: 0.076% C, 0.012% P, 0.026% Si, 0.192% Mn 0.050% Cr, 0.135% Cu, 0.023% Al, 0.050% Ni and Fe as balance. The surface area of the working electrode was 0.2 cm^2, connected through a copper wire, isolated with a thin polystyrene film. It was abraded with emery papers (800 and 1200 grade) and finally washed with acetone and distilled water before use. The electrolyte solution, 1 M HCl, was prepared from analytical grade 37% HCl (Merck) and double distilled water. The measurements were carried out in 1 M HCl in the absence and presence of azomethine compounds SB$_1$–SB$_5$ in the concentration range 5×10^{-6} to 7.5×10^{-5} M. The influence of hydrodynamic flow on corrosion behavior of mild steel in the inhibited and uninhibited solutions was examined using RDE at rotation speeds of 500, 1000, 1500 and 2000 rpm.

2.2. Electrochemical experiment

The electrochemical measurements were carried out at 25 °C using a PGZ 301 voltlab 40 and Voltamaster 4 software. All the electrochemical studies were carried out in a conventional three electrode set up, open to atmosphere. The counter electrode was a platinum sheet (2 cm^2 of area) and saturated calomel electrode (SCE) was used as the reference. The working electrode was first immersed into the test solution for 30 min to establish a steady state open circuit potential (OCP), then the polarization curves in the range of −800 to −250 mV was obtained using a 0.5 mV/s scan rate. The corrosion rates were obtained from the polarization curves by linear extrapolation of the anodic and cathodic arms of the Tafel plots as well as the corrosion potential (E_{corr}). Electrochemical impedance (EIS) measurements were performed at open circuit potential (OCP) with 100 kHz to 10 mHz frequency range, with a 10 mV signal amplitude perturbation then Nyquist plots were drawn from these experiments.

2.3. Corrosion attack morphology investigation

An Optical microscopy (AXIOVERT 40 MAT Microscope) was employed to investigate the corrosion attack morphology in the absence and presence of the inhibitor. The specimen surface was polished. Subsequently, the sample was immersed in 1 M HCl solution in the presence and absence of 7.5×10^{-5} M of the azomethine inhibitors for 4 h at room temperature in static and hydrodynamic conditions. After sample eliciting from solution, it was washed and cleaned by ethanol and dried with air.

3. Results and discussion

3.1. Stagnant condition

3.1.1. Effect of temperature

The temperature can modify the interaction between the steel electrode in acidic medium in the absence and presence of the inhibitors [31]. In order to study the effect of temperature on the inhibition efficiencies of the azomethine compounds SB$_1$–SB$_5$, polarization experiments were conducted in the range of 25–55 °C, in the absence and presence of 5×10^{-6} to 7.5×10^{-5} M of inhibitors (Fig. 1). The values of corrosion potential (E_{corr}), cathodic Tafel slope (bc), anodic Tafel slope (ba), corrosion current density (i_{corr}), the inhibition efficiency IE_P (%) and surface coverage (θ) are given in Table 1 (SB$_1$ taking an example). The inhibition efficiency IE_P (%) and surface coverage (θ) have been calculated according to Eqs. (1) and (2) respectively:

$$IE_P(\%) = \left(\frac{i_{corr} - i_{corr(inh)}}{i_{corr}} \right) \times 100 \tag{1}$$

$$\theta = \frac{i_{corr} - i_{corr(inh)}}{i_{corr}} \tag{2}$$

where i_{corr} and $i_{corr(inh)}$ are uninhibited and inhibited current densities, respectively.

The corrosion current density decreases with increasing inhibitor concentrations because the increasing of the amounts of the inhibitor adsorption on steel surface. Also, the corrosion current density (i_{corr}) increases with increasing temperature both in uninhibited and inhibited solutions (Table 1). Also, we noted that by adding the SB$_1$–SB$_5$ inhibitor, both the anodic and cathodic reactions were inhibited by increasing or temperature, which caused the corrosion potentials to shift to more negative values than blank solution. The negative shift can be explained by increasing the amount of adsorb inhibitors on the active sites, which diminish the hydrogen evolution reaction [32,33].

In anodic domain, the addition of SB$_1$–SB$_5$ leads to a decrease in the current densities in large potential domain. It is also observed also that the inhibitors start to desorbs at potentials higher than −300 mV and the rate of desorption of SB$_1$–SB$_5$ is higher than the adsorption [33,34]. Potentiodynamic polarization curves showed that the SB$_1$–SB$_5$ compounds inhibit both anodic and cathodic reactions by increasing temperature which indicates it is a mixed type inhibitors. It is seen that the corrosion inhibition efficiency is increased with increasing the concentration of the inhibitors (SB$_1$–SB$_5$) and decreased slowly with increasing temperature (Table 1 and Fig. 2). The decrease in inhibition efficiency may be due to etching and desorption of the inhibitor molecules from the mild steel surface. By increasing temperature, the number of active sites on the mild steel surface and the attack by corrosive medium are expected to increase [35].

The inhibiting performance of the studied azomethine compounds follows the order: SB$_1$ > SB$_2$ > SB$_3$ > SB$_4$ > SB$_5$ depends on the substituents on the azomethine compounds. Electron with