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ORIGINAL ARTICLE

# Effect of Tryptophan on the corrosion behavior of low alloy steel in sulfamic acid

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**Abstract** Sulfamic acid is widely used in various industrial acid cleaning applications. In the present work, the inhibition effect of Tryptophan (Tryp) on the corrosion of low alloy steel in sulfamic acid solutions at four different temperatures was studied. The investigations involved electrochemical methods (electrochemical impedance spectroscopy; EIS and the new technique electrochemical frequency modulation; EFM) as well as gravimetric measurements. The inhibition efficiency and the apparent activation energy have been calculated in the presence and in the absence of Tryp. It is most probable that the inhibition property of Tryp was due to the electrostatic adsorption of the protonated form of Tryp on the steel surface. Adsorption of the inhibitor molecule, onto the steel surface followed the Temkin adsorption isotherm. The thermodynamic parameters of adsorption were determined and discussed. All of the obtained data from the three techniques were in close agreement, which confirmed that EFM technique can be used efficiently for monitoring the corrosion inhibition under the studied conditions.



## 1. Introduction

The scaling or deposition on the boiler and heat exchange tubes is a phenomenon of common occurring. Eventually, removal of scales from the boiler tubes becomes essential if damage to the boiler is to be prevented. The common way of removing scales is to chemically clean the boiler. The important step in the chemical cleaning process involves the use of acid to dissolve the scales. If proper cleaning or descaling was not carried out then it would greatly affect the efficiency of the plant. Therefore, industrial acid cleaning is a very important procedure applied chiefly to remove scales and other unwanted deposits from steam generating equipment and from

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chemical and petrochemical reaction vessels (Majnouni and Jaffer, 2003; Natarajan and Sivan, 2003).

Several acid solutions will effectively remove waterside deposits. Hydrochloric, sulfuric, sulfamic and citric acids are employed for such purpose (Sathiyanarayanan et al., 2006).

Although, sulfamic acid is widely used in many diversified industrial acid cleaning applications, for unknown reasons researchers have not been interested in studying the corrosion characteristics of different metal materials in sulfamic acid media. Sulfamic acid is a crystalline solid, and is highly stable. In addition to its strength as an effective solvent for iron oxides and variety of water-formed scales it has also many other advantages such as that it is suitable for use with alloy steels and austenitic stainless steels. The usual concentration of sulfamic acid is 5–10 wt.% by weight at a temperature range of 55–65 °C (Majnouni and Jaffer, 2003; McCoy Jemes, 1984; Morad, 2008).

Because of the general aggressivity of acid solutions, corrosion inhibitors are commonly used to reduce corrosive attack on metallic materials (Ashassi-Sorkhabi et al., 2005; Abdel-Rehim et al., 2006). The uses of corrosion inhibitors in specific applications such as the acid cleaning of steam generator components have been reviewed briefly (Bhrara et al., 2008).

Amino acids are from a class of organic compounds that are completely soluble in aqueous media, relatively cheap, easy to produce with high purity; nontoxic and considered as environmentally friendly compounds. These properties enhance their use as corrosion inhibitors for iron, steel and stainless steel (Oguzie et al., 2007; Ashassi-Sorkhabi et al., 2005; Kalota and Silverman, 1994; Madkour and Ghoneim, 1997; Morad et al., 2002). In the present work, Tryptophan (Tryp) is used as environmental safe corrosion inhibitor.

The purpose of this study is to determine the inhibition efficiency of Tryp on the corrosion of low alloy steel (LAS) in sulfamic acid solutions and to study the reliability of the EFM technique for monitoring the corrosion inhibition under the studied conditions.

## 2. Experimental

Low alloy steel (ASTM A213 grade T12) strips composed of 0.35 wt.% Si, 0.64 wt.% Mn, 2.30 wt.% Cr, 0.86 wt.% Mo and the remaining 95.85 wt.% Fe were used. Generally, low alloy steels are widely employed for manufacturing the steam generating sections (Dobrzanski, 2004; Ghanem et al., 1996).

All solutions were freshly prepared from analytical grade chemical reagents using ultrapure water. The experiments were conducted in stagnant aerated solutions at different temperatures 25, 40, 50 and 60 °C ± 1 °C.

Measurements of weight changes were performed on rectangular coupons of size 1.5 cm × 1 cm × 0.2 cm with total exposed area of (4 $cm^2$). The weight loss was determined by weighing the cleaned samples before and after 24 h immersion in tested solutions at different temperatures.

The electrochemical experiments were carried out using a three-electrode glass cell assembly of 150 $cm^3$ volume capacity. The cell consists of a low alloy steel electrode embedded in epoxy resin with an exposed area of (1 $cm^2$) as working electrode, a saturated calomel electrode as reference electrode, and a platinum foil (1 $cm^2$) as counter electrode. The working electrodes were mechanically abraded with different grades (240, 400, 600 and 1200) of abrasive papers, degreased with acetone in an ultrasonic bath, then washed with ultrapure water and finally dried before use.

The electrochemical impedance spectroscopy (EIS) measurements were carried out using AC signals of amplitude 5 mV peak to peak at the open circuit potential in the frequency range between 15 kHz and 0.3 Hz.

The electrochemical frequency modulation (EFM) is a new technique that provides a new tool for electrochemical corrosion monitoring. The great strength of the EFM is the causality factor, which serves as an internal check on the validity of the EFM measurement. The theory and features of EFM technique was reported previously (Bosch et al., 2001; Abdel-Rehim et al., 2006; Amin et al., 2009).

All electrochemical experiments were carried out using Gamry PCI300/4 Potentiostat, EIS300 software, EFM140 software and Echem Analyst 5.21 for results plotting, graphing, data fitting and calculating.

The corrosion behavior was further confirmed by optical microscope observations.

## 3. Results and discussion

### 3.1. Effect of inhibitor concentration and solution temperature

The inhibition property of Tryp on the corrosion of LAS in sulfamic acid solutions at different temperatures 25, 50, and 60 °C ± 1 was examined using the following techniques.

#### 3.1.1. Electrochemical frequency modulation studies

Fig. 1a and b represents the EFM intermodulation spectra of LAS in stagnant 0.6 M sulfamic acid devoid of and containing 0.04 M Tryp at 60 °C as an example. Similar results were collected for the other concentrations at different temperatures.

The EFM results; corrosion current density ($I_{corr}$), Tafel constants ($\beta_c$ and $\beta_a$) and the causality factors (CF2 and CF3) are given in Table 1.

The inhibition efficiency (IE%) of Tryp was calculated using the following equation:

$$\mathrm{IE\%} = \left[1 - \left(\frac{I_{corr}}{I^0_{corr}}\right)\right] \times 100 \qquad (1)$$

where $I^0_{corr}$ and $I_{corr}$ are the corrosion current densities for uninhibited and inhibited solutions, respectively.

The calculated values of the inhibition efficiency (IE%) at different concentrations of Tryp and at different temperatures (25–60 °C) are also included in Table 1. Analysis of the collected data listed in this table indicates the following:

(a) Tryp has good inhibitory property in corrosion of LAS in 0.6 M sulfamic acid solution. The presence of different concentrations of Tryp reduces the corrosion current density ($I_{corr}$) values and this suppression in $I_{corr}$ increases as the inhibitor concentration increases, indicating that Tryp inhibits the corrosion of LAS in sulfamic acid solution, through adsorption on steel surface.

(b) The value of $I_{corr}$ was directly proportional to temperature as a result of partial de-sorption of inhibitor species from the metal surface.

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