The Inhibition Effect of Gum Arabic on the Corrosion of Carbon Steel in HCl Medium

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Abstract—The inhibition effect of exudate gum from Acacia trees (Gum Acacia, GA) on the corrosion of carbon steel API 5L X60 in acidic media (1 M HCl) was studied by weight loss, electrochemical polarization methods; also, surface morphology. The results of weight loss and electrochemical polarization methods indicated that the inhibitor efficiency (I%) increased with increasing inhibitor concentration. The results show that GA is a good inhibitor in 1 M HCl. The maximum percentage inhibition efficiency was found to be 92% at 4 g L⁻¹. The adsorption of GA on pipeline API 5L X60 steel surface obeys the Langmuir adsorption isotherm, and involves physical adsorption. Polarization curves reveal that GA acts as a mixed-type inhibitor in sulfuric acid.

Keywords: Gum Arabic; corrosion; steel; inhibition efficiency; inhibitor

I. INTRODUCTION

Carbon steel is the most common form of steel because of its relatively low cost and material properties that are acceptable for many applications particularly in food, petroleum, chemical and electrochemical industries, and power production. The major problem of mild steel in many industries is its dissolution in acidic medium where acids are widely used for applications such as acid pickling, acid cleaning, acid descaling, and oil well acidizing.

In order to protect Carbon steel from corrosion, corrosion inhibitors are widely used in industry to control metal dissolution and reduce the corrosion rate in contact with aggressive acid solution. Most acid inhibitors are organic compounds containing nitrogen, sulphur and/or oxygen in their molecule [1].

The inhibition action is due to the formation of protection film on the metal surface blocking the metal from the corrosive agents present in solution. A great number of scientific studies have been dedicated to the corrosion of mild steel and the use of organic compounds as corrosion inhibitors in acidic media [2]. Because most of these synthetic organic inhibitors are expensive and toxic to the environment, investigation and evaluation of naturally occurring substances (organic inhibitors) has continued to receive attention due to the presence of hetero atoms like nitrogen, sulfur and oxygen in their structure. Many researchers examined various naturally occurring substances as corrosion inhibitors for different metals in various environments, and reported their metals corrosion inhibitive effectiveness in aggressive solutions [3].

Gum Acacia (GA) is of particular interest because of their safe use, high solubility in water and high molecular size. GA is used primarily in the food industry as a stabilizer, and as a bio-gooey simulacrum to paint on the surface to test its ease to be removed from our anti-fouling coating [4]. The first ever reports on corrosion inhibition of metals involving Gum Arabic was reported by Umoren et al. [5,6], but the maximum inhibition efficiency (%) was 21.9–43.7 at 30°C, with 0.5 g L⁻¹ of Gum Arabic as the maximum concentration of inhibitor. We will prove that the Gum Arabic is a good inhibitor in acidic medium with inhibitor concentrations higher than 0.5 g L⁻¹. In the present work, the inhibition effect of GA on API 5L X60 pipeline steel in 1 M HCl solution is studied for the first time by weight loss and potentiodynamic polarization curves.

II. Experimental

A. Material preparation

API 5L X60 pipeline steel was used as a test material with the following weight percentage chemical composition: C 0.052, Mn 1.5, Si 0.15, P 0.007, S 0.0027, Cr 0.07, Ni 0.19, Nb 0.067, Ti 0.022. The specimens were cut from petroleum pipeline as cylinders. The surface of these specimens was prepared by wet grinding with silicon carbide abrasive papers (grade 320–500–600–800), rinsed with distilled water and degreased with acetone. The cylindrical specimens with diameter 1.4 cm were used to carry out electrochemical experiments.

B. Samples preparation

Dried Gum Arabic powder, exuded by Acacia Senegal trees, was selected for the present study. GA displayed a low molar mass (3.4 x 10⁵ g mol⁻¹), protein-poor component (population 1) and a high molar mass (1.9 x 10⁶ g mol⁻¹), protein-rich component (population 2) [7]. In earlier studies, population 1, the major component in GA, is referred to as arabinogalactan (AG) [8, 9].

“Fig.1” shows the molecular structure of arabinogalactan (AG)

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was prepared by dilution of 36% HCl with distilled water.

D. Weight loss measurements

In the weight loss experiments, the pre-cleaned carbon steel coupons were immersed in test bath containing test solution (HCL 1M; HCL 1M + GA 2 g/L). The weight loss was determined by retrieving the coupons for several days, washed with distilled water cleaned with bristle brush, rinsed with acetone, dried and reweighed. The weight loss was taken to be the difference between the weight at a given time and the original weight of the coupons. The measurements were carried out for both the inhibited and uninhibited solutions (blank).

The corrosion rate was computed using the expression:

\[
\text{Corrosion rate (CR)} = \frac{m_1 - m_2}{At}
\]

Where, \(m_1\) and \(m_2\) are the weight losses (mg) before and after immersion in the test solutions, respectively, \(A\) is the surface area of the specimens (cm\(^2\)) and \(t\) is the exposure time (Day).

The inhibition efficiency (I\%) of GA was evaluated using the following equation:

\[
\eta = \frac{C_{\text{blank}} - C_{\text{inh}}}{C_{\text{blank}}} \times 100
\]

E. Electrochemical techniques

Electrochemical experiments were performed using a Radiometer PGZ301 potentiostat with Volta Master 4 software, in a conventional three-electrode cell with a reference electrode. In order to minimize ohmic contribution, the Luggin capillary was kept close to working electrode (WE). The system was connected to a computer. A custom-made sample holder was used. Before measurement, the electrode was immersed in test solution at open circuit potential (OCP) for 1 h at 25\(^\circ\)C to be sufficient to attain a stable state. Electrochemical impedance spectroscopy (EIS) was carried out at OCP in the frequency range of 20 kHz to 50 MHz using a 10 mV peak-to-peak voltage excitation. Inhibition efficiency (\(\eta\)) is calculated on the basis of the equation:

\[
\eta_{\text{EIS}}^\% = \frac{R_{\text{E}} - R_{\text{E}}^*}{R_{\text{E}}} \times 100
\]

(1)

Where \(R_{\text{E}}\) and \(R_{\text{E}}^*\) are charge transfer resistances values in the presence and absence of GA, respectively. The potential of potentiodynamic polarization curves was started from a potential of -700 to -300 mV vs. SCE at a sweep rate of 0.3 mV. A sweep rate reported to guarantee obtaining steady-state current-potential curves [10].

Corrosion current density \(i_{\text{corr}}\) (\(\mu\text{Acm}^2\)) was calculated from Stern–Geary equation [11]:

\[
i_{\text{corr}} = \frac{I_{\text{d}} - I_{\text{c}}^*}{23(\eta_{\text{c}} + \eta_{\text{a}}) \times F_p}
\]

(3)

Where \(I_{\text{d}}\) and \(I_{\text{c}}^*\) are the cathodic and anodic Tafel slopes respectively and \((R_p)\) is the polarization resistance (\(\Omega\text{cm}\)). Because of the presence of a degree of non-linearity in the Tafel slope part of the obtained polarization curves, the Tafel constants were calculated as a slope of the points after \(E_{\text{corr}}\) by ±50 mV.

The values of inhibition efficiency (\(p_{\text{OL}}\)) were calculated using the following equation:

\[
p_{\text{OL}}\%^{\text{corr}} = \frac{i_{\text{corr}^\text{inh}} - i_{\text{corr}}} {i_{\text{corr}}} \times 100
\]

(4)

Where \(i_{\text{corr}^\text{inh}}\) and \(i_{\text{corr}}\) represent corrosion current density values without and with inhibitor, respectively. The surface coverage (\(\theta\)) is defined by \(p_{\text{OL}}\%^{\text{corr}} / 100\).

III. Results and discussion

A. Potentiodynamic polarization curves
The polarization behaviour of API 5L X60 pipeline steel in 1 M HCl in the absence and presence of different concentrations of GA at 35° C is shown in "Fig. 2."  

With increasing inhibitor concentration, the anodic and cathodic curves were observed to shift to lower current densities i.e., causes a decrease in the corrosion rate (i_corr). This shift anodic and cathodic curves is a consequence of both cathodic and anodic reactions of API 5L X60 In the presence of GA, the slight change of both Ecorr and Eeq in acid solution indicates that the corrosion mechanism of steel does not change [12] Table 1.

![Fig. 2. Potentiodynamic polarization curves for API 5L X60 pipeline steel in 1 M HCl without and with various concentrations of GA at 45 °C, (a) Logarithmic, (b) Linear curve curve.](image)

### Acknowledgment

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### IV. Conclusion

The following points can be concluded from this research:

1. The results from weight loss and polarization methods proposed the potential applicability of Gum Acacia as a green corrosion inhibitor for mild steel in acidic media.

2. GA acts as a good inhibitor for the corrosion of API 5L X60 pipeline steel in 1 M HCl. Inhibition efficiency increases with the inhibitor concentration, and the maximum value is 92% at 4 g L⁻¹.

3. Polarization measurements showed that the inhibitor (GA) is a mixed type inhibitor (anodic and cathodic).

4. The standard adsorption free energy (ΔG_ads) indicates that the adsorption of GA involves physical adsorption.

5. Langmuir adsorption isotherm was found to give the best description of the adsorption behavior of the studied inhibitor.

### Table I

<table>
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<th>Milieu</th>
<th>C (g/L)</th>
<th>i_corr (µA/cm²)</th>
<th>b_a (mV/dec)</th>
<th>b_bc (mV/dec)</th>
<th>R_p (Ω cm²)</th>
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Reference


