Investigation of Ascorbic Acid as Environment-Friendly Corrosion Inhibitor of Low Carbon Steel in Marine Environment

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Abstract. The inhibition effect of ascorbic acid against the corrosion of low carbon steel in the marine environment which is represented by NaCl 3.5% solution was studied by weight loss method. The investigations were conducted at the various concentrations of ascorbic acid and immersion time. The effect of ascorbic acid concentration and immersion time on the corrosion rate and inhibition efficiency were measured. The corrosion rate was calculated by the weight loss of the sample at initial and after immersion in the corrosive medium. The results showed that the ascorbic acid exhibit good corrosion inhibitor for low carbon steel in NaCl 3.5% solution. The rate of corrosion decreased with the increase of ascorbic acid concentration and immersion time. The efficiency inhibition of ascorbic acid on low carbon steel corrosion in NaCl 3.5% increase with the rise of concentration and immersion time, which is the maximum of 85.4% at 50 ppm and 15 days immersion time. The action of inhibition is attributed to the adsorption of the inhibitor molecules on the low carbon steel surface following Langmuir adsorption isotherm.

1. Introduction

The protection of metals due to corrosion process has received much attention generally due to a massive damage to natural resources and finances due to corrosion. Low 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 [1, 2].

Low carbon steel is known to be a very versatile ferrous alloy utilized for a wide range of applications because of its excellent combination of mechanical properties, ease of fabrication, excellent readability, and low purchase cost. However, it has low corrosion resistance.
Corrosion of metals is a significant problem that must be confronted for safety, environment, and economic considerations. It can be reduced by suitable strategies which in turn stifle, retard or completely stop the anodic or cathodic reactions or both [3]. Among the several methods of corrosion control and prevention, the use of corrosion inhibitors is prevalent. Most inhibitors are organic compounds that contain in their structures, mostly nitrogen, sulfur or oxygen atoms. However, the use of some chemical inhibitors has been limited because of some reasons, namely their synthesis is very often expensive, and they can be toxic and hazardous to the human being’s environment as well [4]. This condition has prompted the search for eco-friendly corrosion inhibitors as an alternative to replace inorganic and organic inhibitors to foster sustainable greenness to the environment.

One of the organic chemical compound that can be used as the corrosion inhibitor is ascorbic acid which is nontoxic and low-cost materials. Several authors have been investigated regarding this organic chemical compound as corrosion inhibitors. The inhibition effect of ascorbic acid (AA) on mild steel corrosion in 1 M HCl and 0.5 M H$_2$SO$_4$ showed that ascorbic acid could become corrosion inhibitor by adsorption mechanism on the mild steel surface [5].

With the presence of ascorbic acid (≥0.05 M) in corroding media (brackish water) influences the formation of the common corrosion species like $\beta$, $\gamma$-FeOOH, and ferrihydrite, and retards the rate of rust formation [6].

The ascorbic acid showed good corrosion inhibition effect of mild steel with 0.3% NaCl solution at 30°C. The corrosion inhibition mechanism was considered to be due to chemical adsorption since ascorbic acid on the steel obeyed the Langmuir adsorption isotherm [7].

The inhibition efficiency of L-ascorbic acid (AA) on mild steel corrosion in pH = 2–6 solutions were investigated using electrochemical and weight loss techniques. The maximum efficiency is 69% which is obtained at 10$^{-3}$ mol/dm$^3$ ascorbic acid and, pH = 4 [8].

The inhibiting behavior of Vitamin C, as a type of green inhibitor, on the destructive behavior of stainless-steel (SS) X4Cr13 within an aqueous solution of hydrochloric acid (HCl) was studied at the concentration of c = (0.01, 0.1 and 1.0) mol/L. The results show that the inhibition efficiency increases with the increase of the inhibitor concentration [9].

In this research, the effect of ascorbic acid concentration and immersion time on the corrosion rate of mild steel in sodium chloride solution were studied. It was also investigated the efficiency inhibition and the adsorption mechanism of the layer formed.

2. Experiment

2.1 Sample preparation

Low carbon steel of composition (wt%) 0.084% carbon, 0.197% manganese, 0.022% silicon, 0.023% phosphorous, 0.022% sulfur, 0.028% chromium, 0.12% molybdenum, 0.015% nickel and the remaining iron was used for gravimetric measurements. Specimens were mechanically cut into 5 x 3 x 0.2 cm. Before use, the specimens were mechanically polished with fine grade emery paper, degreased and dried in acetone and stored in a desiccator.

2.2 Gravimetric measurement

The gravimetric method (weight loss) could be the most widely used methods of inhibition assessment. The simplicity and reliability of the measurement offered by the weight loss method are such that the technique forms the baseline method of measurement in many corrosion monitoring investigations. The gravimetric experiments were carried out according to the ASTM practice standard G-31 [10]. Before carrying out the experiments, the pre-cleaned specimens were weighed on an analytical balance using 0.1 mg precision. The weighed specimens were immersed in 1000 ml of NaCl 3.5% with the absence and presence of different concentration of ascorbic acid and at various immersion time. At the end of the experiment, the specimens were removed from the corrosive medium and rinsed with water, cleaned with acetone, dried in hot air and finally weighed. Three
identical specimen's weight loss values were used to calculate the corrosion rate and inhibition efficiency of the inhibitor. The rate of corrosion was calculated using the formula given in Eq. 1.

\[ Cr = \frac{534 \times W}{A \times T \times D} \]

Where \( Cr \) is corrosion rate in mpy, \( W \) is mass loss in mg, \( A \) is the area of immersed samples in \( \text{in}^2 \), \( T \) is time of exposure in hour, \( D \) is density of low carbon steel specimen in \( \text{g/cm}^3 \).

Inhibition efficiency and surface coverage (\( \theta \)) were also determined using Eqs. 2 and 3.

\[ E = \frac{Cr_{\text{uninhibited}} - Cr_{\text{inhibited}}}{Cr_{\text{uninhibited}}} \times 100\% \]  

(2)

Where \( E \) is inhibition efficiency (%), \( Cr_{\text{uninhibited}} \) is corrosion rate without using inhibitor and \( Cr_{\text{inhibited}} \) is corrosion rate with using inhibitor.

\[ \theta = \frac{Cr_{\text{uninhibited}} - Cr_{\text{inhibited}}}{Cr_{\text{uninhibited}}} \]  

(3)

Where \( \theta \) is surface coverage, \( Cr_{\text{uninhibited}} \) is corrosion rate with the absence of inhibitor and \( Cr_{\text{inhibited}} \) is corrosion rate with the presence inhibitor.

3. Results and discussion

The weight loss method has broad practical application for corrosion investigation. The rate of corrosion can be defined as the ratio of the loss in weight of the sample \( W \) for its area \( A \) and the time length over which the test was undertaken as given in Eq.1. The advantage of this method is its relative simplicity and availability. Also, the method uses a direct parameter for the quantitative evaluation of corrosion, i.e., the loss in mass of the metal. The rate of low carbon steel corrosion in aqueous NaCl 3.5% in the absence and presence of ascorbic acid inhibitor is presented in Figure 1. It can be seen that immersion time influences the corrosion rate of low carbon steel in NaCl solution. The Corrosion rate increase with the increase of immersion time. The higher corrosion rate at the lapse time occurred due to the increase of contact between low carbon steel materials with NaCl as the corrosive medium which give intensive dissolution of the materials.

![Figure 1](image_url)

**Figure 1.** Effect of immersion time on the corrosion rate of mild steel in NaCl 3.5%

The influence of ascorbic acid concentration on the corrosion rate of low carbon steel in NaCl 3.5% solution is shown in Figure 2. It can be seen that in the presence of ascorbic acid, the rate of corrosion decreases with the decreasing of ascorbic acid concentration. This phenomenon occurred due to the intensive absorption of ascorbic acid on the surface of low carbon steel. Higher concentration of ascorbic acid gives a lower corrosion rate. The corrosion rate using ascorbic acid concentration in the
The absence of ascorbic acid in 15 days is 5.1917 mpy while in the presence of 50 ppm ascorbic acid the corrosion rate decreases to 0.7567 mpy.

**Figure 2.** Effect of ascorbic acid concentration on corrosion rate of low carbon steel in NaCl 3.5%

The inhibition efficiency of ascorbic acid for low carbon steel in NaCl 3.5% solution is presented in Fig. 3. The graph reveals that the inhibition efficiency of ascorbic acid increase with the increase of concentration and immersion time. The highest value of inhibition efficiency is reached about 85.4% at the concentration of 50 ppm and immersion time 15 days. This phenomenon can be attributed to the increase of the surface covered, and that due to the absorption of ascorbic acid on the surface of the metal, as the inhibitor concentration increases. The result is in good agreement with other's [11, 12].

**Figure 3.** Efficient inhibition of ascorbic acid on low carbon steel in sodium chloride 3.5%

The corrosion inhibition mechanism may be explained by adsorption behavior. The degree of surface coverage for different inhibitor concentrations was evaluated by weight loss data. The Langmuir postulate adsorption of ascorbic acid on the surface of low carbon steel is presented in Fig. 4. In can be seen that the graph shows that in the initial the layer does not obey the Langmuir
postulate, but in the lapse time the layer follows the Langmuir formula which means that the layer formed in the surface of low carbon steel is the single layer.

![Langmuir plot of adsorption](image)

**Figure 4.** Langmuir plot of adsorption

4. Conclusion
The corrosion rate decreases with the increasing of ascorbic acid concentration. The inhibition efficiency of the ascorbic acid on corrosion inhibition increases with an increase in the concentration of ascorbic acid — the highest efficiency obtained at 50 ppm concentration which is 84.5%. The adsorption mechanisms of inhibition follow Langmuir's adsorption isotherm, which means that the layer formed in the single layer. The results of the studies confirmed that the ascorbic acid has prospective inhibitor to prevent the corrosion of low carbon steel in the marine environment.

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