Green inhibitor of corrosion of aluminium alloy EN AW-2011 in acidic environment

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Abstract. This work presents the results of corrosion inhibition of aluminium alloy EN AW-2011 in 1M HCl environment by Rosmarinus officinalis, using gravimetric and gasometric techniques. The inhibition efficiency increases with increasing the concentration. The investigation showed optimal inhibition efficiency of about 62%. The results confirmed that the adsorption of Rosmarinus officinalis reduces the corrosion rate of this alloy in the acidic medium.

1. Introduction

The first section in your paper Aluminium alloy EN AW-2011 has a wide range of applications in the car industry, in some chemical processing industries and the aircraft industry. It is especially suitable for parts and structures requiring high strength and is often used to make parts that require good strength at temperatures of up to 150°C such as nuts, bolts, screws, studs, car parts and more [1]. Aluminium and its alloys are very reactive metals, predisposed to corrosion. Due to their wide applications, they frequently come in contact with acids, such as hydrochloric acid, during pickling, de-scaling or electrochemical etching of aluminium. Therefore it is very important to add inorganic and organic corrosion inhibitors in order to prevent the dissolution of metal. There are a number of methods for preventing corrosion and one of them is using inorganic corrosion inhibitors.

Inorganic corrosion inhibitors are effective but have a negative influence on the environment. Plant extracts and oils, which consist of organic substances (essential oils, saponnins, amino and organic acids) with heteroatoms oxygen, nitrogen and sulphur in functional groups, are known to evice corrosion inhibitor action [2, 3]. Green inhibitors are eco-friendly, non-toxic, highly efficient, renewable and cheap [4].

A review of the literature written on the matter revealed that plant materials such as Aloe plant extract [5], Sansaviera infasciata extract [6], aqueous [7] and ethanol extract of Rosemary [8], extract of Mentha pulegium [3], Terminalia ivorensis extract [9], acetone extract of red onion skin [10], gum exudates from pachylobus edulis in the presence of halide ions, [11], to mention but a few, have all been used to inhibit the corrosion of aluminium in acid media in recent years. In Rosmarinus officinalis, the presence of phenolic diterpenoids with antioxidant activity such as rosmarin acid, rosmanol, rosmadial, epirosmanol and carnosol. These organic compounds are generally considered to be the main corrosion inhibitors present in Rosemarinus [8].
The present work is focused on the corrosion inhibition performance of essential oil of Rosmarinus officinalis on aluminium alloy EN AW-2011 in 1M HCl solution. The study was conducted by using gravimetric and gasometric techniques.

2. Experimental
2.1. Gravimetric technique
The experiments were performed with cylindrical samples of aluminium alloy EN AW-2011 with an exposed area of 8.54 cm$^2$. Before immersion in the solution, the experimental samples were mechanically cleaned, washed in detergent for five minutes and then rinsed with distilled water and dried. The dried samples were weighed with an analytical balance Acculab ATILON with accuracy to ± 0.0001g and then immersed in a test solution of 1 M HCl for 3 hours at room temperature. The aluminium alloy was exposed to the acid solution without the inhibitor and also to acid environment containing different concentrations of essential oil of Rosmarinus officinalis (from 0.0% to 0.05%) which served as the inhibitor. After the immersion period, the samples were withdrawn from the solution, washed with distilled water, dried under a stream of air and weighed. For each of the immersion period the corrosion rate (CR) of alloy were determined using the following equation:

$$CR = \frac{(m_1-m_2)}{S \cdot t} \quad (1),$$

where $m_1$ is the weight of the sample, g; $m_2$ is the weight of the sample after the corrosion test, g; $S$ is the area of the sample, m$^2$ and $t$ is the test time, h.

The surface coverage ($\theta$) and the inhibition efficiency ($\eta \%$) were also calculated from the following equation:

$$\theta = \frac{CR_{\text{blank}}-CR_{\text{inh}}}{CR_{\text{blank}}} \quad (2)$$

$$\eta \% = \theta \cdot 100 \quad (3),$$

where $CR_{\text{blank}}$ and $CR_{\text{inh}}$ are the corrosion rate values in the absence and presence of the inhibitor, respectively.

2.2. Gasometric technique
The progress of the corrosion reaction was defined through volumetric measurement of the evolved hydrogen gas [3]. The materials used for constructing the working electrode were the same as those used for the gravimetric technique. From the volume of the evolved hydrogen gas, the corrosion rate was calculated using the following equation:

$$\eta \% = \frac{V_{\text{blank}}-V_{\text{inh}}}{V_{\text{blank}}},$$

where $V_{\text{blank}}$ and $V_{\text{inh}}$ are the volumes of hydrogen gas that evolved in the absence and presence of the inhibitor, respectively.

3. Results and discussion
3.1 Gravimetric technique
The obtained corrosion rate data of EN AW-2011 are presented in figure 1. The gravimetric results show that the inhibition efficiency increased and the corrosion rate decreased with the increase in the concentration of the inhibitor, indicating that the Rosmarinus officinalis oil acted as a good inhibitor.
The inhibition efficiencies of the different concentrations of Rosmarinus officinalis oil as the inhibitor are shown in figure 2.

The results obtained in this work also showed that in the employed conditions the highest inhibition efficiency of 62% was obtained for 0.05% concentration of Rosmarinus officinalis oil.

The corrosion rate and inhibition efficiencies of Rosmarinus oil at different concentrations are summarised in table 1.

Table 1. Inhibition efficiencies of various concentrations of Rosmarinus oil after 3 hours of immersion in 1 M HCl.

| Concentrations of Rosmarinus officinalis, % | CR, g/m².h | Inhibition efficiencies, % |
|-------------------------------------------|------------|---------------------------|
| blank                                     | 0,011      | -                         |
| 0,01                                      | 0,008      | 27,3                      |
| 0,03                                      | 0,005      | 51                        |
| 0,05                                      | 0,004      | 62                        |

The successful inhibitory action of oil of Rosmarinus officinalis could be explained by the presence of organic compounds such as rosmadial, rosmanol, epirosmanol, carnosol and others [12-14] in it.
3.2. Gasometric technique
The volume of hydrogen evolved during the corrosion reaction of aluminum alloy immersed in 1 M HCl solution for 3 hours is measured as a function of the concentration of Rosmarinus, and the data are represented graphically in figure. 3.

![Graph showing volume of hydrogen evolved vs concentration of inhibitor](image)

**Figure 3.** Volume of hydrogen evolved during the corrosion of EN AW-2011 in the absence and presence of different concentrations of Rosmarinus officinalis oil after 3 hours of immersion in 1 M HCl.

The volume of the evolved hydrogen was observed to sensibly reduce in the presence of Rosmarinus oil and it decreased with the increase in the concentration of the inhibitor of Rosmarinus.

4. Conclusion
On the basis of this study, it can be concluded that the rate of corrosion of aluminium alloy EN AW-2011 in hydrochloric acid environment is a function of the concentration of the oil of Rosmarinus officinalis. The results obtained in this work showed that, in the conditions employed in the present study, the oil of Rosmarinus officinalis proved to be a good corrosion inhibitor for this alloy in 1 M HCl solution. The inhibition efficiency increases with increasing the concentration of Rosmarinus oil.

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