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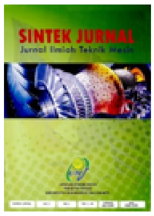

ANALYSIS OF CORROSION RATE AL 7075 USING SEAWATER AND RAINWATER MEDIA USING THE K2CRO4

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ABSTRACT

Aluminum is one of the most widely used materials today due to several advantages, including its lightweight nature, relatively high tensile strength, good formability, corrosion resistance, and non-magnetic properties, making it a preferred choice in industries such as aerospace. However, metals, including 7075 aluminum alloy commonly used in the aerospace industry, are still susceptible to corrosion in corrosive environments. One effective method to control corrosion is the use of inhibitors. An inhibitor is a chemical substance that, when added in small amounts to a corrosive environment, can effectively slow down or reduce the corrosion rate. This study investigates the corrosion rate using the potentiodynamic polarization method (Tafel plot) in seawater from Parangtritis Beach and rainwater from Yogyakarta City. The inorganic inhibitor used in this research is K_2CrO_4 with a concentration of 0.3%. The results show that the corrosion rate in seawater without inhibitors (pH 7.34) is 0.027799 mm/yr, while with inhibitors (pH 7.50), it decreases to 0.0053243 mm/yr. Similarly, the corrosion rate in rainwater without inhibitors (pH 6.66) is 0.0021987 mm/yr, while with inhibitors (pH 7.74), it reduces to 0.0017807 mm/yr. These findings demonstrate the effectiveness of K_2CrO_4 inhibitors in minimizing corrosion rates in both seawater and rainwater environments.

Keywords: Aluminum 7075; corrosion inhibitor; K_2CrO_4; potentiodynamic polarization; corrosion rate

ABSTRAK

Aluminium adalah salah satu bahan yang paling banyak digunakan saat ini karena beberapa keunggulan, termasuk sifatnya yang ringan, kekuatan tarik yang relatif tinggi, kemampuan bentuk yang baik, ketahanan terhadap korosi, dan sifat non-magnetis, sehingga menjadi pilihan utama dalam industri seperti kedirgantaraan. Namun, logam, termasuk paduan aluminium 7075 yang biasa digunakan dalam industri kedirgantaraan, masih rentan terhadap korosi di lingkungan yang korosif. Salah satu metode yang efektif untuk mengendalikan korosi adalah penggunaan inhibitor. Inhibitor adalah zat kimia yang, ketika ditambahkan dalam jumlah kecil ke lingkungan yang korosif, secara efektif dapat memperlambat atau mengurangi laju korosi. Penelitian ini menginvestigasi laju korosi dengan menggunakan metode polarisasi potensiodinamik (Tafel plot) pada air laut dari Pantai Parangtritis dan air hujan dari Kota Yogyakarta. Inhibitor anorganik yang digunakan dalam penelitian ini adalah K_2CrO_4 dengan konsentrasi 0,3%. Hasil penelitian menunjukkan bahwa laju korosi pada air laut tanpa inhibitor (pH 7.34) adalah 0.027799 mm/thn, sedangkan dengan inhibitor (pH 7.50) menurun menjadi 0.0053243 mm/thn. Demikian pula, laju korosi pada air hujan tanpa inhibitor (pH 6,66) adalah 0,0021987 mm/tahun, sedangkan dengan inhibitor (pH 7,74), laju korosi menurun menjadi 0,0017807 mm/tahun. Temuan ini menunjukkan keefektifan inhibitor K_2CrO_4 dalam meminimalisir laju korosi baik di lingkungan air laut maupun air hujan.

Kata Kunci: *Aluminium 7075; inhibitor korosi; K_2CrO_4; polarisasi potensiodinamik; laju korosi*

1. Introduction

Corrosion is defined as the degradation of metal quality due to electrochemical reactions with its environment [1-4]. In practical applications, corrosion cannot be entirely prevented but can only be controlled to extend the service life of structures or components [5]. Corrosion occurs when metals react with moist air, weak acidic solutions, or saline solutions, which can ultimately lead to material failure, such as leaks [6].

Such material degradation can have catastrophic consequences, particularly in applications requiring high precision, such as in the aerospace industry. To mitigate these risks, corrosion inhibitors are often employed to reduce the corrosion rate [7].

The 7xxx series aluminum alloys are widely used in the aerospace industry due to their optimal balance of strength, damage tolerance, and corrosion resistance [8-11]. These alloys, primarily composed of aluminum and zinc (3-7% Zn), are heat-treatable, which enhances their mechanical properties. Applications of 7xxx series aluminum in aircraft include fuselage skins, empennage (tail structures), and upper wing skins [12,13]. Among these alloys, aluminum 7075 is particularly favored due to its lightweight nature and corrosion resistance. However, even 7075 aluminum can experience corrosion, especially in aggressive environments such as saline conditions (e.g., seawater) or atmospheric conditions (e.g., humid air or rain) [14,15].

Aluminum 7075-T6, a temper designation for heat-treated aluminum 7075, is extensively utilized in aerospace, military, marine, and automotive industries [16,17]. This material is notable for its unique combination of low density, high strength, and excellent ductility, making it ideal for structural components subjected to high stress [18,19]. The alloy achieves its desirable mechanical and corrosion-resistant properties through heat treatment, which optimally distributes its elemental components, including zinc (5.1–6.1%), magnesium (2.1–2.9%), and copper (1.2–2.0%) [20,21]. Research has shown that the combined addition of zinc and magnesium provides superior strength compared to the individual addition of either element [22,23]. This enhanced strength led to the development of aluminum 7075 alloys containing Al-Zn-Mg-Cu during the early 1940s, making them suitable for various critical aerospace applications, including use in airplane toilet areas [24].

When exposed to air or water, aluminum forms a protective oxide layer on its surface. This natural oxide layer acts as a barrier, preventing further corrosion. The reaction for the formation of this protective layer can be expressed as follows:

$$Al + O_2 \rightarrow Al_2O_3 \tag{1}$$

Aluminum can also react with water, particularly with hydroxide ions (OH^-), which can influence the corrosion rate. The reaction is represented as follows:

$$Al + 3H_2O \rightarrow Al(OH)_3 + 3H^+ \tag{2}$$

Although aluminum is generally corrosion-resistant, certain alloying elements in aluminum alloy 7075, such as copper (Cu), can increase its susceptibility to corrosion [25]. This characteristic contributes to the overall corrosion tendency of aluminum alloys. Corrosion typically begins with the most reactive and easily corroded elements within the alloy.

2. Methods

Sample Preparation

The material used in this study is aluminum 7075, which was prepared by cutting the aluminum plate into specimens with dimensions of 50 × 30 × 2 mm as shown in Figure 1. To minimize surface imperfections, the specimens were smoothed using sandpaper and polished to eliminate any scratches, ensuring uniformity of the surface.

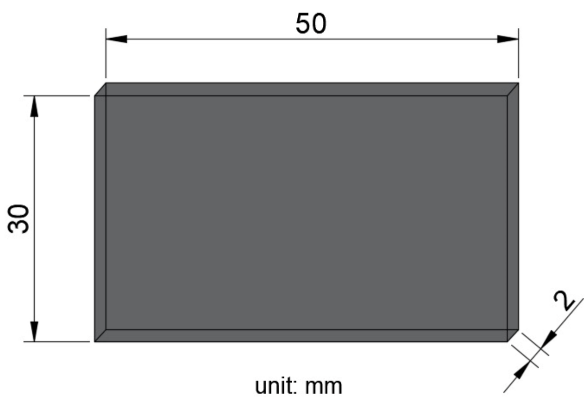

Figure 1. Test Specimen

Corrosion Inhibition

A protective layer was formed on the aluminum surface by coating it with a potassium chromate (K_2CrO_4) solution. The dichromate ions (CrO_4^{2-}) in the solution reacted with the aluminum surface to form a chromate oxide (Cr_2O_3) layer. This chromate layer inhibits the penetration of the electrolyte during the anodic reaction and suppresses the formation of hydroxide ions at the cathode, thereby reducing the overall corrosion rate.

Corrosion Testing Setup

This study aims to evaluate the corrosion rate of aluminum 7075, a material widely used in the aerospace industry. The corrosion behavior of aluminum 7075 will be assessed in seawater and rainwater environments, with potassium chromate (K_2CrO_4) as an inhibitor. The objective is to compare and quantify the corrosion rates in these conditions. The experiments will be conducted at Sebelas Maret University.

Prior to the corrosion tests, the pH of the seawater and rainwater electrolytes will be measured, and the initial weight of each aluminum sample will be recorded. The corrosion rate will be measured using the potentiodynamic polarization method, known for its superior accuracy compared to other techniques [26,27].

The potentiodynamic polarization method uses a three-electrode system, connected to a potentiostat.
The electrodes consist of:

- Working electrode: The aluminum specimen under investigation.
- Auxiliary electrode: An inert metal, such as platinum or carbon, which facilitates current flow.
- Reference electrode: A saturated calomel electrode, providing a stable reference point for potential measurements.

The schematic of the corrosion test setup is shown in Figure 2. The potential is applied incrementally, either positive or negative, over time. A negative potential leads to cathodic polarization (reduction reaction), while a positive potential leads to anodic polarization (oxidation reaction).

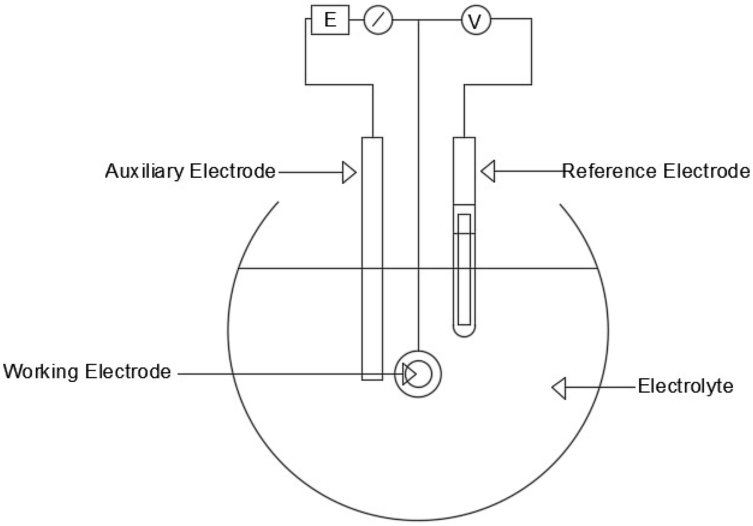

Figure 2. Scheme of Corrosion Test Electrode Cell

Corrosion Rate Calculation

The corrosion rate (CR) was calculated for each test condition using the following formula:

$$CR = (0.00327) \times \frac{(9.649\text{gr}) \times \text{current } (\mu A/\text{cm}^2)}{(0.2811768\,\text{gr}/\text{cm}^2)} \text{mm/yr} \quad (3)$$

Efficiency of Corrosion Inhibitors

The efficiency (E) of the corrosion inhibitor was evaluated by comparing the corrosion rates with and without the inhibitor. The efficiency is calculated using the following equations:

$$\Delta CR = CR_{\text{without inhibitor}} - CR_{\text{with inhibitor}} \quad (4)$$

$$E(\%) = \frac{\Delta CR}{CR_{\text{without inhibitor}}} \times 100\% \quad (5)$$

Electrochemical Reactions

During the polarization test, the anodic reaction (aluminum oxidation) and cathodic reaction (oxygen reduction) can be represented as follows:

Anodic reaction (aluminum oxidation):

$$\text{Al} \rightarrow \text{Al}^{3+} + 3\text{e}^{-1} \quad (6)$$

Cathodic reaction (oxygen reduction):

$$O_2 + 2H_2O + 4^{e-} \rightarrow 4OH^{-1} \quad (7)$$

The interaction between the anode and cathode leads to the release of aluminum ions (Al^{3+}) and the formation of hydroxide ions (OH^-), resulting in the appearance of a white crust or powder on the aluminum surface, as shown in Figure 3.

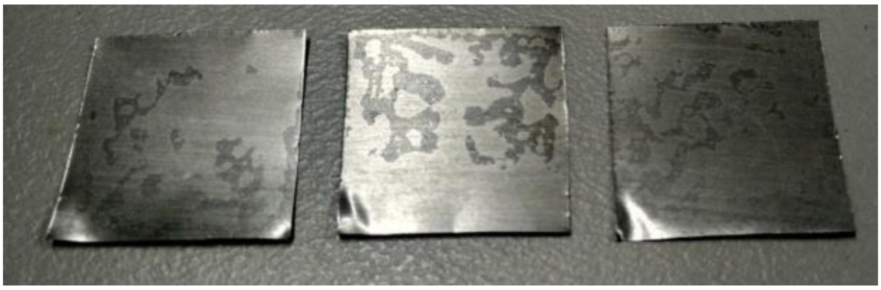

Figure 3. Corrosion on Aluminum

3. Results and Discussion

Corrosion tests were performed using the potentiodynamic polarization method in a three-electrode system, with aluminum 7075 samples exposed to seawater and rainwater, both with and without the addition of potassium chromate (K_2CrO_4) as an inhibitor. The experiments were conducted using potentiostat/galvanostat equipment at Sebelas Maret University, with each test performed four times:

- Aluminum in seawater without inhibitor
- Aluminum in seawater with inhibitor
- Aluminum in rainwater without inhibitor
- Aluminum in rainwater with inhibitor

The corrosion test results were analyzed and presented in Table 1 and Figures 4, 5, 6, and 7 to facilitate comparison and detailed analysis. The data analysis helps to identify the influence of the different variables on the corrosion rate. The results were plotted to provide a clear understanding of the corrosion behavior under the different conditions.

Corrosion Rate Calculation

The results of the calculation of corrosion rate (CR) for each test condition are:

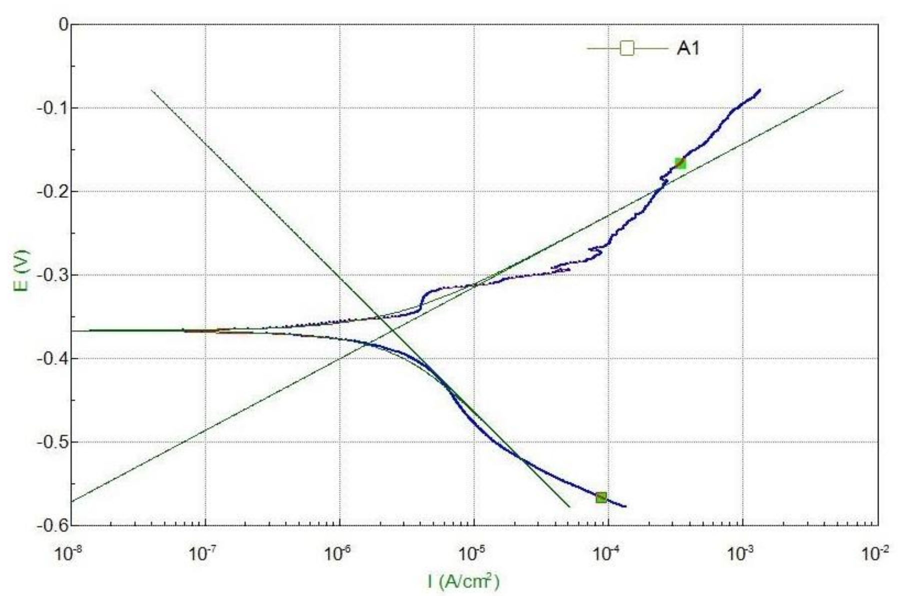

Figure 4. Potentiodynamic Corrosion Test Results of Al 7075 Seawater Without Inhibitors

Calculation:

$$CR = (0.00327) \times \frac{(9.649) \times (0.24773)}{(0.2811768)} \text{mm/yr}$$
$$= 0.027799 \text{ mm/yr}$$

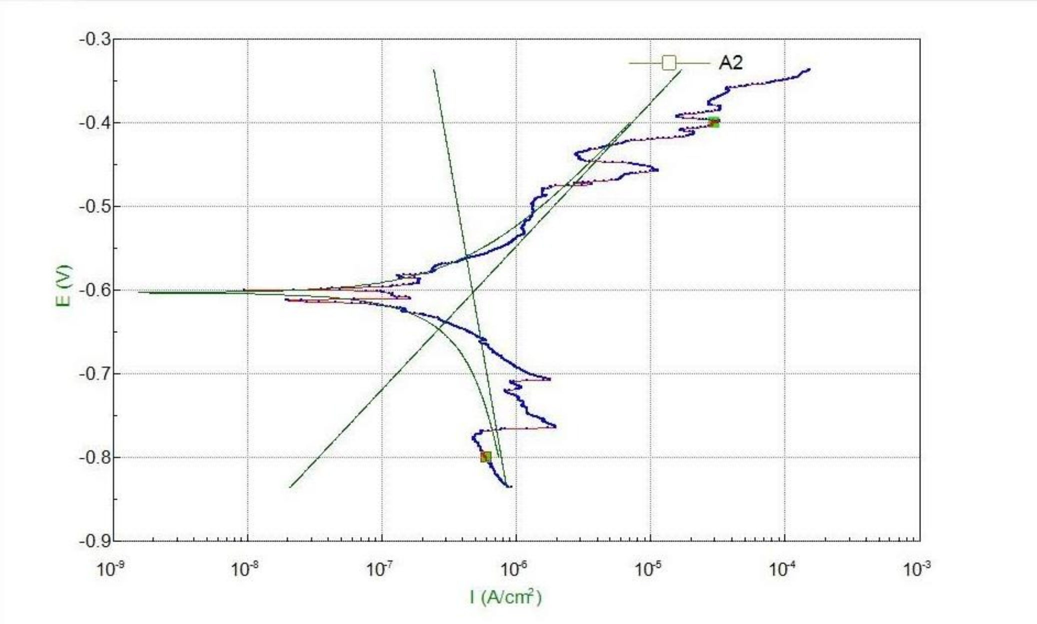

Figure 5. Potentiodynamic Corrosion Test Results of Al 7075 Seawater With Inhibitors

Calculation:

$$CR = (0.00327) \times \frac{(9.649) \times (0.047447)}{(0.2811768)} \text{mm/yr}$$
$$= 0.0053243 \text{ mm/yr}$$

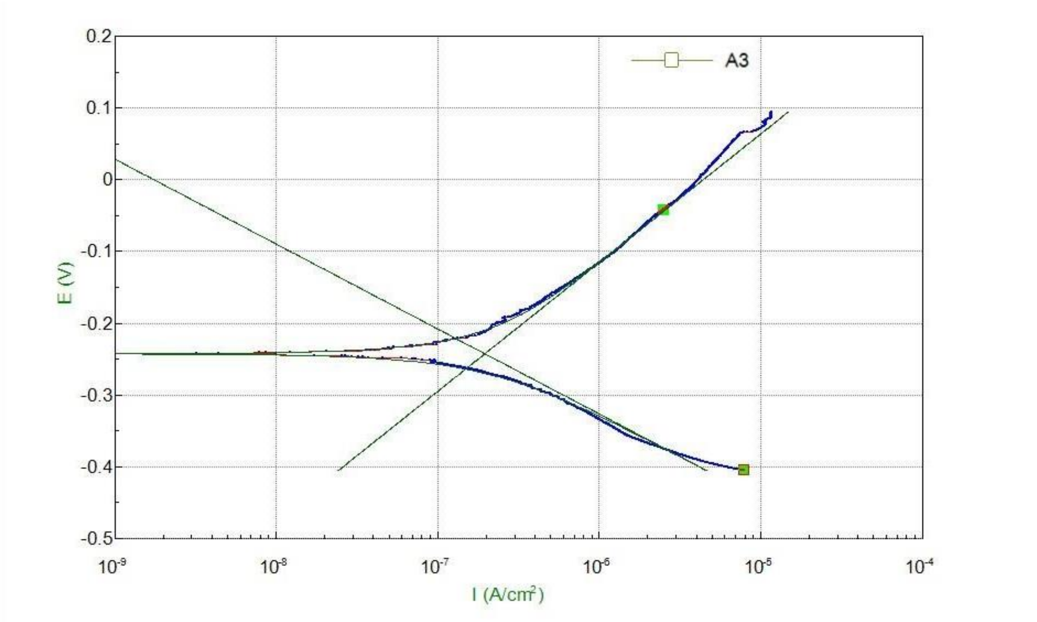

Figure 6. Potentiodynamic Corrosion Test Results of Al 7075 Rainwater Without Inhibitors

Calculation:

$$CR = (0.00327) \times \frac{(9.649) \times (0.019594)}{(0.2811768)} \text{mm/yr}$$
$$= 0.0021987 \text{ mm/yr}$$

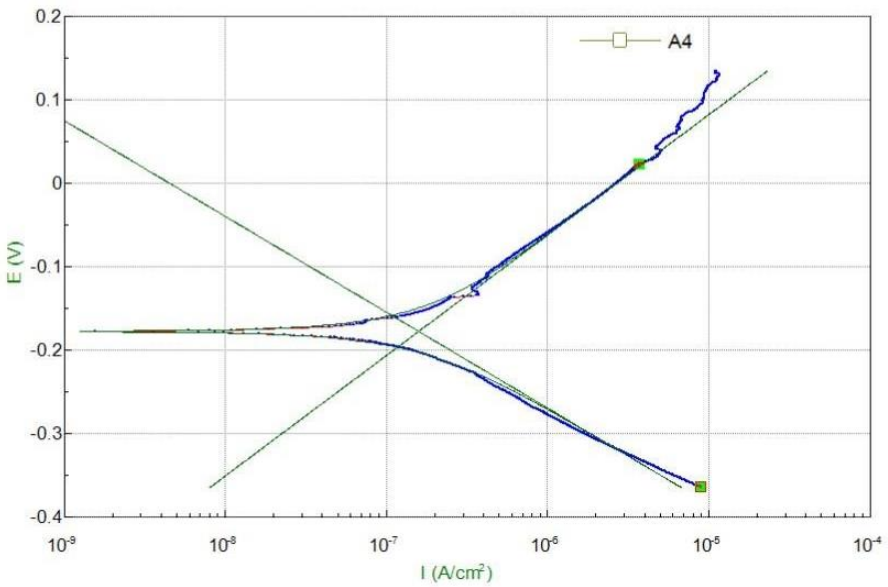

Figure 7. Potentiodynamic Corrosion Test Results of Al 7075 Rainwater With Inhibitors

Calculation:

$$CR = (0.00327) \times \frac{(9.649) \times (0.015868)}{(0.2811768)} \text{mm/yr}$$
$$= 0.0017807 \text{ mm/yr}$$

Table 1. Corrosion Rate

Corrosion Rate	Seawater	Rainwater
Without Inhibitor	0.027799 mm/yr pH 7.34	0.0021987 mm/yr pH 6.66
With Inhibitor	0.0053243 mm/yr pH 7.5	0.0017807 mm/yr pH 7.74

Data Analysis

Table 1 shows the corrosion rates of aluminum 7075 in seawater and rainwater, with and without the inhibitor. The following observations were made:

- Seawater without inhibitor (pH 7.34) resulted in a corrosion rate of 0.027799 mm/yr, whereas seawater with inhibitor (pH 7.5) showed a reduced corrosion rate of 0.0053243 mm/yr.
- In rainwater, the corrosion rate without inhibitor (pH 6.66) was 0.0021987 mm/yr, while with inhibitor (pH 7.74), the rate decreased to 0.0017807 mm/yr.

The addition of potassium chromate significantly reduced the corrosion rate in both seawater and rainwater, indicating the effective role of the inhibitor.

Role of Potassium Chromate (K_2CrO_4) Inhibitor

The potassium chromate inhibitor plays a critical role in reducing the corrosion rate by:

- Formation of Oxide Layer: Potassium chromate enhances the formation of a protective oxide layer on the aluminum surface, reducing interactions between aluminum and the corrosive environment.
- Redox Reactions: Chromate ions (CrO_4^{2-}) participate in redox reactions, reducing to chromium ions (Cr^{3+}), which further inhibit the corrosion process.
- Deposition of Protective Compounds: The inhibitor can form protective compounds or deposits on the aluminum surface, acting as a barrier against corrosive ions.
- Increasing pH Stability: Potassium chromate helps maintain a more stable pH in the solution, further reducing the corrosion rate.

Inhibitor Efficiency

The efficiency of the potassium chromate inhibitor was calculated for both seawater and rainwater, as follows:

Efficiency in Seawater:

$$\Delta CR = CR_{\text{without inhibitor}} - CR_{\text{with inhibitor}}$$
$$= (0.027799 - 0.0053243)\ \text{mm/yr}$$
$$= 0.0224747\ \text{mm/yr}$$

$$E(\%) = \frac{\Delta CR}{CR_{\text{without inhibitor}}} \times 100\%$$
$$= (0.0224747/\ 0.027799) \times 100\%$$
$$= 0.808471 \times 100\%$$
$$= 80.85\%$$

Efficiency in Rainwater:

$$\Delta CR = CR_{\text{without inhibitor}} - CR_{\text{with inhibitor}}$$
$$= (0.0021987 - 0.0017807)\ \text{mm/yr}$$
$$= 0.000418\ \text{mm/yr}$$

$$E(\%) = \frac{\Delta CR}{CR_{\text{without inhibitor}}} \times 100\%$$
$$= (0.000418/0.0021987) \times 100\%$$
$$= 0.19011 \times 100\%$$
$$= 19\%$$

The results demonstrate that the addition of potassium chromate significantly reduces the corrosion rate of aluminum 7075 in both seawater and rainwater environments. The efficiency of the inhibitor was higher in seawater (80.85%) compared to rainwater (19%), highlighting its greater effectiveness in seawater conditions.

4. Conclusion

The corrosion rate of aluminum 7075 in seawater without an inhibitor at pH 7.34 was found to be 0.027799 mm/yr, while with the addition of potassium chromate (K_2CrO_4) as an inhibitor at pH 7.5, the corrosion rate decreased to 0.0053243 mm/yr. This resulted in an inhibitor efficiency of 80.85%. In rainwater, the corrosion rate without an inhibitor at pH 6.66 was 0.0021987 mm/yr, whereas with the inhibitor at pH 7.74, the corrosion rate reduced to 0.0017807 mm/yr, yielding an inhibitor efficiency of 19%.

The difference in inhibitor efficiency between seawater and rainwater can be attributed to several factors, including the chemical composition of seawater, which contains salts and various ions (e.g., Mg^{2+}, Ca^{2+}, SO_4^{2-}), compared to rainwater, which generally has lower concentrations of dissolved ions. Additionally, the presence of microorganisms in seawater can contribute to microbiological corrosion, which may diminish the effectiveness of the inhibitor, particularly if it is not designed to counteract this type of corrosion. In contrast, rainwater tends to be cleaner and less prone to microbiological corrosion.

The limitation of this study is the variation in pH levels between seawater and rainwater across different geographic locations, which may influence the corrosion behavior.

Understanding corrosion rates is crucial for the aerospace industry, as it directly impacts factors such as safety, maintenance costs, aircraft lifespan, operational performance, adherence to regulations, and the overall reputation of the company.

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