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Examining the Inhibitive Effect of Alanine on Corrosion of Aluminium in Acidic Medium

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Abstract - The study examined how alanine inhibits corrosion of aluminium coupons in an acidic environment using a 0.5M HCl solution. The weight loss method was used for synthesis. Aluminium sheets with a purity of 98.98% were cut into rectangular coupons measuring 2cm x 4cm and were 1.0 mm thick. The total surface area of each coupon was 8 cm2, which was reduced by washing with absolute ethanol and drying in acetone. These rectangular coupons were fully immersed in the acid solution with different concentrations of the inhibitor for time intervals ranging from 30 minutes to 3 hours. The inhibitor at the optimal concentration reduced aluminium corrosion by about 14.6%, and the inhibition efficiency varied significantly with different alanine concentrations. The presence of heteroatoms in the inhibitor helped absorb onto the metal surface, displacing water molecules and creating a protective barrier. The findings indicated that alanine in 0.5M HCl has some inhibiting properties for lowering the corrosion rate of aluminium. However, the results also showed that alanine is not an effective inhibitor for aluminium corrosion due to its low inhibition efficiency.

Keywords - Alanine, Inhibitive effect, Aluminium Coupon, HCl, Corrosion Rate.

I. INTRODUCTION

Corrosion is a natural process that transforms refined metals into more stable oxides (Bardal et al., 1993; Obruche et al., 2019; Umudi et al., 2022). It involves the gradual deterioration of materials, typically metals, through chemical reactions with their surroundings, which is often unavoidable. Regardless of the various definitions, it is clear that corrosion results from the interaction between materials and their environment. In nature, metals are rarely found in their free state due to their reactivity (Abiola et al., 2009; Obruche et al., 2018). Metals usually exist in a high energy state because energy is introduced during their production from ores. Low energy state ores are more stable compared to high energy state metals. Due to this thermodynamic challenge, metals have a strong tendency to release energy and return to their original form. Thus, metals revert to their original state or ore in a suitable corrosive environment. The electrochemical process of corrosion is naturally the opposite of the extractive metallurgy used in metal production (Ebenso et al., 2008; Umudi et al., 2025). Consequently, corrosion is sometimes viewed as the reverse of extractive metallurgy, as illustrated in figure 1.

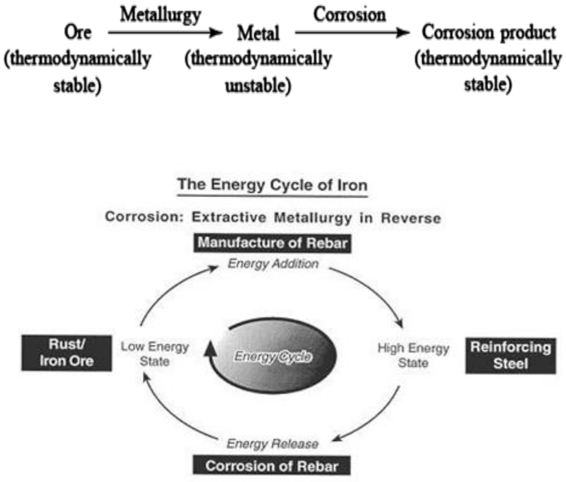

Figure 1: The Energy Cycle of Iron Indicating its Extractive Metallurgy

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Corrosion happens through an electrochemical process. Metal dissolves at the anode where the corrosion current enters the electrolyte and moves to the cathode (Loto, 1998; Itodo et al., 2021). A basic corrosion cell includes an anode, a cathode, an electrolyte, and a metallic path for electron flow. It's important to note that the corrosion current (z) enters the electrolyte at the anode and travels to the cathode. Corrosion is a natural and expensive destructive process, similar to earthquakes, tornadoes, floods, and volcanic eruptions, but with one key difference (Oguzie et al., 2006; Erienu et al., 2022).

In the case of these destructive events, we can only be passive observers. The issue of metallic corrosion is significant; it is estimated that about 5% of an industrial nation's income is allocated to corrosion prevention and the maintenance or replacement of products lost or damaged due to corrosion reactions. The impacts of corrosion are numerous, and their effects on the safe, reliable, and efficient functioning of equipment or structures can often be more severe than just the loss of metal mass (Okafor et al., 2005; Obruche et al., 2025). Equipment failures and the necessity for costly replacements can happen even if the amount of metal lost is relatively small. Some of the main harmful effects of corrosion can be summarized as follows: • Perforation of vessels and pipes, leading to the escape of their contents and potential harm to the environment. For instance, a leaking domestic radiator can cause significant damage to carpets and decor, while corrosive seawater may infiltrate the boilers of a power station if the condenser tubes are perforated. • Deterioration of important surface properties of a metallic component. These factors may include the properties of friction and bearings, the ease of fluid movement over a pipe's surface, the electrical conductivity of connections, surface reflectivity, or heat transfer across a surface.

- Mechanical damage to valves, pumps, etc., or blockages in pipes caused by solid corrosion products.
- Increased complexity and cost of equipment that must be designed to endure a specific level of corrosion and allow for the easy replacement of corroded parts.
- Thinning of metal leading to a reduction in mechanical strength and potential structural failure or breakdown.

When metal is lost in localized areas, resulting in cracks in the structure, significant weakening can occur from a relatively small amount of metal loss. Corrosion can be prevented or at least managed. Plant juice has demonstrated a promising ability to inhibit corrosion (Ogwuche & Obruche, 2020). Corrosion inhibitors are chemicals that interact with the metal's surface or the environmental gases that cause corrosion, thus interrupting the chemical reactions responsible for corrosion. Inhibitors can function by adhering to the metal's surface and creating a protective layer. Inhibitors are substances that, when added in low concentrations to the environment, reduce its corrosiveness.

A corrosion inhibitor is a chemical compound that, when introduced to a liquid or gas, lowers the corrosion rate of a material, usually a metal or an alloy. The use of inhibitors is one of the most established methods used to combat corrosion, particularly in acidic environments (Ekpo et al., 2023; Obruche et al., 2019). The effectiveness of a corrosion inhibitor is influenced by the composition of the fluid, the amount of water present, and the flow conditions.

A typical way to prevent corrosion is by creating a coating, usually a passivation layer, that stops corrosive substances from reaching the metal. Alternatively, corrosion inhibitors are substances added to the fluids surrounding the metal or related items. These inhibitors work by forming a barrier of one or more molecular layers to protect against acid damage. This protective effect is often linked to chemical and/or physical adsorption, which involves changes in the charge of the adsorbed material and the transfer of charge between different phases (Ekpo et al., 2025).

The purpose of this study is to examine how alanine inhibits corrosion of aluminum in a 0.5 M HCl solution using the weight loss method.

II. MATERIALS AND METHOD

Materials

All chemicals used in this research were of reagent grade and required no further processing. Hydrochloric acid (HCl) (99.99% purity), ethanol (C_2H_5OH) (90% purity), acetone (C_3H_6O) (37.7%), and hydrogen peroxide were provided by Merck. Distilled water was sourced from the chemistry department at Delta State College of Education, Mosogar.

Preparation of Stock Solution of Alanine

The preparation method followed the process outlined by (Obruche et al., 2019). A stock solution of 0.02 M alanine was created by combining 0.3564 g of alanine with 200 ml of 0.5 M HCl in a round-bottom flask. The blank corrodent used was a 0.5 M HCl solution. Different concentrations of the inhibitor solutions (2.5×10^{-3} M, 5×10^{-3} M, 1.5×10^{-2} M, 2.5×10^{-2} M, 4×10^{-2} M) were prepared by diluting the stock solution with the appropriate amount of 0.5 M HCl.

Method

The sample synthesis method was based on Umanah et al. (2020) with some minor changes. Aluminum sheets with a purity of 98.8% were utilized in this research. Each sheet had a thickness of 1.0mm and was cut into rectangular coupons measuring 2cm x 4cm. The total surface area of each coupon was 8 cm^2. These coupons were used without any additional polishing. However, the surface treatment included degreasing in absolute ethanol and drying in acetone (Obruche et al., 2025). The coupons were then kept in a moisture-free desiccator to prevent contamination before they were used for corrosion studies. The initial weight of each sample was recorded. They were used as received without further purification. The inhibitor used was alanine. Various concentrations (2.5×10^{-3} M to 4×10^{-2} M) were prepared in a 0.5 M hydrochloric acid solution for all measurements.

Weight loss measurement.

The weight loss measurement method was adapted from the process described by Festus-Amadi (2021), Obruche et al. (2019), and Abeokuta et al. (2025) with some modifications. This study involved adding the prepared concentrations of the inhibitor into separate beakers maintained at 300 °C. A total of seven beakers labeled L1 to L7 were used; L1 and L2 contained 100 mL of 0.5 M HCl solution only (without alanine) and served as the blank (control) experiment. The other beakers labeled L3 to L7 contained different volumes of the stock solution of the inhibitor (2.5×10^{-3} M, 5×10^{-3} M, 1.5×10^{-2} M, 2.5×10^{-2} M, 4×10^{-2} M) along with the appropriate volume of 0.5 M HCl. Seven coupons, initially weighed, were labeled B1 to B7, with B1 and B2 serving as control coupons. These coupons were immersed in their respective beakers. The weight loss was monitored at 30-minute intervals for a total of 3 hours. The coupons were taken out at 30-minute intervals over a period of 3 hours, rinsed in distilled water to halt the reaction, and the corrosion products were removed, followed by rinsing in absolute ethanol. After rinsing, the samples were dried and weighed again. Rinsing eliminated loose parts of the film from the corroded samples. The weight difference of the coupons was measured again as the weight loss. Using the initial and final weights of the aluminum coupons, the weight loss and inhibition efficiency were calculated using equations 1 and 2, respectively.

$$CR = W/AT \ldots\ldots 1$$

W is the weight loss of the aluminium coupon after time t (grams), A is the area of the aluminium coupon (cm^2) and t is the time of immersion (hours)

$$I.E(\%) = (CR(blank) - CR(inhibited))/CR(blank) \ldots\ldots 2$$

Where CR (blank) and CR (inhibited) refer to the corrosion rates of the aluminium coupons without and with the inhibitors, respectively. All experiments were conducted in duplicate.

Results and Discussion

The results for the corrosion behavior of the aluminium coupons, both with and without the inhibitor, as well as the inhibition efficiency, are presented in tables 1 to 9 and figures 1 and 2. The impact of alanine on the acid corrosion of aluminium in 0.5 M HCl was examined at various concentrations (2.5 × 10-3 M, 5 × 10-3 M, 1.5 × 10-2 M, 2.5 × 10-2 M, 4 × 10-2 M in 0.5 M HCl solution) of alanine.

The changes in weight loss and inhibition efficiency over time for aluminium coupons in 0.5 M HCl solution, both with and without different concentrations of the inhibitor, are displayed in tables 1 and 2.

Table 1: Aluminium coupon in 0.5 M HCl (control 1) without inhibitor compound.

Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
30	1.0069	0.9493	0.0576	
60	1.0069	0.8401	0.1668	
90	1.0069	0.7805	0.2264	
120	1.0069	0.7329	0.2740	
150	1.0069	0.7122	0.2947	
180	1.0069	0.7079	0.2990	

Table 2: Aluminium coupon in 0.5 M HCl (control 2) without inhibitor compound.

Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
30	0.9927	0.9468	0.0459	
60	0.9927	0.8447	0.1480	
90	0.9927	0.7639	0.2288	
120	0.9927	0.7307	0.2620	
150	0.9927	0.7001	0.2926	
180	0.9927	0.6947	0.2980	

Table 3: Aluminium coupon in 0.5 M HCl containing 2.5 × 10-3 M inhibitor compound

Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)

30	0.9496	0.9004	0.0492	4.9
60	0.9496	0.8089	0.1407	10.6
90	0.9496	0.7327	0.2169	4.7
120	0.9496	0.6891	0.2605	2.8
150	0.9496	0.6643	0.2853	2.9
180	0.9496	0.6597	0.2899	2.8

Table 5: Aluminium coupon in 0.5 M HCl containing 1.5 × 10-2 M inhibitor compound.

Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
30	0.9996	0.9452	0.0544	-5.1
60	0.9996	0.8325	0.1671	-6.2
90	0.9996	0.7602	0.2394	-5.2
120	0.9996	0.7226	0.2770	-3.4
150	0.9996	0.6994	0.3002	-2.2
180	0.9996	0.6955	0.3041	-1.9

Table 6: Aluminium coupon in 0.5 M HCl containing 2.5 × 10-2 M inhibitor compound.

Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
30	0.9660	0.9218	0.0442	14.6
60	0.9660	0.8157	0.1503	4.5
90	0.9660	0.7333	0.2327	-2.2
120	0.9660	0.7193	0.2467	7.9
150	0.9660	0.6692	0.2968	-1.1
180	0.9660	0.7079	0.3012	-0.9

Table 7: Aluminium coupon in 0.5 M HCl containing 4 × 10-2 M inhibitor compound.

Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
30	1.0033	0.9578	0.0455	12.1
60	1.0033	0.8579	0.1454	7.6
90	1.0033	0.7728	0.2305	-1.3
120	1.0033	0.7295	0.2738	-2.2
150	1.0033	0.7087	0.2946	-0.3
180	1.0033	0.7056	0.2977	0.3

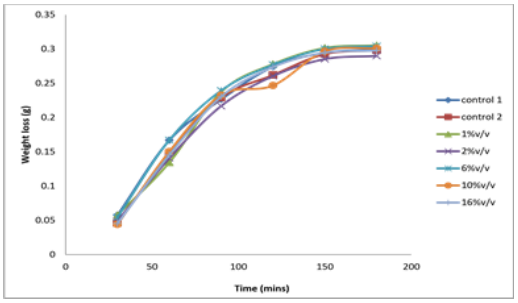

Figure 1: Variation of Weight Loss with Immersion Time

The variation in weight loss and inhibition efficiency over a period of two hours for aluminum coupons immersed in a 0.5 M HCl solution, both in the absence and presence of varying concentrations of an inhibitor.

Table 8: Aluminium coupon in 0.5 M HCl (control 1) without inhibitor compound.

Controls	Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
Control 1	120	0.9657	0.5685	0.3972	
Control 2	120	0.996	0.6028	0.3934	

Table 9. Aluminium coupon in 0.5 M HCl containing different inhibitor compound concentration.

Inhibitor compound. concentration	Time (min)	Initial weight of specimen, W_I	Final weight of specimen, W_F	Weight loss, $\Delta W_{(g)}$	Inhibition efficiency (%)
2.5×10^{-3} M Conc.	120	0.9860	0.5878	0.3982	-0.7
5×10^{-3} M Conc.	120	0.9752	0.5805	0.3947	0.2
1.5×10^{-2} M Conc.	120	1.0049	0.6104	0.3945	0.2
2.5×10^{-2} M Conc.	120	0.9898	0.6031	0.3867	2.2
4×10^{-2} M Conc.	120	1.0255	0.6361	0.3894	1.2

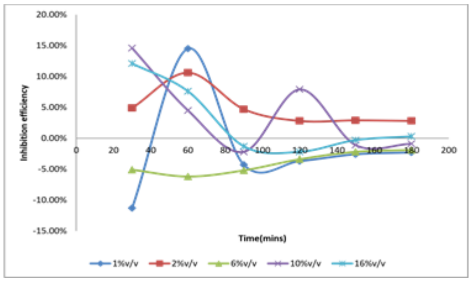

Figure 2: Variation of Inhibition Efficiency with Immersion Time

Table 1 and Table 2 demonstrated a high corrosion rate of aluminum in 0.5 M HCl without alanine, which are control 1 and control 2. As time progresses, there is a gradual increase in weight loss with the controls. When alanine is added to the HCl solution, there is a significant decrease in material loss from the aluminum surface compared to the controls (0.5 M HCl). Figures 1 and 2 illustrate the graph of weight loss versus immersion period for aluminum corrosion in 0.5 M HCl and with varying concentrations of alanine. From the same figures, it is also noted that the inhibition efficiency values rise with higher concentrations of alanine, indicating that the inhibitor can reduce the corrosion rate of metals. The study found that alanine has inhibiting properties that lower the corrosion rate of aluminum in 0.5 M HCl acid, but with an optimum inhibition efficiency of 14.6%, it suggests that alanine is not a strong inhibitor in the acid corrosion of aluminum in 0.5 M HCl solution.

III. CONCLUSION

This study indicates that alanine inhibits the corrosion of aluminum in 0.5 M hydrochloric acid solution to a less satisfactory level.The inhibitor at the optimal concentration reduced aluminium corrosion by approximately 14.6% efficiency, and the efficiency varied greatly with different alanine concentrations. The inhibition occurred due to the presence of heteroatoms in the inhibitor, which attach to the metal surface, displacing water molecules and creating a protective barrier. The findings indicate that alanine is not an effective inhibitor for aluminium corrosion. Given that the maximum inhibition efficiency is only about 14.6%, which is relatively low, further research should explore using a higher concentration of alanine as an inhibitor.

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