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The Effect of Acids, Bases and Salts in Removing Rust Using the Electrolysis Method

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ABSTRACT

Corrosion is a natural process of metal deterioration caused by chemical or electrochemical reactions with the surrounding environment, and it commonly occurs in iron and steel. This study examined the use of electrolysis as a simple method to reduce rust on iron surfaces by applying several electrolyte solutions. The solutions tested included sodium chloride, citric acid, acetic acid, sodium bicarbonate, and water, each at a concentration of 10%, while citric acid was also varied up to 100%. Electrolysis was performed for 10 to 30 minutes on both positive and negative poles. The findings showed that sodium chloride solution gave the highest effectiveness in rust removal, with 0.93% rust loss on the negative pole and 0.58% on the positive pole. Increasing solution concentration and treatment time further improved the rust removal rate, reaching 2.50% at 30 minutes.

Keywords: Corrosion, Electrolysis, Sodium Chloride (NaCl), Rust Removal, Electrolyte Solution

1. INTRODUCTION

Corrosion is a naturally occurring process defined as the degradation of metal properties due to electrochemical reactions with the surrounding environment over time. It represents one of the major causes of structural failure in infrastructure and metallic equipment, contributing to enormous global economic losses.[1,2] In general, corrosion can be categorized as the spontaneous deterioration of metals driven by thermodynamic tendencies to reach equilibrium with their environment.[3]

Corrosion may occur through physical, chemical, or biological pathways. Physical corrosion arises from direct interactions between metals and ionic species, while chemical corrosion is often caused by aggressive compounds such as acids, chlorides, or mercury. Biological corrosion, on the other hand, involves microbial activities in both aerobic and anaerobic environments, leading to microbial-induced corrosion.[4,5] Since corrosion is a natural process, it cannot be completely prevented, but it can be controlled or slowed down through different mitigation strategies.[6]

Electrochemical approaches such as electrolysis have been increasingly applied for rust removal and corrosion control. Electrolysis utilizes a direct current to decompose electrolytes, producing oxidation reactions at the anode and reduction at the cathode, enabling the detachment of corrosion products from metallic surfaces.[7,8] In practical applications, electrolysis shares similarities with processes in batteries, which convert chemical reactions into electrical energy via redox mechanisms.[9] Electrolytic rust removal is considered advantageous compared to mechanical or chemical cleaning because it is more environmentally friendly and effective in restoring corroded iron surfaces.[10]

Electrolyte solutions play a critical role in the efficiency of the electrolysis process. Electrolytes are broadly classified into strong and weak electrolytes based on their ionization degree. [11] Strong electrolytes such as sodium chloride (NaCl) dissociate completely in water, providing high conductivity and efficient rust removal, while weak electrolytes such as acetic acid (CH_3COOH) and sodium bicarbonate ($NaHCO_3$) exhibit limited ionization, reducing electrochemical performance.[12] Citric acid, although a weak electrolyte, has been widely studied as a green chelating agent in rust removal due to its ability to form soluble complexes with iron ions.[13]

Several studies highlight that NaCl solutions are among the most effective electrolytes for electrochemical cleaning of iron, as they significantly accelerate rust removal compared to weaker electrolytes.[6] On the other hand, water (H_2O) exhibits very low conductivity due to its limited self-ionization, making it an inefficient electrolyte unless salts or acids are added.[14] These findings underline the importance of electrolyte selection for optimizing the electrolysis process.

Therefore, this study aims to evaluate the corrosion inhibition and rust removal efficiency of iron using electrolysis with various electrolyte solutions, namely NaCl, citric acid, acetic acid, sodium bicarbonate, and water. The novelty of this work lies in providing a direct comparison of these electrolytes under controlled experimental conditions, thereby offering insights into their electrochemical effectiveness for rust removal and practical implications for corrosion control.[15]

2. EXPERIMENTAL

2.1. Chemicals, Equipment and Instrumentation

This study employed several chemicals and instruments to support the rust removal electrolysis process on iron. The chemicals used were sodium chloride (NaCl, 99%, Merck), citric acid ($C_6H_8O_7$, 99%, Merck), acetic acid (CH_3COOH, 99.8%, Merck), sodium bicarbonate ($NaHCO_3$, 99%, Merck), and distilled water (H_2O). The main instruments included a 100 mL beaker glass (Pyrex), an analytical balance (accuracy ±0.0001 g, capacity 200 g, Ohaus), a digital multimeter (Sanwa CD800a, accuracy ±0.5%), crocodile clamp cables, a stopwatch (Casio), rusted iron samples ($Fe_2O_3 \cdot nH_2O$), and a 9 V battery (Panasonic).

2.2. Research Procedure

Initially, the rusted iron (Fe) samples were weighed using an analytical balance and then marked to distinguish the positive and negative terminals for the electrolysis process. Electrolyte solutions were prepared as follows: sodium chloride (NaCl), citric acid ($C_6H_8O_7$), acetic acid (CH_3COOH), sodium bicarbonate ($NaHCO_3$), and distilled water (H_2O), each with a concentration of 10%. For citric acid, the solution concentrations were varied to 10%, 30%, 50%, 70%, and 100%. The electrolysis process was carried out by immersing the iron samples in the prepared solutions and applying a direct current using a 9 V battery for 30 minutes.

3. RESULTS AND DISCUSSION

3.1. Comparison Test of Iron on the Positive and Negative Poles Of a Battery

The corrosion tests were conducted using sodium chloride (NaCl), citric acid ($C_6H_8O_7$), acetic acid (CH_3COOH), sodium bicarbonate ($NaHCO_3$), and water (H_2O) as electrolyte solutions, each prepared at a concentration of 10%. Although some of these are weak electrolytes, they were included to compare their electrical conductivity and their effectiveness in rust removal.

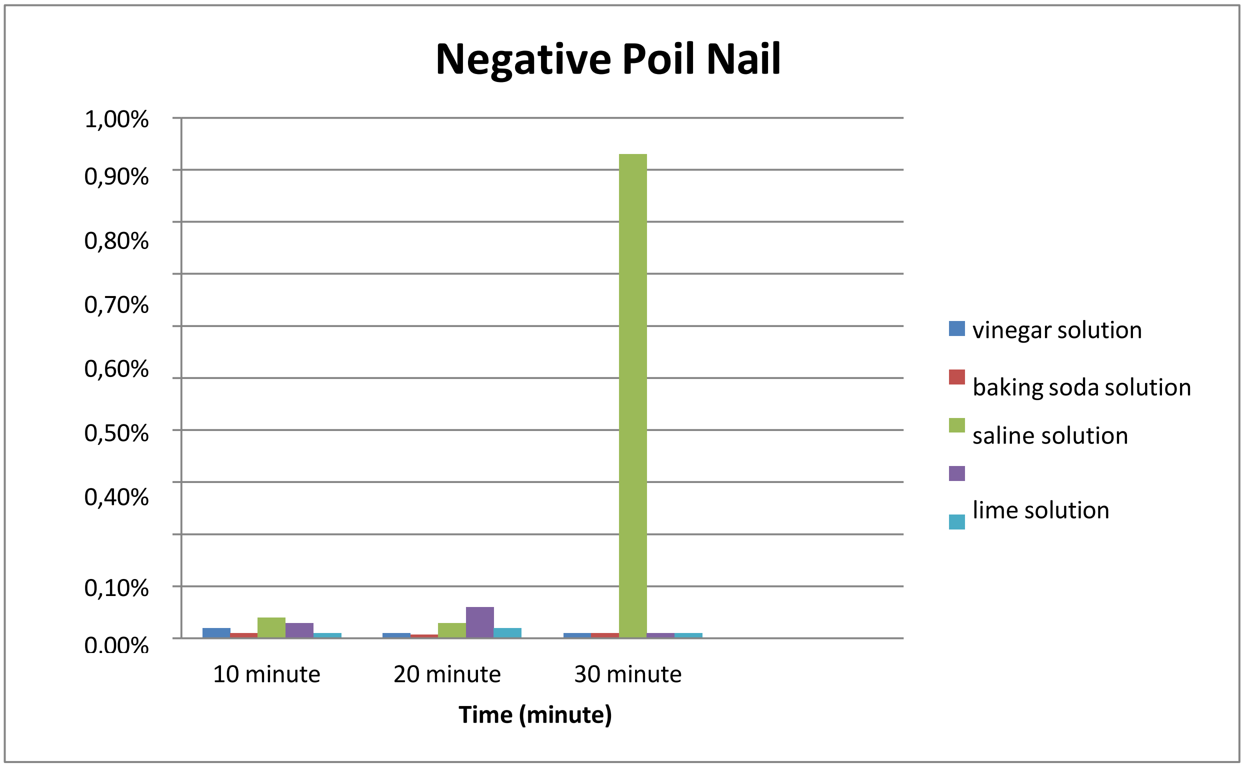

Figure 1. Rust removal percentage of iron nail at the negative pole in various electrolyte solutions with 10% concentration

As shown in Figure 1, the nail connected to the negative pole exhibited the highest rust removal in NaCl solution. After 10 minutes of electrolysis, the rust reduction reached 0.04%. At 20 minutes, the citric acid solution showed a slightly higher effect (0.06%) compared to NaCl (0.05%). However, at 30 minutes, NaCl solution demonstrated the most significant increase, with rust removal reaching 0.93%. In contrast, sodium bicarbonate ($NaHCO_3$) consistently showed the lowest performance, with only 0.01% rust removal throughout the process.

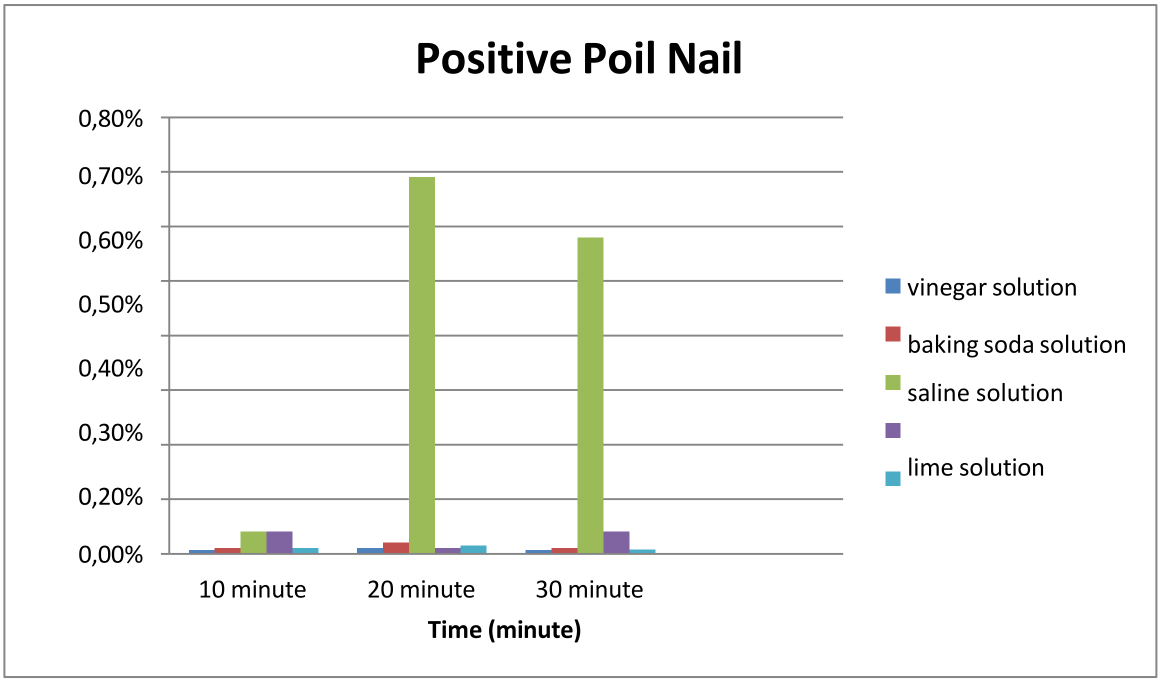

Figure 2. Rust removal percentage of iron nail at the positive pole in various electrolyte solutions with 10% concentration.

In the positive pole (Figure 2), NaCl again produced the best performance. At 10 minutes, both NaCl and citric acid solutions achieved 0.04% rust removal, while the others remained at 0.01%. At 20 minutes, NaCl solution reached 0.69%, followed by sodium bicarbonate (0.02%), while the rest remained at 0.01%. After 30 minutes, NaCl slightly decreased to 0.58%, but still showed the highest value compared to citric acid (0.04%) and other solutions (0.01%).

From these observations, it can be stated that NaCl solution exhibits the most effective rust removal properties in both negative and positive poles, with greater efficiency observed at the negative pole (0.93%) compared to the positive pole (0.58%). This is attributed to NaCl being a strong electrolyte that dissociates completely in water, providing abundant Na^+ and Cl^- ions that facilitate the redox reactions during electrolysis.

3.2. Positive Iron Test Varying Solition Concentrations

The electrolysis process was further investigated using different concentrations of sodium chloride (NaCl) solution, since in the previous experiment NaCl demonstrated the highest rust removal performance

(0.98%). As the concentration of NaCl increases, the number of dissociated ions (Na^+ and Cl^-) in solution also increases, thereby enhancing the conductivity of the electrolyte. This, in turn, facilitates a higher current flow during electrolysis, provided that the applied voltage and other parameters remain constant. Consequently, it is expected that increasing solution concentration will improve the efficiency of rust removal from iron surfaces.

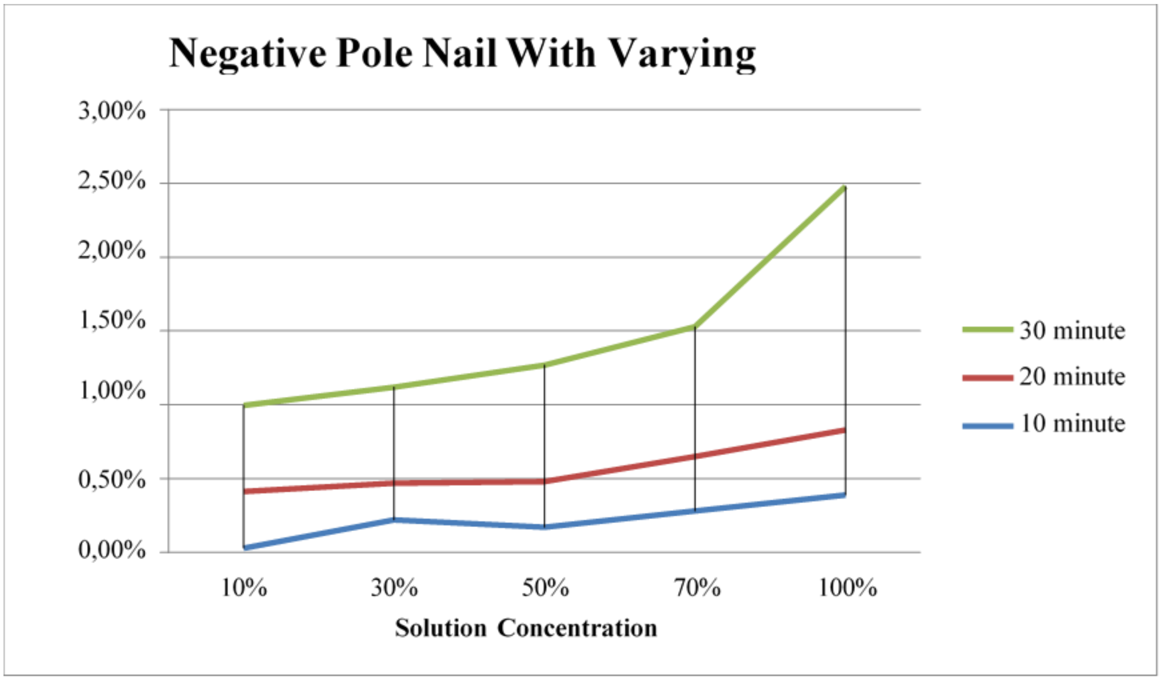

Figure 3. Effect of NaCl solution concentration and electrolysis time on rust removal percentage at the negative pole.

As shown in Figure 3, the concentration of the electrolyte plays a crucial role in determining the extent of rust removal. At lower concentrations (10%), the reduction in rust is relatively small across all time intervals. However, as the concentration increases to 30%, 50%, 70%, and finally 100%, the rust removal percentage rises significantly. In addition to concentration, electrolysis duration is also an important factor. At 10 minutes, the rust removal is still minimal, whereas extending the process to 20 minutes leads to an increase to 0.57%. The most significant improvement occurs at 30 minutes, where rust removal reaches 2.50%, indicating the synergistic effect of both higher concentration and longer electrolysis time.

These results confirm that both solution concentration and electrolysis duration substantially influence the effectiveness of rust removal. Higher concentrations provide more ions to support electrochemical reactions, while longer durations allow more complete reduction and oxidation processes, thereby maximizing rust elimination. A recent study reported in the Yanbu Journal of Engineering and Science demonstrated that increasing NaCl concentration significantly enhances the material removal rate (MRR) in electrochemical machining due to improved conductivity and accelerated surface reactions.[16] Similarly, optimizing electrolyte concentration and processing time is essential for efficient corrosion mitigation, as these parameters directly control ion availability and electrochemical reaction kinetics.[17] Together, these findings reinforce that electrolyte concentration and electrolysis duration are critical factors governing the efficiency of rust removal in iron through electrolysis.

4. CONCLUSION

This study demonstrates that electrolysis is an effective and simple method for removing rust from iron. Among the electrolyte solutions tested, sodium chloride (NaCl) was the most effective due to its strong ionic conductivity, enabling efficient electrochemical reactions.

The results also show that solution concentration and electrolysis duration are critical factors influencing rust removal efficiency. Higher concentrations and longer treatment times lead to greater rust reduction. These findings highlight the potential of NaCl-based electrolysis as a practical, low-cost approach for rust removal, while future research may explore optimization of parameters for broader applications.

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