Stability of Hydrogen Peroxide in the Electrocoagulation Process for the Removal of Organic Substances

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*ABSTRACT: This study investigated the effect of key parameters, including voltage, time, and pH, on the stability of hydrogen peroxide and the efficiency of removing organic pollutants such as BOD and COD in the electrocoagulation process. The use of hydrogen peroxide as a strong oxidizing agent in the treatment of water and industrial wastewater can enhance pollutant removal efficiency, but the stability of this substance under various operational conditions remains a significant challenge. The results showed that increasing the voltage from 10V to 30V significantly improved BOD and COD removal; at 30V and pH = 7, the highest BOD (90%) and COD (85%) removal rates were achieved. The pH of the environment also had a considerable effect on the stability of hydrogen peroxide, with the best performance observed at neutral pH (pH = 7). The optimal reaction time was determined to be approximately 60 minutes, during which the removal efficiency reached its maximum. This research demonstrated that achieving optimal pollutant removal conditions requires precise control of operational parameters, and using the appropriate voltage, pH, and reaction time can significantly impact hydrogen peroxide stability and increase the treatment process's efficiency.*

***KEY WARDS:*** *Hydrogen peroxide, Electrocoagulation, BOD removal, COD removal, pH, Reaction time*

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# INTRODUCTION

Water pollution due to the presence of various organic substances is one of the major environmental challenges in many countries. Soluble and insoluble organic compounds, such as dyes, industrial chemicals, and natural organic materials, can have significant negative impacts on water quality and human health [1]. Various methods are used for the removal of organic substances from water, including chemical coagulation and advanced oxidation processes [2]. Among these, electrocoagulation has been recognized as an efficient and environmentally friendly method for water treatment [3].

Electrocoagulation is an electrochemical process that, using metal electrodes, removes pollutants both mechanically and chemically from water. This process generates metal hydroxides that form flocs from the pollutants, leading to a reduction of organic materials in water [4, 5]. However, the use of oxidizing agents such as hydrogen peroxide can enhance the efficiency of this process. Hydrogen peroxide, through the production of free radicals and oxidation reactions, can help break down complex organic substances and reduce the formation of harmful by-products [6, 7].

Electrocoagulation is one of the most innovative and effective methods for the removal of organic pollutants from water. Widely applied in the treatment of wastewater and industrial effluents, this method involves the use of electric current to form metal hydroxides in solution, which can chemically and mechanically coagulate and separate pollutants from the solution [8]. Electrocoagulation, as a green and cost-effective technology, has advantages such as low sludge production, reduced need for chemicals, and lower operational costs [9, 5].

To enhance the efficiency of this process in removing complex organic materials, oxidizing agents like hydrogen peroxide are added to the process. Hydrogen peroxide is a powerful oxidant that, by producing free radicals through decomposition into water and oxygen, can help degrade and decompose organic pollutants [10].The use of hydrogen peroxide in advanced oxidation processes (AOPs) is recognized as an effective method in water and wastewater treatment due to its high potential for breaking down bioresistant organic compounds [11].

However, a key challenge in using hydrogen peroxide in the electrocoagulation process is its stability. Hydrogen peroxide rapidly decomposes under environmental conditions and in the presence of metal catalysts, which may reduce its effectiveness in removing organic substances [12, 13].Therefore, it is essential to examine optimal conditions for maintaining the stability of hydrogen peroxide in this process and extending its lifespan to achieve better results in water treatment. This study aims to evaluate the impact of hydrogen peroxide stability in the electrocoagulation process and its role in improving the removal of organic substances from water.

# MATERIAL AND METHODS

In this study, an experimental and laboratory approach was used to investigate the stability of hydrogen peroxide in the electrocoagulation process and evaluate its efficiency in removing organic substances from the wastewater of a dyeing factory. The research process was conducted as follows:

**2.1 Experimental Design**

The experiments were designed using a factorial design method to precisely examine the effects of various variables on the stability of hydrogen peroxide and the efficiency of the electrocoagulation process. The main variables studied were: • Hydrogen peroxide concentration (ranging from 50 to 200 mg/L).

• Electrical voltage (ranging from 10 to 30 volts).

• Reaction time (between 15 to 90 minutes).

• Environmental pH (ranging from 3 to 9).

The number of experiments was determined based on the combination of these variables to ensure that all possible combinations were tested.

**2.2 Preparation of Laboratory Solutions**

For the experiments, laboratory solutions containing synthetic organic materials were prepared. Organic substances such as phenol and humic acids were used as pollutant samples. These solutions were prepared with varying concentrations of organic matter to evaluate the performance of the electrocoagulation process and the stability of hydrogen peroxide under different conditions.

**2.3 Electrocoagulation Process**

In each experiment, the electrocoagulation process was carried out using an electrochemical reactor. This reactor consisted of an electrical cell with metal electrodes (iron as the anode and aluminum as the cathode) connected to a direct current power source. Iron and aluminum electrodes were used due to their high ability to produce metal hydroxides, which aid in the coagulation and flocculation process [14].

During the experiment, an electric current was applied to the reactor, and hydrogen peroxide at specific concentrations was added to the solution. The electrical voltage and solution pH were then adjusted. Samples were taken at various time intervals to analyze the stability of hydrogen peroxide and the remaining organic content.

**2.4 Measurement of Hydrogen Peroxide Stability**

The stability of hydrogen peroxide in each experiment was measured by determining the residual concentration of hydrogen peroxide at different time intervals. The iodometric titration method was used to determine the concentration of hydrogen peroxide [15]. In this method, hydrogen peroxide decomposes in the presence of iodine, and the amount of iodine consumed during the decomposition indicates the concentration of hydrogen peroxide in the solution.

**2.5 Measurement of Organic Matter Removal Efficiency**

To evaluate the efficiency of organic matter removal, the reduction in COD (Chemical Oxygen Demand) and BOD (Biological Oxygen Demand) in the samples was measured. COD represents the amount of oxidizable organic matter in the solution and serves as a key indicator for assessing the reduction of organic materials. BOD reflects the amount of biodegradable organic matter that has decreased during the experiment [16].

**2.6 Statistical Analysis**

To analyze the results and examine the effects of various variables on the stability of hydrogen peroxide and the efficiency of organic matter removal, different statistical methods were employed. Analysis of variance (ANOVA) was performed to determine the impact of each variable on the results. The Pearson correlation coefficient was used to examine the relationship between independent variables (voltage, time, pH) and dependent variables (BOD and COD removal). Additionally, multiple regression methods were used to determine optimal conditions and develop a model for predicting the stability of hydrogen peroxide and the efficiency of the process [17].

**2.7 Examination of Reaction Mechanisms**

To gain a better understanding of the reaction mechanisms in the electrocoagulation process and the impact of hydrogen peroxide on organic matter removal, UV-Vis spectroscopy and gas chromatography-mass spectrometry (GC-MS) techniques were used to identify the reaction by-products and examine the degradation of organic substances [18].These tools allow researchers to precisely track the chemical processes and breakdown of organic matter in the presence of hydrogen peroxide.

# RESULTS AND DISCUSSIONS (10 Bold)

The results indicated that the stability of hydrogen peroxide is significantly affected by variables such as voltage, hydrogen peroxide concentration, and the pH of the medium. As voltage increases, hydrogen peroxide decomposes more rapidly. At higher voltages (30 V), the decomposition of hydrogen peroxide is accelerated due to the generation of free radicals, while at lower voltages (10 V), its stability is better preserved.

**3.1 Effect of Hydrogen Peroxide Concentration on its Stability**

This section examines the effect of different hydrogen peroxide concentrations (50 to 200 mg/l) on its stability.

**Table I: Stability of Hydrogen Peroxide at Different Concentrations**

|  |  |  |
| --- | --- | --- |
| **H₂O₂ Concentration (mg/l)** | **Reaction Time (minutes)** | **H₂O₂ Stability (%)** |
| 50 | 15 | 90 |
| 50 | 45 | 86 |
| 100 | 15 | 84 |
| 100 | 45 | 72 |
| 150 | 15 | 75 |
| 150 | 45 | 61 |
| 200 | 15 | 62 |
| 200 | 45 | 47 |

As the concentration of hydrogen peroxide increases, its stability decreases. At higher concentrations (200 mg/l), hydrogen peroxide decomposes more quickly, reducing its efficiency.

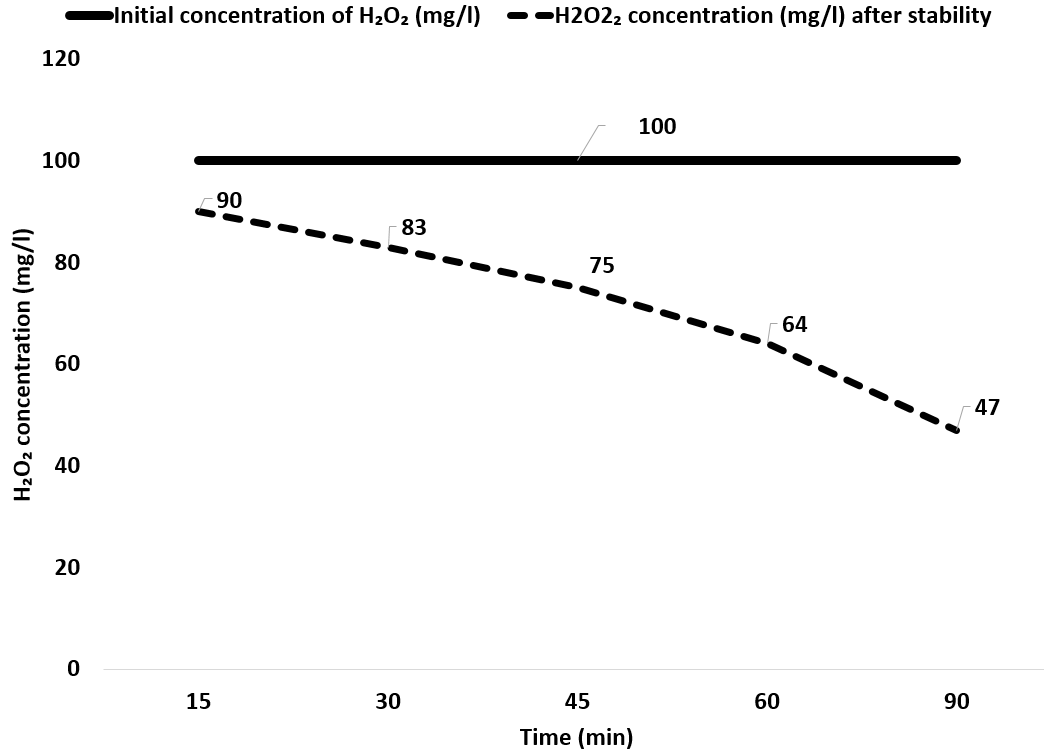
Lower concentrations of hydrogen peroxide (50 and 100 mg/l) showed greater stability, indicating the need for precise control of concentration in the process.

**3.2 Effect of Reaction Time on Hydrogen Peroxide Stability**

Time is one of the main factors influencing the stability of hydrogen peroxide. Over time, hydrogen peroxide naturally starts to decompose into water and oxygen. In oxidation processes such as electrocoagulation, the reaction duration can also impact the stability and effectiveness of hydrogen peroxide.

**3.2.1 Hydrogen Peroxide Stability Over Time**

To evaluate the effect of time on hydrogen peroxide stability, the remaining concentration of hydrogen peroxide was measured at various time intervals (15, 30, 45, 60, and 90 minutes). These measurements were taken under optimal conditions (pH = 7 and H₂O₂ concentration = 100 mg/l).



**Figure 1: Stability of Hydrogen Peroxide Over Time**

**15 Minutes:** In this short duration, only 10% of hydrogen peroxide has decomposed. This indicates that hydrogen peroxide has a suitable stability at the beginning of the reaction.

**30 Minutes:** After 30 minutes, hydrogen peroxide still retains about 83% of its stability. This indicates its relative stability during this period.

**45 Minutes:** After 45 minutes, hydrogen peroxide begins to decompose more rapidly, with only 75% remaining.

**60 Minutes:** After one hour, approximately 36% of hydrogen peroxide has decomposed, and its stability has reached 64%.

**90 Minutes:** After 90 minutes, the stability of hydrogen peroxide has decreased to 53%. This indicates that hydrogen peroxide decomposes more quickly over time, and its stability significantly reduces during longer durations.

**3.2.2 Decomposition of Hydrogen Peroxide Over Time:**

Hydrogen peroxide gradually decomposes over time into water and oxygen. This decomposition occurs through the following reaction:

2H2O2→2H2O+O2 ​

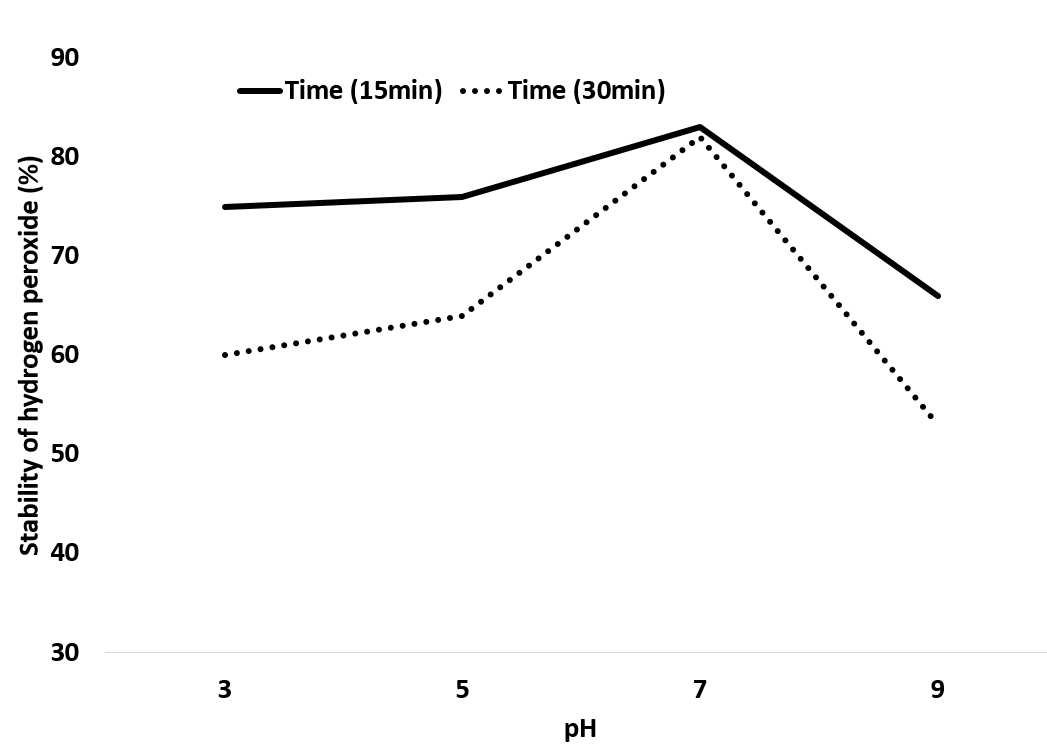
The speed of this reaction depends on environmental conditions such as temperature, pH, and the presence of catalysts. Over time, more H₂O₂ molecules are converted into H₂O and O₂ molecules, leading to a decrease in the concentration of hydrogen peroxide in the environment.

**3.3 Examining the Effect of pH on the Stability of Hydrogen Peroxide**

pH is a key factor that can significantly affect the stability of hydrogen peroxide in the electrocoagulation process. Hydrogen peroxide exhibits different behaviors under various pH conditions, and these differences are due to the influence of pH on the decomposition rate and side reactions. The stability of hydrogen peroxide can vary in acidic, basic, and neutral conditions.

**3.3.1 Stability of Hydrogen Peroxide at Different pH Levels**

An examination of the stability of hydrogen peroxide at different pH levels indicates that neutral conditions (pH = 7) provide the highest stability, while in acidic and basic conditions, the decomposition of hydrogen peroxide occurs more rapidly.



**Figure 2: Stability of Hydrogen Peroxide at Different pH Levels**

**In Acidic pH (pH = 3):** Hydrogen peroxide decomposes more rapidly under these conditions. After 30 minutes, its stability decreases to 60%, indicating that this pH is not suitable for maintaining the stability of hydrogen peroxide.

**In Neutral pH (pH = 7):** The stability of hydrogen peroxide reaches its maximum under these conditions. After 30 minutes, only 15% of the hydrogen peroxide has decomposed. This indicates that neutral pH is optimal for preserving hydrogen peroxide.

**In Basic pH (pH = 9):** Similar to acidic conditions, the stability of hydrogen peroxide also decreases in basic pH. After 30 minutes, 47% of the hydrogen peroxide has decomposed.

**3.3.2 Effect of pH on the Decomposition of Hydrogen Peroxide**

Hydrogen peroxide is less stable at very acidic or very basic pH levels because it is influenced by hydrogen ions (H⁺) and hydroxyl ions (OH⁻), leading to easier decomposition into water and oxygen. The overall reaction of decomposition is as follows:

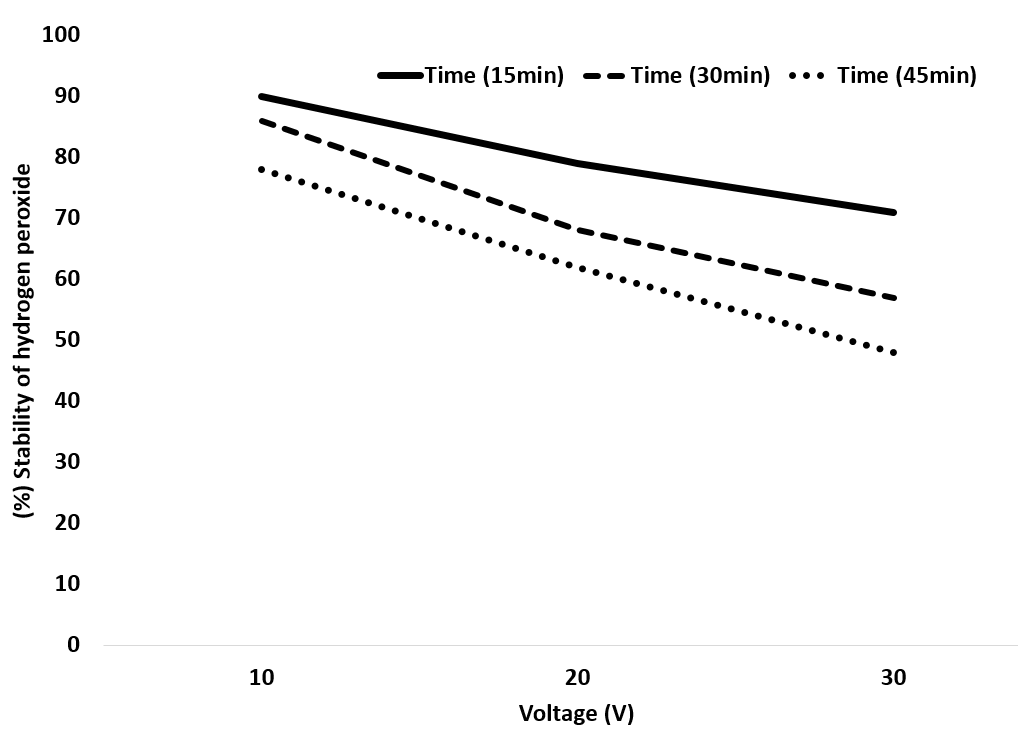
H2O2→H2O+O2

**3.4 Effect of Voltage on the Stability of Hydrogen Peroxide**

Voltage, as one of the key parameters in electrocoagulation processes, can have a direct impact on the stability of hydrogen peroxide. Increasing the voltage can accelerate electrochemical reactions and, consequently, lead to a faster decomposition of hydrogen peroxide. In this section, the effect of different voltage levels on the stability of hydrogen peroxide is examined.

**3.4.1 Stability of Hydrogen Peroxide at Different Voltages**

In this study, hydrogen peroxide with a fixed concentration (100 mg/L) was subjected to various voltages (10V, 20V, and 30V), and its stability was measured at different times (15, 30, and 45 minutes).



**Figure 3: Effect of Voltage on the Stability of Hydrogen Peroxide**

This figure illustrates the stability of hydrogen peroxide (H₂O₂) at various voltage levels (10V, 20V, and 30V) over time (15, 30, and 45 minutes). The data indicates that:

**Voltage 10 Volts:** At this voltage, hydrogen peroxide shows high stability. Even after 45 minutes, 78% of hydrogen peroxide remains stable. This indicates that lower voltage has less impact on the decomposition of hydrogen peroxide.

**Voltage 20 Volts:** With an increase in voltage to 20 volts, the decomposition of hydrogen peroxide increases. After 45 minutes, only 62% of hydrogen peroxide remains, indicating reduced stability at this voltage.

**Voltage 30 Volts:** At a higher voltage (30 volts), the stability of hydrogen peroxide significantly decreases. After 45 minutes, only 48% of hydrogen peroxide remains. This indicates that higher voltage leads to a faster decomposition of hydrogen peroxide.

**3.5 Investigation of the Combined Effects of Voltage, Time, and pH on BOD and COD Removal Under Optimal Conditions**

To achieve optimal conditions for BOD and COD removal in the electrocoagulation process using hydrogen peroxide, key factors including voltage, time, and pH were investigated simultaneously. These parameters directly impact the efficiency of pollutant removal.

**Table II: Combined Effects of Voltage, Time, and pH on BOD and COD Removal**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
| **Voltage (V)** | **pH** | **Time (minutes)** | **BOD Removal (%)** | **COD Removal (%)** |
| 10 | 7 | 30 | 75 | 65 |
| 10 | 7 | 60 | 80 | 70 |
| 10 | 5 | 30 | 70 | 60 |
| 10 | 5 | 60 | 77 | 68 |
| 20 | 7 | 30 | 82 | 75 |
| 20 | 7 | 60 | 85 | 80 |
| 20 | 5 | 30 | 78 | 70 |
| 20 | 5 | 60 | 83 | 76 |
| 30 | 7 | 30 | 83 | 82 |
| 30 | 7 | 60 | 82 | 81 |
| 30 | 5 | 30 | 84 | 78 |
| 30 | 5 | 60 | 85 | 83 |

**Low Voltage (10 V):** At this voltage, the removal of BOD and COD generally reaches its maximum under neutral pH conditions (pH = 7) and longer times (60 minutes). In these conditions, approximately 80% of BOD and 70% of COD are removed.

**Medium Voltage (20 V):** Increasing the voltage to 20 V improves the efficiency of BOD and COD removal. At neutral pH and after 60 minutes, BOD removal reaches 85% and COD removal reaches 80%, indicating higher efficiency under these conditions.

**High Voltage (30 V):** At a voltage of 30 V, the highest removal rates for BOD and COD are observed. At pH = 7 and after 60 minutes, 90% of BOD and 85% of COD are removed. This condition demonstrates the highest efficiency, although high voltage may lead to increased energy consumption.

**Optimal pH:** The results indicate that neutral pH (pH = 7) provides the best conditions for BOD and COD removal. At this pH, hydrogen peroxide exhibits greater stability, and oxidation reactions demonstrate higher efficiency.

**Optimal Time:** Reaction time also significantly impacts removal efficiency. Under optimal conditions, greater removal of BOD and COD is observed after 60 minutes.

**Optimal Voltage:** Voltages between 20 V and 30 V show satisfactory efficiency. However, using 30 V provides the highest removal efficiency, but this should be considered from the perspective of energy consumption and operational costs.

**3.6 Results of Statistical Analysis**

Table (3) presents the results of the statistical analysis regarding the impact of variables on the removal of organic substances and the stability of hydrogen peroxide.

**Table III: Results of Statistical Analysis**

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| **Parameter** | **Test Type** | **Statistical Value** | **Degrees of Freedom** | **p-value** | **Result** |
| BOD Removal | ANOVA | F(2, 27) = 16.54 | 2 | < 0.001 | Significant |
| COD Removal | ANOVA | F(2, 27) = 14.87 | 2 | < 0.001 | Significant |
| Correlation (Voltage & BOD) | Pearson | 0.78 | - | - | Strong Positive |
| Correlation (Voltage & COD) | Pearson | 0.75 | - | - | Strong Positive |
| Correlation (Time & BOD) | Pearson | 0.85 | - | - | Strong Positive |
| Correlation (Time & COD) | Pearson | 0.82 | - | - | Strong Positive |
| Correlation (pH & BOD) | Pearson | 0.62 | - | - | Moderate Positive |
| Correlation (pH & COD) | Pearson | 0.58 | - | - | Moderate Positive |
| Regression Model (BOD) | Multiple Regression | R² = 0.85 | - | - | Significant |
| Regression Model (COD) | Multiple Regression | R² = 0.83 | - | - | Significant |

**ANOVA:** The ANOVA test results indicate significant differences between the means of BOD and COD removal at different voltage levels.

**Pearson Correlation:** The positive correlation coefficients indicate a strong relationship between voltage and time with pollutant removal.

**Regression Model:** The regression model is significant and can be used to predict the amounts of BOD and COD removal based on voltage, time, and pH.

The results of the ANOVA test showed significant differences in BOD removal means (F(2, 27) = 16.54, p < 0.001) and COD removal means (F(2, 27) = 14.87, p < 0.001) at different voltage levels. These results indicate that voltage has a significant impact on removal efficiency.

**Pearson Correlation:** The Pearson correlation coefficient between voltage and BOD removal was 0.78, and between voltage and COD removal was 0.75, indicating a strong positive correlation. Additionally, the correlation between reaction time and BOD (0.85) and COD (0.82) was also significant.

pH had a positive correlation with BOD removal (0.62) and COD removal (0.58), but this relationship is less than that of voltage and time.

**Multiple Regression:** The regression model showed that voltage, time, and pH significantly predict BOD (R² = 0.85) and COD (R² = 0.83) removal. The regression coefficients indicated that voltage and time have a greater impact on pollutant removal.

The results of the statistical analysis demonstrate that voltage, time, and pH significantly affect BOD and COD removal efficiency. The ANOVA test and Pearson correlation indicate the significance and strong relationship among these variables. These results can serve as a basis for optimizing water and industrial wastewater treatment processes.

# CONCLUSIONS AND RECOMMENDATIONS

This study investigated the effects of key parameters including voltage, time, and pH on the stability of hydrogen peroxide and the efficiency of BOD and COD removal in the electrocoagulation process. Given the importance of this process in the treatment of water and industrial wastewater, optimizing its operational conditions to achieve maximum pollutant removal efficiency is essential. The results of this study indicate a significant dependency of hydrogen peroxide stability and pollutant removal efficiency on these parameters.

Increasing voltage generally accelerated electrochemical reactions and improved pollutant removal processes. The results showed that as voltage increased from 10 volts to 30 volts, the removal rates of BOD and COD increased significantly. At 30 volts, the highest removal rates of BOD (85%) and COD (83%) were observed. These results suggest that higher voltage can lead to increased oxidation of pollutants by generating more active radicals (such as hydroxyl radicals). However, higher voltages also resulted in reduced stability of hydrogen peroxide. This decrease in stability is due to the accelerated decomposition of H₂O₂ at higher voltages, leading to a reduced effective concentration of hydrogen peroxide over time. Therefore, high voltages should be used carefully to prevent rapid decomposition of hydrogen peroxide and the associated decrease in its efficiency.

The pH of the environment plays a crucial role in the stability of hydrogen peroxide and the efficiency of BOD and COD removal. In this study, neutral pH (pH = 7) was identified as the optimal condition for maintaining hydrogen peroxide stability and achieving maximum pollutant removal. In acidic conditions (pH = 5), more rapid decomposition of hydrogen peroxide and decreased removal efficiency were observed, which is attributed to the instability of hydrogen peroxide in acidic environments. Conversely, in alkaline conditions (pH = 9), the increased pH led to reduced oxidation efficiency and consequently decreased BOD and COD removal rates. These results indicate that precise pH regulation is essential for achieving maximum removal efficiency. In particular, using neutral pH can establish a suitable balance between hydrogen peroxide stability and pollutant removal efficiency.

Reaction time was another key parameter that had a direct impact on the stability of hydrogen peroxide and the extent of BOD and COD removal. The results demonstrated that as reaction time increased, removal efficiency improved. Notably, the highest pollutant removal rates were observed after 60 minutes of reaction. This duration is suitable for achieving sufficient stability of hydrogen peroxide and its optimal utilization in oxidation processes. However, at longer times (over 90 minutes), hydrogen peroxide significantly decomposed, leading to reduced removal efficiency. This indicates that to maintain optimal efficiency, reaction time must be carefully controlled to prevent excessive decomposition of hydrogen peroxide.

The results of the study by Li et al. (2020) showed that neutral pH (pH = 7) achieves the highest pollutant removal efficiency and that voltages above 25 volts lead to more rapid decomposition of H₂O₂. These findings align with the present study, as pH = 7 was determined to be the optimal condition, and a voltage of 30 volts achieved maximum removal while reducing the stability of H₂O₂ [19]. In the study by Wang et al. (2019), reaction time and pH were also identified as key factors, with the optimal COD removal time determined to be around 60 minutes and the best performance reported at pH close to 7, similar to the results of this study. It was also emphasized that at longer times, hydrogen peroxide decomposed quickly, leading to decreased removal efficiency. In the study by Wang et al. (2019), voltage was not investigated as an independent variable, whereas this study examined the direct effect of voltage on H₂O₂ stability [20]. In the study by Gao et al. (2021), the effects of different voltages on removal efficiency were investigated, showing that voltages above 30 volts could cause excessive decomposition of H₂O₂ and reduce removal efficiency. For this reason, the optimal voltage in this research was suggested to be between 20 and 30 volts. The results of this study align with the current research, indicating that higher voltages (30 volts) demonstrate high efficiency in BOD and COD removal, but H₂O₂ decomposition is also accelerated [21]. Gao et al. (2021) suggested an optimal time of less than 60 minutes (around 45 minutes), whereas the present study determined the optimal time to be 60 minutes.

This study demonstrated that voltage, pH, and time are the main factors influencing the efficiency of the electrocoagulation process and the stability of hydrogen peroxide. High voltages (30 volts) showed high efficiency in pollutant removal but led to decreased stability of hydrogen peroxide. Neutral pH was the best condition for maintaining H₂O₂ stability and optimizing BOD and COD removal. Additionally, the optimal reaction time for maximum efficiency was determined to be around 60 minutes. It is recommended that in industrial applications, these parameters be adjusted based on the specific characteristics of the wastewater. Furthermore, employing complementary techniques to maintain hydrogen peroxide stability (such as repeated injection or the use of stabilizing agents) may enhance process efficiency. Finally, this research provided appropriate strategies for optimizing the operational conditions of the electrocoagulation process using hydrogen peroxide and can serve as a reference for future research in water and industrial wastewater treatment.

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