Pollutants removal in electrocoagulation of detergent wastewater

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Abstract. Detergent wastewater contains pollutants, mainly nutrients (phosphor), that have harmful impact on the environment (eutrophication). Electrocoagulation is an alternative for treatment of detergent waste, so that the levels of pollutants contained in the wastewater can be reduced and the treated wastewater can be discharged to the environment safely. The purpose of this study is to identify the effect of voltage and contact time on the electrocoagulation process using aluminum electrodes in removing nutrients and other pollutants of detergent wastewater. The electrocoagulation process was carried out using aluminum electrodes. The detergent wastewater before and after treatments were characterized, and the effect of voltage and process duration on removal of pollutant levels in detergent waste was analyzed to determine the best operating condition of the treatment. The voltage of 15, 18, 21 and 24 volts were evaluated at various durations of electrocoagulation process. The results showed that the electrocoagulation process was able to reduce ammonium and phosphate and also color parameter, turbidity, TSS, MBAS and COD. The pH parameter values increased during the electrocoagulation process. The best combination of treatments was identified at 21 volts for 120 minutes, with an energy consumption of 0.084 kWh/liter and an estimated cost of only Rp 377/liter.

Keywords: aluminum electrode, detergent wastewater treatment, electrocoagulation, nutrients removal

1. Introduction

Detergent waste is liquid waste produced from the laundry industry and household activities. The main compounds found in detergents are surfactants, builders (phosphate compounds) and additives. Surfactants and builders can cause direct and indirect effects on the environment and humans [1]. Surfactants can eliminate natural moisture on the surface, causing rough surface and increase the permeability of the outer surface. Phosphates used as builders in detergents are commonly found in the form of Sodium Tri Poly Phosphate (STPP). Phosphate is one of the important nutrients needed by living things (plants and animals) and is non-toxic. Nitrogen compounds contained in detergent waste will also affect the metabolism of organisms found in the bodies of water. However, too much phosphate and nitrogen in the environment can cause excessive eutrophication in water so that it can cause oxygen deficiency as a result of algal growth (phytoplankton) and other uncontrolled aquatic biota. Algae and other aquatic biota are food sources for bacteria, so that uncontrolled algal growth can result in an
excessive bacterial population increase. Bacteria will use oxygen contained in water, causing water to lack oxygen and thus will endanger the life of aquatic creatures and their surroundings [1].

Detergent wastewater treatment before being discharged into the environment can be done to minimize the impact caused by the waste. Electrocoagulation is a waste treatment technique which is carried out by combining electrochemical processes and flocculation-coagulation processes [2]. The principle used in the electrocoagulation is to use electrode plates which are inserted into vessels containing liquid waste to be treated. Current flowed in the electrocoagulation process will flow to the electrode plate so as to produce ions that can act like coagulants to bind impurities in the waste. Aluminum is one type of electrode that can be used in the electrocoagulation process. Aluminum electrodes are able to conduct electricity well and have a high resistance to corrosion [3].

Direct electric current (DC) which is flowed to the aluminum electrode will cause a reduction reaction at the cathode to produce OH$^{-}$ and H$_2$ ions, while at the anode pole the decay of Al$^{3+}$ ions will occur. Al$^{3+}$ ions which decay will then be bound with OH ions so that they will form Al(OH)$_3$ compounds. Al(OH)$_3$ compound will act as a coagulant which will adsorb organic or inorganic compounds in the waste. The formed hydrogen gas will strengthen hydrodynamic process so that the flotation process in the reactor increases [2].

The electrocoagulation process is influenced by several factors, namely temperature, electric current density, contact time, voltage, acid content (pH), plate thickness and electrode distance [4]. Waste treatment using electrocoagulation method has several advantages, namely the floc produced from the electrocoagulation process is the same as produced by normal coagulation, the ability to reduce the content of colloids/smallest particles in the waste is faster because the application of electricity into the water will accelerate the process, gas bubbles produced during the electrocoagulation process will bring pollutants to the surface to facilitate the separation process, and there is a high process efficiency because waste treatment with this method is not affected by temperature, does not require pH control, and does not require additional chemicals. As for the drawbacks, waste treatment using this method cannot be used to treat wastes which have high electrolyte properties because it will cause a short-circuit between electrodes, electricity is quite expensive, and we need to replace electrode plates due to corrosion [5]. This study aims to identify the effect of voltage and contact time on the electrocoagulation process using aluminum electrodes in the removal of nutrients and other pollutants contained in detergent wastewater.

2. Research method

2.1. Materials and tools
The materials used consist of detergent wastewater, distilled water and chemicals for characterizing detergent wastewater and analysing the reduction of nutrient content contained in the waste. The tools used are power supply, aluminium electrodes, cables, pump controllers, analytical balance, pH meters, HACH spectrophotometers, turbidimeters, and glassware. The test equipment scheme can be seen in figure 1.
2.2. Research method

2.2.1. Wastewater characterization. At this stage characterization of detergent wastewater which will be used as a test sample was done. Detergent wastewater was characterized to determine phosphate, ammonia, and MBAS (Methylene Blue Active Substance) concentration, COD (Chemical Oxygen Demand) level, pH value, color value, turbidity and TSS (Total Suspended Solid) content, prior to electrocoagulation.

2.2.2. Main Research. Detergent wastewater which was characterized will then be treated by electrocoagulation method using aluminum electrodes with electrical voltage variations (15, 18, 21, and 24-volts) and time variations (30, 60, 90 and 120 minutes). The electro coagulated waste was analyzed to determine the concentration of phosphate, ammonia, MBAS, COD level, pH value, color value, turbidity and TSS content therein, then it would be compared with the waste characterization result. This was done to determine the effect given by the electrocoagulation process to detergent wastewater. Laboratory analysis of these parameters was carried out using standard analysis procedures, according to APHA ed. 21th 4500-P 2005 for testing phosphate concentrations, SNI 06-6989.30-2005 for testing ammonia concentrations, SNI 06-6989.51-2005 for testing MBAS concentrations, APHA Ed. 21th 5220-C.2005 for testing COD levels, APHA Ed.21th 4500-H + B.2005 for testing pH values, APHA Ed.21th 2120-C.2005 for testing color values, APHA Ed.21th 2120-B.2005 for turbidity tests, and APHA Ed.21th 2540-D.2005 for TSS content tests.

2.2.3. Experimental design. The experimental design used in this study was a Factorial Complete Randomized Design with two replications. There were two treatment factors used, namely contact time and voltage. The experimental design model for this study was as follow [6]:

\[ Y_{ijk} = \mu + A_i + B_j + A_iB_j + \epsilon_{ijk} \]  \hspace{1cm} (1)

\( Y_{ijk} \) = The results of observations for contact time treatment \( i \)-th and voltage treatment \( j \)-th on replicates \( k \)-th.
\( \mu \) = Overall mean effect
\( A_i \) = Effect of the \( i \)-th level of the contact time treatment
\( B_j \) = Effect of the \( j \)-th level of the voltage treatment
\( A_iB_j \) = Effect of the interaction between \( A_i \) and \( B_j \)
\( \epsilon_{ijk} \) = Random error component

Factors examined in this study include:
\( A \) = Contact Time
A1 = 0 minutes
A2 = 30 minutes
A3 = 60 minutes
A4 = 90 minutes
A5 = 120 minutes
B = Voltage
B1 = 15 volt
B2 = 18 volt
B3 = 21 volt
B4 = 24 volt

Data analysis was carried out by focusing on the elimination of the nutrient elements (phosphorus and ammonia) and other important parameters. In addition, the electrocoagulation process was also evaluated in terms of energy and costs requirements for treating detergent wastewater.

3. Result and discussion

3.1. Detergent wastewater characterization result
Detergent wastewater used as sample in this study was taken from the laundry industry located in Babakan Village, Bogor, West Java. The result of detergent wastewater characterization can be seen in table 1.

| Parameters | Units | Values             | Quality Standards |
|------------|-------|--------------------|-------------------|
| Phosphate  | mg/l  | 18.28±0.35         | 2                 |
| Ammonia    | mg/l  | 7.64±0.19          | 5 – 10            |
| MBAS       | mg/l  | 77.83±2.17         | 3                 |
| COD        | mg/l  | 2296.80±112.01     | 180               |
| pH         |       | 7.20±0.14          | 6 – 9             |
| Color      | PtCo  | 2818.50±23.33      | -                 |
| Turbidity  | NTU   | 169.10±3.18        | -                 |
| TSS        | mg/l  | 727.50±3.54        | 60                |

*Source: Regulation of the Minister of Environment of the Republic of Indonesia No. 5/2014 concerning Wastewater Quality Standards for Businesses and/or Activities of Soap, Detergent and Vegetable Oil Products Industry

*Source: Regulation of the Minister of Environment of the Republic of Indonesia No. 5/2014 concerning Wastewater Quality Standards for Businesses and/or Activities that Do Not Have Wastewater Quality Standards Set

3.2. Effect of electrocoagulation process on phosphate concentration
The analysis result of phosphate concentrations in detergent wastewater treated using electrocoagulation method showed a decrease in phosphate concentration from an initial value of 18.82 mg/l to 2.89 mg/l. The decrease in phosphate levels in detergent wastewater after treatment occur because phosphate which had negative ions (PO$_4^{3-}$) would be bound with Al$^{3+}$ ions produced by the anode through oxidation in the electrocoagulation process producing colloids which would be used as coagulants [6]. ANOVA test result (α = 0.05) on the phosphate parameters showed that the contact time, electrical voltage and interaction (contact time and voltage) during the electrocoagulation process affected the phosphate content of detergent wastewater (the ANOVA test results are not presented). The effect of the electrocoagulation process on phosphate concentrations in detergent wastewater can be seen in figure 2.
3.3. Effect of electrocoagulation process on ammonia concentration

The initial characterization result showed that the concentration of ammonia from untreated detergent wastewater was 7.64 mg/l. Ammonia concentration decreased after the electrocoagulation process was carried out with a value of 1.76 mg/l. The decreased in ammonia concentration was the result of oxidation of ammonia to the electrodes used to form N\textsubscript{2} and H\textsubscript{2}. This oxidation reaction was controlled by the mass transfer of ammonia to the electrode surface [8]. ANOVA test results ($\alpha = 0.05$) on ammonia parameters indicate that the contact time, voltage and interaction (contact time and voltage) during the electrocoagulation process affected the ammonia content of detergent wastewater (the ANOVA test results are not presented). The effect of electrocoagulation process on ammonia concentration in detergent wastewater can be seen in figure 3.

3.4. Effect of electrocoagulation process on MBAS concentration

Detergent wastewater used as a sample in this study had an MBAS concentration of 77.83 mg/l. The electrocoagulation process caused a decrease in the concentration of MBAS in detergent wastewater with the smallest value of 20.72 mg/l. The decrease of MBAS concentration in detergent wastewater could be caused by the surfactant adsorption process on the particles surface to form a hydrophobic surface. This would cause particles in the wastewater to rise to the surface with the help of bubble gas
formed during the electrocoagulation process [9]. The influence of the electrocoagulation process on the MBAS concentration in detergent wastewater can be seen in figure 4.

![Figure 4](image)

**Figure 4.** The influence of the electrocoagulation process on the MBAS concentration in detergent wastewater.

ANOVA test results ($\alpha = 0.05$) on the MBAS parameter showed that among contact time, voltage and interaction (contact time and voltage) factors, only the time factor affected the MBAS value of detergent waste during the electrocoagulation process (the ANOVA test results table is not presented).

3.5. **Effect of electrocoagulation process on COD level**

Detergent wastewater characterization result showed that the COD value of untreated detergent wastewater was 2296.80 mg/l. The COD value in detergent wastewater decreased after the electrocoagulation process was carried out with a value of 118.80 mg/l. Decrease in COD value in detergent wastewater could be caused by direct oxidation at the anode which was then followed by coagulation and flotation process [9]. In addition, it was known that organic compounds in detergent wastewater such as surfactants, ammonia, and phosphate have decreased after the process, thus decreasing the COD value. ANOVA test results ($\alpha = 0.05$) on the COD parameters showed that the contact time, voltage and interaction (contact time and voltage) during the electrocoagulation process affected the COD concentration of detergent wastewater (the ANOVA test results are not presented). The electrocoagulation process effect on the COD value in detergent wastewater can be seen in figure 5.

![Figure 5](image)

**Figure 5.** The electrocoagulation process effect on the COD value in detergent wastewater.
3.6. Effect of electrocoagulation process on pH value

Detergent wastewater characterization result shows that detergent wastewater had an initial pH of 7.2. The pH value in the detergent wastewater increased after electrocoagulation with the highest pH value of 8.70. The increase in pH that occurs in the electrocoagulation process was caused by the accumulation of OH⁻ ions originating from the sample reduction reaction at the cathode [10]. The number of OH⁻ ions formed increased the alkalinity in the treated waste. While the quality standard values for pH parameters range from pH 6 to pH 9, ANOVA test results (α = 0.05) showed that the contact time and voltage during the electrocoagulation process affected the pH of the detergent waste, while the interaction factors (contact time and voltage) did not have a significant effect on the pH value (the ANOVA test results are not presented). The effect of the electrocoagulation process on the pH value in detergent wastewater can be seen in figure 6.

![Figure 6](image)

**Figure 6.** The effect of the electrocoagulation process on the pH value in detergent wastewater.

3.7. Effect of electrocoagulation process on color value

The color parameter value in detergent wastewater after electrocoagulation process decreased. The color parameter value obtained from initial characterization was 2818.50 PtCo and decreased to 792 PtCo after the electrocoagulation process. This decolorization occurred due to the coagulation process of dyes in detergent wastewater by coagulant Al(OH)₃ formed during the electrocoagulation process. This coagulation process was caused by differences in charge between the dye and the coagulant Al(OH)₃. The decrease in the value of color parameters in the electrocoagulation process would be faster along with the addition of a large voltage. The greater the electric voltage in the electrocoagulation process, the greater the current flowing, this would form more and more Al(OH)₃ coagulants making the coagulation process faster [11]. ANOVA test results (α = 0.05) showed that the contact time, voltage and interaction (time and voltage) during the electrocoagulation process affected the color of the detergent wastewater (the ANOVA test results are not presented). The effect of the electrocoagulation process on the color value in the detergent wastewater can be seen in figure 7.
3.8. Effect of electrocoagulation process on turbidity

Detergent wastewater used as a sample in this study had a high turbidity, 169.10 NTU. The electrocoagulation process decreased the turbidity to a value of 43.40 NTU. This decrease occurred due to the coagulation process carried out by coagulant Al(OH)$_3$ on the suspended solids in the detergent wastewater. Coagulants resulting from the electrocoagulation process would break down pollutants which cause turbidity and then charge instability would occur [12]. This coagulation process would then form insoluble flocks enabling stability. ANOVA test results ($\alpha = 0.05$) on the turbidity parameters showed that the contact time, voltage and interaction (contact time and voltage) during the electrocoagulation process affected the turbidity of detergent waste (the ANOVA test results are not presented). The effect of the electrocoagulation process on turbidity in detergent wastewater can be seen in figure 8.

![Figure 7](image1.png)

**Figure 7.** The effect of the electrocoagulation process on the color value in the detergent wastewater.

3.9. Effect of electrocoagulation process on TSS content

TSS value obtained from the detergent wastewater characterization result was 727.50 mg/l. The analysis result of detergent wastewater treated by the electrocoagulation process showed a decrease in TSS content as much as 92.50 mg/l. The TSS reduction occurred because of suspended materials in solid form in the waste will be easily coagulated with Al(OH)$_3$ coagulant or adsorbed into bubble gas formed during the process. Coagulated solids would form flocks and settle at the bottom of the reactor, while

![Figure 8](image2.png)

**Figure 8.** The effect of the electrocoagulation process on turbidity in detergent wastewater.
solids flattened by hydrogen gas were brought to the surface so that they could be separated [13]. ANOVA test results ($\alpha = 0.05$) on TSS parameters showed that contact time, voltage and interaction (contact time and voltage) during the electrocoagulation process affected the TSS value of detergent waste (the ANOVA test results are not presented). The effect of the electrocoagulation process on TSS content in detergent wastewater can be seen in figure 9.

![Figure 9. The effect of the electrocoagulation process on TSS content in detergent wastewater](image.png)

### 3.10. Energy and cost requirements

Wastewater treatment using electrocoagulation methods or other methods requires certain costs and energy. Cost is one of the problems in handling waste that was not considered by the company or industry [14]. Energy needs were calculated based on the power usage and the length of time used in the process, while costs was calculated based on the total amount of the used materials and equipment during the process and the estimated electricity costs [15]. The following equation was used to calculate the energy needed during the electrocoagulation process:

$$ W = P \times t $$  \hspace{1cm} (2)

$$ W = V \times I \times t $$  \hspace{1cm} (3)

Where is,

- $W$ = Electrical energy used (kWh)
- $P$ = Power (watt)
- $t$ = Time (hour)
- $V$ = Voltage (volt)
- $I$ = Amperage (ampere)

Material requirements in electrocoagulation, soluble plates are calculated by the formula:

$$ w = \frac{I \times t \times Mr}{n \times F} $$  \hspace{1cm} (4)

Where is,

- $w$ = Mass (kg)
- $t$ = Time (hour)
- $I$ = Amperage (ampere)
$Mr$ = Molecular mass
$n$ = The number of moles of electrons for each mole of substance or valence
$F$ = Faraday constant (coulomb)

Based on the analysis of the eight parameters tested, namely phosphate, ammonia, MBAS, COD, pH, color, turbidity and TSS it was known that the combination of 24-volt treatment for 120 minutes resulted in the greatest decrease in the phosphate, ammonia, MBAS, COD, color, turbidity and TSS. However, from the statistical test it was known that the result given by the 21-volt treatment combination for 120 minutes were not significantly different from the result given by the 24-volt treatment combination for 120 minutes on the decrease in the value of the phosphate, COD and pH parameters.

The energy and costs required in the waste treatment process were factors considered in determining the best treatment combination. The total costs required in the treatment of detergent wastewater by the electrocoagulation method using aluminum electrodes at a 21-volt treatment for 120 minutes was Rp.377,-/liter, while a 24-volt treatment for 120 minutes requires Rp.390,-/liter. Based on the calculation result, the combination of 21-volt treatment for 120 minutes required less energy and costs than the that of 24 volts for 120 minutes.

4. Conclusion and recommendation

4.1. Conclusion
Detergent wastewater that had not been processed had a phosphate concentration of 18.28 mg/l, ammonia concentration of 7.64 mg/l, MBAS with a concentration of 77.83 mg/l, COD value of 2296.80 mg/l, pH value of 7.20, color of 2818.50 PtCo, turbidity of 169.10 NTU and containing TSS of 727.50 mg/l. The electrocoagulation process carried out in detergent wastewater caused a decrease in the phosphate, ammonia, MBAS, COD level, color value, turbidity and TSS content, while the pH value increases. The energy needed for the waste treatment method with the best combination of treatments in this study (21-volts for 120 minutes) was 0.084 kWh/liter with a total cost of Rp.377,-/liter.

4.2. Recommendation
Results of this study indicate that electrocoagulation can effectively reduce levels of phosphate and other pollutants in detergent wastewater significantly. Further research is needed to evaluate its performance on a larger scale for treating detergent wastewater and other wastewater with similar pollutants.

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