Effect of electrode configuration and voltage variations on electrocoagulation process in surfactant removal from laundry wastewater

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Abstract. Almost all human life requires water, one of which is washing clothes. However, city people tend to use laundry services. It is necessary to treat laundry wastewater because it contains parameters that can cause environmental pollution. A promising technique has been found to treat urban wastewater, especially laundry wastewater. An electrochemical method for water treatment is known as electrocoagulation, in which a solution of an active coagulant in the form of metal ions (aluminum or iron) is introduced into a solution. In electrocoagulation, the processes of adsorption, coagulation, precipitation, and flotation taking place. This research was conducted to determine the impact of current on electrocoagulation using Al-Al, Fe-Fe, Al-Fe, Fe-Al electrodes in reducing surfactant levels in laundry wastewater with variations in the voltage used were 20 V, 30 V, 40 V, and 60 V. The results showed that the electrocoagulation process could remove surfactants in laundry wastewater. A voltage of 30 volts with Al-Al electrode configuration was used for 30 minutes to obtain optimum conditions so that it will get a surfactant effluent concentration of 5.77 mg/L with a removal efficiency of 72.89%.

1. Introduction

The majority of the needs and activities of human life use water; therefore, water is a vital element for human life. The water resulting from the human activity process is called wastewater. One of the activities that use water is washing clothes. People in the city tend to use laundry services for doing their clothes. Because of this, laundry service activities are increasing every year in Indonesia, especially in the metropolitan areas. This service has great benefits for the community, both for providers and users of the laundry service.

The laundry process uses many chemicals to remove stains from fabrics, such as surfactants, builders, bleaching agents, enzymes [1]. Laundry wastewater can have adverse effects on the environment, such as surfactants which can have a toxic effect on flora and fauna in water bodies (0.8 – 2.0 mg/L) [2,3,4]. The choice of technology in laundry wastewater treatment must meet several criteria, including efficiency, low operational and maintenance costs, simplicity, and reliability in treating laundry wastewater. Coagulation is one method that can be used to treat laundry wastewater because the costs incurred are relatively cheap, with a reasonably high removal efficiency [5].

A technique that is quite promising in treating urban wastewater, especially for laundry wastewater, is electrocoagulation. In electrocoagulation, an electrochemical process occurs by releasing an active
coagulant in the form of metal ions (aluminum or iron) into a solution. The mechanism of the process includes adsorption, coagulation, precipitation, and flotation [6,7,8]. To produce iron aluminum or iron hydroxide by reaction at the anode, an aluminum or iron anode is used in electrocoagulation. This reaction at the anode is followed by hydrolysis.

This study aims to determine the effect of the electrocoagulation process used to remove surfactants from wastewater using several voltages and electrode configuration variations.

2. Methodology

2.1. Preliminary test

The preliminary test was carried out using a voltage of 20 volts and the type of aluminum electrode for the anode and cathode. The voltage used is 20 volts, referring to research, that the optimum condition for treating palm oil waste with electrocoagulation technology is at a voltage condition of 20 volts which can remove 93.37% (COD); 97.64% (TSS); and 40.78% (TDS). The type of electrode used in the preliminary test is Aluminum, referring to the research done that uses electrocoagulation technology to process glyphosate in pesticides by comparing several electrodes such as aluminum, iron, steel, and copper.

2.2. Real test

The actual test refers to the preliminary test, the preliminary test using the Al-Al electrode configuration at a voltage of 20 volts can eliminate surfactant by 63% so that the variations that will be used include variations in voltage (20 volts, 30 volts, 40 volts, 60 volts) and variations in the configuration of the type of electrode at the anode and cathode (Al-Al, Al-Fe, Fe-Al, Fe-Fe). The parameters used to determine the success of the research include surfactants and phosphates. Testing these parameters at sampling times of 5 minutes, 10 minutes, 15 minutes, 20 minutes, 25 minutes, and 30 minutes is calculated when the effluent begins to overflow in the reactor.

2.3. Surfactant test

The surfactant test was carried out by SNI 06-6989.51-2005 on how to test the concentration of anionic surfactants with a spectrophotometer using methylene blue. The working principle is that anionic surfactants react with methylene blue to form blue ion pairs soluble in organic solvents. The intensity of the blue color formed was measured by a spectrophotometer at a wavelength of 652 nm. The measured uptake is equivalent to the anionic surfactant concentration.

The working steps are as follows:
1. Samples of laundry wastewater were taken 50 mL and put into a 250 mL separatory funnel;
2. Samples were added with 12.5 mL of methylene blue solution;
3. 5 mL of chloroform was added and shaken vigorously for 30 seconds, occasionally opening the funnel cover to release the gas;
4. Phase separation will occur, shake the separating funnel slowly, if an emulsion is formed add a little isopropyl alcohol until the emulsion disappears;
5. The bottom layer (chloroform phase) is separated and accommodated in another separating funnel;
6. Re-extract the aqueous phase in a separatory funnel by repeating steps (4) to (6) 2 times and unite all the chloroform phases;
7. Add 25 mL of washing solution to the combined chloroform phase and shake vigorously for 30 seconds;
8. Add 5 mL of chloroform, shake vigorously for 30 seconds, opening the funnel cap to release the gas;
9. Phase separation will occur, shake the separating funnel slowly;
10. The bottom layer of the bottom layer (chloroform phase) is separated and accommodated in a volumetric flask;
11. Re-extract the aqueous phase in a separatory funnel by repeating steps (8) to (10) 2 times and unite all the chloroform phases;
12. The extracted sample was measured with a spectrophotometer at a wavelength of 652 nm and recorded the absorption.

3. Result and discussion

3.1. Characteristic of laundry wastewater

Before being treated by the electrocoagulation method, samples of laundry wastewater were tested for parameters pH, COD, TSS, TDS, phosphate, and surfactant. The following are the results of the initial characteristics of laundry wastewater before processing with electrocoagulation with several treatments:

| Parameters | Unit | Test Results | Quality Standard* | Description |
|------------|------|--------------|-------------------|-------------|
| Surfactant | mg/L | 21.30        | 3                 | Not Meet    |
| Phosphate  | mg/L | 9.58         | 2                 | Not Meet    |
| pH         | -    | 8.7          | 6-9               | Meet        |
| TSS        | mg/L | 260          | 60                | Not Meet    |
| TDS        | ppt  | 1.55         | -                 | -           |

*) Based on Central Java Regional Regulation No. 5 of 2012 concerning Wastewater Quality Standards in the Soap and Detergent Industry

In this case, laundry wastewater has a surfactant content of 21.3 mg/L, which does not meet the quality standard for soap and detergent industry wastewater treatment which is 3 mg/L. Therefore, a minimum surfactant concentration reduction efficiency of 85.91% is required to meet the quality standard. In this study, laundry wastewater treatment with the electrocoagulation method was carried out by several treatments with variations in electrode configuration and voltage variations.

Laundry wastewater tends to have an alkaline pH, with an initial pH of 8.7. Laundry wastewater treatment with this coagulation method causes the pH to increase because of an OH-release reaction at the cathode.

3.2. Effect of electrode configuration and voltage variations on surfactant value

The results of testing the concentration of surfactant using methylene blue in laundry wastewater after processing with the electrocoagulation method on a laboratory scale using two electrode plates made of aluminum (Al) and iron (Fe) with variations in the configuration of the Al-Al, Al-Fe, Fe-Fe, and Fe-Al as anodes-cathodes, as well as the voltage from the power supply with variations of 20 volts, 30 volts, 40 volts, and 60 volts are shown in the following research results. Research samples were taken every 5 minutes for 30 minutes after the treated wastewater overflowed with 20 minutes of HRT, so the contact time was 25 minutes to 50 minutes. The following are the results of the surfactant concentration test with Al and Fe electrode configurations:
Table 2. Al-Al electrode configuration surfactant concentration test results.

| Voltage (volt) | Time (minute) | Initial Concentration (mg/L) | Final Concentration (mg/L) | Removal Efficiency (%) |
|---------------|---------------|------------------------------|---------------------------|------------------------|
| 20            | 25            | 21.3                         | 11.91                     | 44.07                  |
|               | 30            | 21.3                         | 12.66                     | 40.57                  |
|               | 35            | 21.3                         | 11.86                     | 44.32                  |
|               | 40            | 21.3                         | 11.27                     | 47.08                  |
|               | 45            | 21.3                         | 11.21                     | 47.39                  |
|               | 50            | 21.3                         | 12.62                     | 40.76                  |
| 30            | 25            | 21.3                         | 8.72                      | 59.08                  |
|               | 30            | 21.3                         | 5.77                      | 72.89                  |
|               | 35            | 21.3                         | 9.45                      | 55.64                  |
|               | 40            | 21.3                         | 12.64                     | 40.64                  |
|               | 45            | 21.3                         | 12.18                     | 42.82                  |
|               | 50            | 21.3                         | 11.37                     | 46.64                  |
| 40            | 25            | 21.3                         | 10.49                     | 50.76                  |
|               | 30            | 21.3                         | 11.63                     | 45.39                  |
|               | 35            | 21.3                         | 11.98                     | 43.76                  |
|               | 40            | 21.3                         | 11.73                     | 44.95                  |
|               | 45            | 21.3                         | 10.51                     | 50.64                  |
|               | 50            | 21.3                         | 10.97                     | 48.51                  |
| 60            | 25            | 21.3                         | 10.62                     | 50.14                  |
|               | 30            | 21.3                         | 13.19                     | 38.07                  |
|               | 35            | 21.3                         | 10.89                     | 48.89                  |
|               | 40            | 21.3                         | 11.34                     | 46.76                  |
|               | 45            | 21.3                         | 11.15                     | 47.64                  |
|               | 50            | 21.3                         | 10.37                     | 51.33                  |

Based on Table 2, it can be seen that the highest removal efficiency at the Al-Al electrode configuration is 72.89% from the initial surfactant concentration of 21.3 mg/l to a concentration of 5.77 mg/l, achieved at a voltage of 30 volts at a contact time of 30 minutes.

Table 3. Al-Fe electrode configuration surfactant concentration test results.

| Voltage (volt) | Time (minute) | Initial Concentration (mg/L) | Final Concentration (mg/L) | Removal Efficiency (%) |
|---------------|---------------|------------------------------|---------------------------|------------------------|
| 20            | 25            | 21.3                         | 7.94                      | 62.70                  |
|               | 30            | 21.3                         | 10.12                     | 52.51                  |
|               | 35            | 21.3                         | 10.30                     | 51.64                  |
|               | 40            | 21.3                         | 8.13                      | 61.83                  |
|               | 45            | 21.3                         | 10.42                     | 51.08                  |
|               | 50            | 21.3                         | 10.06                     | 52.76                  |
| 30            | 25            | 21.3                         | 11.69                     | 45.14                  |
Based on Table 3, the highest removal efficiency at the Al-Fe electrode configuration was 62.70% from the initial surfactant concentration of 21.3 mg/L until it reached a concentration of 7.94 mg/L, achieved at a voltage of 20 volts at a contact time of 25 minutes.

Table 4. Fe-Fe electrode configuration surfactant concentration test results.

| Voltage (volt) | Time (minute) | Initial Concentration (mg/L) | Final Concentration (mg/L) | Removal Efficiency (%) |
|----------------|---------------|------------------------------|----------------------------|------------------------|
| 20             |               |                              |                            |                        |
| 25             | 21.3          | 11.34                        | 46.76                      |
| 30             | 21.3          | 10.95                        | 48.58                      |
| 35             | 21.3          | 10.63                        | 50.08                      |
| 40             | 21.3          | 11.30                        | 46.95                      |
| 45             | 21.3          | 11.26                        | 43.70                      |
| 50             | 21.3          | 12.82                        | 39.82                      |
| 30             |               |                              |                            |                        |
| 25             | 21.3          | 11.11                        | 47.83                      |
| 30             | 21.3          | 10.70                        | 49.76                      |
| 35             | 21.3          | 9.73                         | 54.33                      |
| 40             | 21.3          | 9.91                         | 53.45                      |
| 45             | 21.3          | 10.59                        | 50.26                      |
| 50             | 21.3          | 10.09                        | 52.64                      |
| 40             |               |                              |                            |                        |
| 25             | 21.3          | 12.10                        | 43.20                      |
| 30             | 21.3          | 10.69                        | 49.83                      |
| 35             | 21.3          | 13.59                        | 36.20                      |
| 40             | 21.3          | 12.79                        | 39.95                      |
| 45             | 21.3          | 13.46                        | 36.82                      |
| 50             | 21.3          | 12.15                        | 42.95                      |
The highest removal efficiency was 54.33% from the initial surfactant concentration of 21.3 mg/L to a concentration of 9.73 mg/L, achieved at a voltage of 30 volts on the Fe-Fe electrode configuration with a sampling time of 15 minutes. 

**Table 5.** Fe-Al electrode configuration surfactant concentration test results.

| Voltage (volt) | Time (minute) | Initial Concentration (mg/L) | Final Concentration (mg/L) | Removal Efficiency (%) |
|---------------|--------------|-------------------------------|---------------------------|------------------------|
| 25            | 25           | 21.3                          | 13.35                     | 37.32                  |
| 30            | 25           | 21.3                          | 12.96                     | 39.14                  |
| 35            | 25           | 21.3                          | 13.16                     | 38.20                  |
| 40            | 25           | 21.3                          | 13.08                     | 38.57                  |
| 45            | 25           | 21.3                          | 13.35                     | 37.32                  |
| 50            | 25           | 21.3                          | 13.86                     | 34.95                  |
| 20            | 25           | 21.3                          | 11.53                     | 45.89                  |
| 30            | 25           | 21.3                          | 12.15                     | 42.95                  |
| 35            | 25           | 21.3                          | 13.76                     | 35.39                  |
| 40            | 25           | 21.3                          | 11.99                     | 43.70                  |
| 45            | 25           | 21.3                          | 14.23                     | 33.20                  |
| 50            | 25           | 21.3                          | 11.23                     | 47.26                  |
| 30            | 25           | 21.3                          | 12.19                     | 42.76                  |
| 35            | 25           | 21.3                          | 11.75                     | 44.82                  |
| 40            | 25           | 21.3                          | 14.36                     | 32.57                  |
| 45            | 25           | 21.3                          | 13.56                     | 36.32                  |
| 50            | 25           | 21.3                          | 13.32                     | 37.45                  |
| 40            | 25           | 21.3                          | 12.42                     | 41.70                  |
| 35            | 25           | 21.3                          | 11.66                     | 45.26                  |
| 40            | 25           | 21.3                          | 10.86                     | 49.01                  |
| 45            | 25           | 21.3                          | 12.83                     | 39.76                  |
| 50            | 25           | 21.3                          | 11.35                     | 46.70                  |
| 60            | 25           | 21.3                          | 11.94                     | 43.95                  |
| 30            | 25           | 21.3                          | 12.17                     | 42.89                  |
| 35            | 25           | 21.3                          | 11.95                     | 43.89                  |
| 40            | 25           | 21.3                          | 11.85                     | 44.39                  |
| 45            | 25           | 21.3                          | 13.08                     | 38.57                  |
| 50            | 25           | 21.3                          | 12.92                     | 39.32                  |

Based on Table 5, the highest removal efficiency at the Fe-Al electrode configuration is 49.01% from the initial surfactant concentration of 21.3 mg/L until it reaches a concentration of 10.86 mg/L, achieved at a voltage of 40 volts at a contact time of 35 minutes. The efficiency of reducing the surfactant
concentration of the overall treatment is quite good, but the surfactant concentration has not been able to meet the quality standard of Central Java Regional Regulation No. 5 of 2012 concerning Wastewater Quality Standards 3 mg/L.

Theoretically, the decrease in surfactant concentration in the electrocoagulation method in laundry wastewater is due to the oxidation and reduction processes in the electrocoagulation reactor. Surfactants in laundry wastewater are colloidal; there are two types of colloids formed: colloids formed from surfactants and contaminants on clothing, and colloids formed from a collection of surfactants, commonly called surfactant micelles. In principle, the coagulation process occurs when the particles in the wastewater are destabilized so that they break up and form precipitable flocs. The destabilization process in laundry wastewater uses an electric field arising from the electrodes to move the particles [9]. At the electrodes (anodes), gas is formed, the resulting gas in the form of oxygen gas and hydrogen gas will affect the reduction.

Based on the measurement results of surfactant concentration from each treatment with various electrode configurations and voltage variations, the maximum removal result for reducing surfactant concentration was obtained using the Al-Al electrode configuration with a large voltage of 20 volts. The use of varying electrode configurations has a significant effect on the removal of surfactant concentrations. The results of the four-electrode configurations used, the efficiency of reducing the surfactant concentration to the maximum, is achieved at the Al-Al electrode configuration conditions. In the voltaic series, Al metal is located to the left of Fe, which means that Al metal is more easily oxidized than Fe metal. In the voltaic series, the further to the left, it is more easily oxidized, which means that Al is easier to oxidize or release electrons more easily than Fe.

4. Conclusion

Based on the data analysis that has been carried out, it shows that applying the electrocoagulation process with several electrode configurations and voltages in laundry wastewater has succeeded in reducing the concentration of the amount of surfactant. The optimum condition for laundry wastewater treatment is to use an Al-Al electrode configuration with a voltage of 30 volts at a processing time of 30 minutes to obtain a surfactant effluent concentration of 5.77 mg/L with a removal efficiency of 72.89%.

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