The Effectivity of Aluminum Electrode for River Water Purification Using Electrocoagulation

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Abstract. Electrocoagulation process is expected to be widely applied not only in wastewater treatment but also in water purification. In this work, electrocoagulation process was used for clean water treatment. The effectivity of aluminum electrode in the electrocoagulation process has been investigated. The water samples used in the experimentation were obtained from the Bengawan Solo river. The samples were characterized to have a normal pH, high turbidity of 388,33 NTU, high organic matter shown from the KMnO4 value of 52,46 mg/L, alkalinity value 79,16 mg CaCO3/L, hardness value of 180 mg CaCO3/L and iron content of 4,59 mg/L. A set of experiments have been carried out to investigate the percentage of removal of water parameters using electrocoagulation processes compared to those with chemical coagulation processes. The chemical process was carried out with a jar test of alum dosage variation. In the electrocoagulation process 10 aluminum electrodes were used with an area of 100 cm2 at which all electrodes were mounted in series, with variations in time and current density. Jar test and electrocoagulation test result, both, show significant improvement of water parameters indicated by a high percentage of removal of turbidity, iron content and KMnO4 number. However, removal of hardness has not shown significant result, even in the electrocoagulation process of hard water.

Keywords. Electrocoagulation, Aluminum Electrode, Water Purification, River Water

1. Introduction

Raw material for clean water that is commonly used is surface water i.e. river water because of its availability. River water is very vulnerable to pollution because there are still many people or industries that dispose of liquid or solid waste into water bodies. Therefore, before the water can be utilized, the river water must be treated to remove the pollutants in order to produce the required water quality according to its application [1].

Raw water usually has turbid properties, high hardness, high metal content, high organic content, non-neutral pH, and so on. These problems may be overcome properly by using appropriate technology. Water treatment widely used is treatment with coagulant materials such as alum, FeCl3, PAC, lime, and others. Although the results of water treatment with chemicals are relatively clear, it requires skilled operators in determining the coagulant dose, especially if the quality of the raw water is uncertain. In addition, it produces a by-product in the form of sedimentation sludge which may
become another serious problem. If the water is in adverse condition, the chemicals used will also increase. This leads to the increase of processing operational costs.

Electrocoagulation is a water treatment technology that is widely applied to water and wastewater treatments. Many researches have been carried out on the application of this electrocoagulation system for wastewater treatment from various industries [2, 3, 4]. For example, the application of electrocoagulation for dairy wastewater treatment [5], tapioca wastewater [6], plating industrial wastewater [7], domestic wastewater [8], and so on.

Assuming the condition of surface water quality that contains many pollutants, electrocoagulation which is commonly applied for wastewater treatment should also be able to be used to treat clean water by removing water impurities. But this needs to be enhanced by researches on the operating conditions that are suitable for the characteristics of the raw water. Application of electrocoagulation to produce drinking water has been widely applied to certain water characteristics, such as application of electrocoagulation for turbidity removal [9, 10, 11], hardness removal [12, 13], fluoride removal [14], arsenic removal [15], and so on.

The research aimed to examine electrocoagulation variables that affect water quality parameters (pH, turbidity, TDS, hardness, alkalinity, Fe content, and KMnO₄ number) for raw water with specific characteristics, namely river water with complex pollutants, especially mud with colloidal size, hard water with high lime content and water with high iron content. This research will be carried out by looking for the relationship between variables that influence the electrocoagulation process to get the optimum conditions. Once the optimum condition has been achieved the research will proceed to continuous system experiments.

2. Methods

2.1. Water quality parameter test
The data collection method was carried out by measuring the characteristics of the raw water before and after treatment on a laboratory scale. Effectiveness of electrocoagulation by aluminum electrodes determined from some parameters such as pH, Total Dissolved Solid (TDS), turbidity, conductivity, hardness, KMnO₄ Number, and Fe content in water samples. The testing method used was according to the SNI and APHA standard.

2.2. Application of chemical coagulation process
Before the electrocoagulation water treatment was conducted, the jar test was done first with a chemical process using alum coagulant. This process was carried out as a comparison of the removal percentage in water parameters between the chemical process and electrocoagulation. The chemical process was carried out to determine the optimum alum dosage to get good water.

Six beaker glasses were filled with 500 mL river water and then was added to each glass with alum solution from 50 ppm to 100 ppm Al₂(SO₄)₃.18 H₂O. The glasses were then introduced in jar test equipment. In the jar test, first do a rapid stirring ±110 rpm for 1 minute, followed by a slow stirring ±30 rpm for 15 minutes and finally sedimentation for an hour.

2.3. Application of electrocoagulation process
Aluminum electrode was chosen for the experimentation as the electrode is the most appropriate electrode for electrocoagulation to obtain required parameters for drinking water. The electrocoagulation process was carried out in two stages. The first step was to test the electrolysis of the sample water to determine the effect of variation on the current density generated by the electrocoagulation process. The second stage was the electrocoagulation process to determine the removal percentage of water quality parameters.
2.3.1. Electrolysis test

The electrolysis test was carried out by varying the distance between the electrodes, electrode area, and voltage using two aluminum electrodes. This test was conducted to determine the effect of various parameters on the current density generated by the electrocoagulation process. The equipment in this process was assembled as illustrated in Figure 1 below.

![Figure 1. Schematic diagram of electrocoagulation in the electrolysis test](image)

2.3.2. Electrocoagulation process

The electrocoagulation process for the river water treatment with a bath system was carried out using 11 aluminum electrodes that were installed in series as illustrated in Figure 2. The first experiment was carried out at various times of 60, 90, 120, 150 and 180 seconds with a constant voltage of 40 V. The second experiment was performed at a current variation of 0.3, 0.5, 0.8, 1.2, and 1.5 A at different voltages for 120 seconds.

![Figure 2. Schematic diagram of electrocoagulation process in bath mode](image)

2.4. Calculation

Electrocoagulation performance was evaluated based on the removal efficiency of the parameter characteristics, namely pH, turbidity, hardness, alkalinity, KMnO₄ number, and Fe content. The removal percentage efficiency of chemical and electrocoagulation process was computed using an equation as a function of operating time by Eq. (1):
Removal Percentage (%) = \frac{C_0 - C_t}{C_0} \times 100\% \quad (1)

Where \( C_0 \) and \( C_t \) are water parameter values before and after treatment.

3. Result and Discussion

3.1. Water characteristics

The sample water from the Bengawan Solo River can possibly be used as a source of clean water. However due to widespread pollution, it is necessary to treat it first in order to remove impurities. From the results of the water characteristics test, it can be seen that the water has a pH that tends to be normal with high turbidity, which is 388.33 NTU and the organic matter content shown by the KMnO_4 number of 52.46 mg/L, as shown in Table 1.

In this research, hard water and iron water were used to see the selectivity of hardness removal and iron content by electrocoagulation. The hard water sample used had high hardness (308.33 mg/L) which was sourced from groundwater in Bangsan Hamlet, Kedungtuban District. While the iron water sample was taken from Ngelo Village, Cepu District, which had an iron content of 10.77 ppm.

| Parameters                  | Test Method       | Water River | Hard Water | Iron Water |
|-----------------------------|-------------------|-------------|------------|------------|
| pH                          | pH meter          | 7.6         | 6.7        | 6.6        |
| Turbidity (NTU)             | Turbidity meter   | 388.33      | 0          | 13.5       |
| Conductivity (mS/cm)        | Conductivity meter| 0.32        | 0.44       | 0.64       |
| TDS (ppm)                   | TDS meter         | 228.33      | 308.33     | 455.67     |
| Total Hardness (ppm CaCO_3) | Titrimetric       | 180         | 302.67     | 586.67     |
| Fe Content (ppm)            | Spectrophotometer | 4.98        | 0.11       | 10.77      |
| KMnO_4 Number (ppm)         | Titrimetric       | 52.46       | 2.84       | 4.74       |
| Alkalinity (ppm CaCO_3)     | Titrimetric       | 79.16       | 160.74     | 241.65     |

3.2. Chemical treatment

Before the electrocoagulation water treatment was conducted, the jar test was carried out with a chemical process using alum coagulant. This process was carried out to see whether the electrocoagulation was more effective or not compared to the chemical in terms of the removal percentage in water parameters. The chemical process was carried out to determine the optimum alum dosage to obtain the required water quality.

Six beaker glasses were filled with 500 mL river water and alum solution of around 50 ppm to 100 ppm of \( \text{Al}_2(\text{SO}_4)_3 \cdot 18 \text{H}_2\text{O} \) was then added to each glass. The glasses were then introduced in a jar test equipment. In the jar test, first a rapid stirring \( \pm 110 \text{ rpm} \) for 1 minute was carried out, followed by a slow stirring of \( \pm 30 \text{ rpm} \) for 15 minutes and finally the glasses were unstirred for an hour to allow sedimentation process take place.

The jar test results show that the process of river water treatment using chemical coagulants effectively removes turbidity, organic matter content, and Fe content on the range 90-100 ppm of alum, as illustrated in Figure 3. However, removal of hardness and alkalinity has not shown significant result.
The addition of alum did not affect the pH. This was due to the alkalinity of the water sample. Since alkalinity is a chemical measurement of water’s ability to neutralize acids, when alum coagulant was added, these alkalis neutralize some of the acid. In simple terms, total alkalinity is a measurement of the water’s ability to resist change in pH. The ion that forms alkalinity in river water is the bicarbonate ion. Bicarbonates represent the major form of alkalinity in natural waters and are derived from the partitioning of CO₂ from the atmosphere and the weathering of carbonate minerals in rocks and soil.

The addition of the alum dose also increases the total dissolved solid (TDS) in the processed water, this is in line with the increasing conductivity.

3.3. Electrocoagulation treatment
Electrocoagulation is an alternative method to chemical coagulation in the treatment of water and wastewater [16]. The chemical reactions taking place at the aluminum cathode and anode are given as follows.

The reaction at the anode:

\[
\text{Al(s)} \rightarrow \text{Al}^{3+} (aq) + 3e^{-} (l) \quad (2)
\]

At alkaline conditions:

\[
\text{Al}^{3+} (aq) + 3\text{OH}^{-} (aq) \rightarrow \text{Al(OH)}_3 \quad (3)
\]

At acidic conditions:

\[
\text{Al}^{3+} (aq) + 3\text{H}_2\text{O} (l) \rightarrow \text{Al(OH)}_3 (s) + 3\text{H}^+ (aq) \quad (4)
\]

The reaction at the cathode:

\[
2\text{H}_2\text{O} (l) + 2e^- \rightarrow \text{H}_2 (g) + 2 \text{OH}^- (aq) \quad (5)
\]

3.3.1. Electrolysis test of variation of distance between electrodes, electrode area, and voltage
The electrochemical tests were carried out with variations in the distance between electrodes, electrode area, and voltage using two aluminum electrodes in the Bengawan Solo water sample. This test was conducted to determine the effect of these variations on the current density generated by the electrocoagulation process.
Figure 4. (a) The influence of the electrode area on the current density, (b) The influence of the electrode’s distance on the current density, and (c) the influence of the voltage on the current density

As shown in Figure 4. (a), the results of the two-electrode electrolysis test on various electrode area show that the larger the electrode area, the greater the current density. From the results of the two-electrode electrolysis test with variations in the distance between the electrodes, it can be concluded that the greater the distance between the electrodes, the smaller the resulting current density will be, as illustrated in Figure 4. (b) From the results of the electrolysis of two electrodes with voltage variations, it can be concluded that the greater the voltage applied, the greater the current density, as illustrated in Figure 4. (c) Thus, higher current densities used for electrocoagulation can be achieved by increasing the electrode area, decreasing the inter electrode distance, and increasing the voltage.

3.3.2. Effect of operating time on electrocoagulation process

The electrocoagulation process of the batch system to treat river water was carried out using 11 electrodes that were installed in series with variations in time and current. The first electrocoagulation process was carried out for time variations of 60, 90, 120, 150, and 180 seconds with a constant voltage of 40 V which flows a current of 0.8 A. As illustrated in Figure 3, it shows that the highest removal results are Fe content which reaches more than 99% with a 60-second process. With a longer time, the removal of iron content becomes even greater. The removal of turbidity also showed good results, reaching 90% starting from the 90-second process. The allowance for the KMnO₄ value shows that the graph has increased to reach a percentage of 80.72% with a 180-second electrocoagulation process. The effect of electrocoagulation time on hardness removal has not shown significant result.
This also happens with TDS, conductivity and alkalinity. However, these result are better than the chemical coagulation process results. Operation time did not affect the pH value. This happens because in the electrocoagulation process, there is no addition of acidic chemical coagulants.

Figure 5. Effect electrocoagulation time on removal percentage for water parameters

From Figure 5. It can be seen that the processing time affected the quality of the water parameters. However, from the graph it can be seen that the changes that occur are not too significant. So, that we can choose the results with good water quality in a short time to save the operating cost.

3.3.3. Effect of current on electrocoagulation process

The second electrocoagulation process was carried out at current variations of 0.3, 0.5, 0.8, 1.2, and 1.5 A by varying the voltages for a fixed time of 120 seconds. The current shown on the multimeter which functions as an ammeter was multiplied by the number of electrode cells, namely 10 cells. The supply of current to electrocoagulation system determines the amount of Al<sup>3+</sup> ion released from the respective electrode [17]. As illustrated in Figure 4, it shows that the highest removal results are Fe content which reaches more than 99% starting from current 0.3 A onwards. The best results for other parameters are seen at current of 1.5 A, namely 95.8 % turbidity, 37.8% total hardness, 26% alkalinity, and 78.9 % KMnO₄ number. The best TDS and conductivity removal occurs at a current of 0.8 A, namely 22.6 % and 25%. Current variation treatment in electrocoagulation process does not affect the pH value.
From Figure 6, it can be seen that the current will affect the quality of the water parameters. In determining the optimum current, the operating cost incurred must be taken into account. The greater the current applied, the greater the operating cost would be.

3.3.4. Electrocoagulation process on hard water

Electrocoagulation process for water with specific characteristics i.e. hardness and iron has also been carried out. In this test, 2 (two) sample of water, namely hard water and iron water were examined. The test using hard water was carried out to determine the effectiveness of the electrocoagulation process in reducing water hardness. The test using iron water was carried out to determine the effectiveness of the electrocoagulation process in reducing iron levels in the water.
The test results of the electrocoagulation process on the hard water using the sample from Dusun Bangsan Kec. Kedungtuban show that the process has not been shown to reduce hardness. It is evidenced by the percentage of hardness of 4.18% at a current of 2.2 A, as illustrated in Figure 7. Thus, to be able to reduce the hardness it takes a much greater flow of electrical current, as consequence it will increase water TDS.

3.3.5. Electrocoagulation process on iron water

The test results of the electrocoagulation process on the water containing iron using sample water from Ngelo Village, Kec. Cepu show that the process was relatively effective in reducing iron content. This is evidenced by the percentage of removal of iron content which can reach 98% at a current of 4.4 A, as illustrated in Figure 8. From this experiment, it can be proven and concluded that electrocoagulation using aluminum electrode is very effective in reducing iron content in water.

4. Conclusion

Water treatment using electrocoagulation process with aluminum electrodes has been shown to be effective as an alternative method of a chemical coagulation process for Bengawan Solo river water purification, especially for removing turbidity, iron content, and KMnO₄ number.

Removal of hardness has not shown significant result, even in the electrocoagulation process of hard water. Application of electrocoagulation for removing total hardness and alkalinity must be developed and adapted in direct relation with the characteristics of water source.

Current density plays an important role in electrocoagulation. There are three ways to increase the current density, namely by increasing the electrode area and the voltage as well as by decreasing the inter electrode distance.

Electrocoagulation has been shown to be effective in reducing turbidity, iron and organic matter content. But, it needs further study for its ability to reduce hardness. A complete study of the relationship between parameters, especially alkalinity, pH and hardness is also needed.

The advantages of electrocoagulation over chemical coagulation are shown by better performance in reducing hardness, alkalinity, conductivity, and TDS without affecting the pH value.
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