

Research Article

# Effectiveness of Iron Electrode Pairs Electrocoagulation on Total Suspended Solid Removal in Coal Mine Water with a Continuous Flow Reactor

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## Abstract

Indonesia is a country with large potential for energy and mineral resources, including coal. Coal mine water is characterized by high levels of total dissolved solids (TSS). This occurs when overburden excavation activities are carried out so that clay minerals are exposed. Rainwater at a certain volume contacts the minerals contained in the overburden and flows on the surface carrying solid material and oxidation products. This study aims to determine the effect of current strength and detention time on electrocoagulation performance in removing TSS levels. The configuration of the electrocoagulation study is to use a pair of monopolar iron electrodes with a continuous operation method. This study used artificial waste with a TSS content of 3865 mg/L. The variations used in this study were current strength (2 A; 4 A; and 6 A) and detention time (15 minutes; 30 minutes; and 45 minutes). The results showed that the electrocoagulation process was able to eliminate TSS levels. The optimum condition for TSS removal in this study was achieved at a current strength of 4 A and a detention time of 30 minutes with a TSS removal percentage of 98,64% from the initial TSS concentration of 3865 mg/L to 52,43 mg/L. The TSS content has met the quality standards of East Kalimantan Provincial Regulation Number 02 of 2011 concerning Management of Water Quality and Control of Water Pollution in the TSS parameter.

**Keywords:** detention time, electrocoagulation, mine water, total suspended solid

## ARTICLE INFO

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## 1. Introduction

Mining activities have several stages including land clearing, overburden stripping, drilling for blasting, blasting, excavation and loading, hauling, and reclamation of mining areas (Septriariva, 2014). The problem that is often faced in mining activities is the high turbidity value. The high turbidity value is influenced by the levels of Total Suspended Solid (TSS) contained in coal mine water. The turbidity value in mining areas, especially coal, is influenced by the mineral and soil content in overburden transported by surface water flows. The surface water (run-off) both from the mining pit and disposal area is flowed to the treatment system before being flowed into water bodies in accordance with applicable quality standards. This phenomenon requires serious attention due to the nature and characteristics of colloidal systems that are difficult to settle so that special processing is needed in order to meet environmental quality standards before being flowed out of the mining area (Abfertiawan & Tonanga, 2017).

Electrocoagulation involves the formation of coagulants in-situ by dissolving the metal anode followed by the simultaneous formation of hydroxyl ions and hydrogen gas at the cathode (Hakizimana et al., 2017). The advantage of electrocoagulation technique compared to conventional coagulation is that electrocoagulation

technique is a simple, efficient, good method to remove organik compounds without the addition of chemicals so as to reduce the formation of residue (sludge), effective for removing suspended solids, and the energy required is low, so this process can be done with green energy sources such as solar, wind or fuel cells (Moussa et al., 2017). Factors affecting the electrocoagulation process include temperature, contact time, electric current strength, voltage, and acidity (pH) (Chopra et al., 2001).

This study refers to previous research on the removal of Total Suspended Solid (TSS) by electrocoagulation process. In the research of Hasan et al (2017), it was found that the percentage of TSS removal efficiency of coal mine water using the electrocoagulation method was 99.58% from the initial concentration of 5400 mg/L to 22.84 mg/L. In this study, electrocoagulation experiments were carried out using monopolar aluminum electrode pairs with the batch operation method. Based on the results of the study, the optimum conditions in setting aside the highest TSS levels were achieved at a strong current of 2 A and a contact time of 15 minutes. This study is intended to determine the level of effectiveness of the ability of the electrocoagulation process using iron electrodes in reducing Total Suspended Solid (TSS) levels in coal mine water by using a continuous flow reactor as an effort to meet wastewater quality standards for coal mining activities.

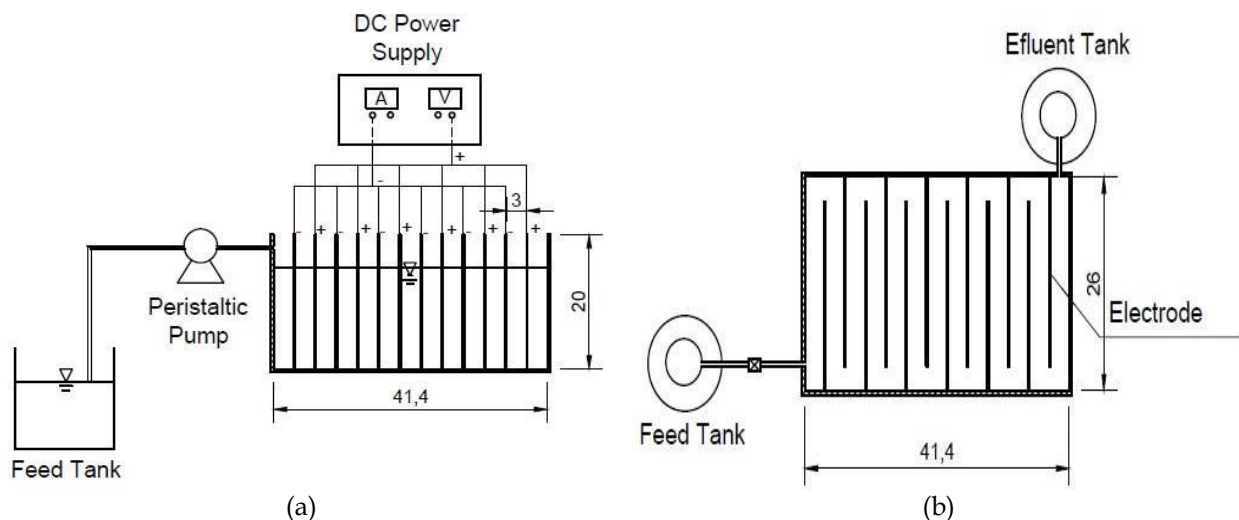
## 2. Methodology

### 2.1 Preparatory stage

The preparation stage in this study begins with the formation of artificial waste of coal mine water using clay as an effort to form TSS parameters to reach the desired level. In this study, the expected TSS target of 5400 mg/l adjusts to the TSS levels of one of the coal mines in East Kalimantan. After that, a characteristic test of coal mine water artificial waste samples was carried out to determine the quality of the physical and chemical parameters contained in the water samples. The parameters tested are pH, conductivity, TDS, and TSS. Then, the preparation of tools and materials to be used in electrocoagulation experiments is carried out. The tools used are an electrocoagulation reactor with a capacity of 15 liters with a baffle channel model, peristaltic pump, DC power supply, wastewater tank, water quality parameter test equipment, glass bottles, and avometers. The materials used are artificial waste from coal mine water, aquades, iron electrodes, filter paper, and clay.

### 2.2 Electrocoagulation reactor configuration

The electrocoagulation reactor is made of acrylic (5 mm) with dimensions of 41.4 cm x 26 cm x 20 cm with a capacity of 15 liters. The electrocoagulation reactor model used in this study is in the form of a *baffle channel*. The reactor model with a horizontal flow *baffle channel* will keep wastewater homogeneous due to hydraulic stirring that utilizes water flow as stirring power (Holt, 2002). The electrode plates are placed along the reactor as many as 12 pieces (6 cathodes and 6 anodes) with a distance between the plates of 3 cm. The electrode configuration is installed monopolar and arranged in parallel. The dimensions of the electrode plate used have a thickness of 2 mm with an electrode length of 23 cm and an electrode width of 20 cm. The electrode part is submerged in water by 13 cm so that the total wet area of the electrode surface is 0.312 m<sup>2</sup>.



**Figure 1.** Continuous flow electrocoagulation reactor: (a) reactor side view and (b) reactor top view

### 2.3 Electrocoagulation experiments

This research was conducted on a laboratory scale using artificial waste coal mine water. Before electrocoagulation trials are carried out, iron electrode purity tests are first carried out with the aim of determining the quality of the purity of the electrodes used in the electrocoagulation process. The purity of the iron electrode in this study was 95%. Electrocoagulation experiments were carried out 9 times and carried out duplo, then a total of 18 electrocoagulation experiments were carried out. The variations used in this study were current strength (2 A; 4 A; and 6 A) and detention time (15 minutes; 30 minutes; and 45 minutes). The operation of the reactor is carried out for 120 minutes and sampling of treated water samples will be carried out every 15 minutes. The extracted water sample will be deposited for 60 minutes. After that, the treated water will be analyzed for physico-chemical parameters in the form of pH, temperature, conductivity, Total Dissolved Solid (TDS), and Total Suspended Solid (TSS).

### 2.4 Sample test method

Test methods and sample analysis are shown in Table 1.

**Table 1.** Test methods and sample analysis

No	Parameter	Sample Testing	Analysis Methods
1	pH	SNI 6989.11 : 2019	pH meter
2	Temperature	SNI 6989.23-2005	Thermometer
3	Conductivity	SNI 6989.1 : 2019	Conductivity meter
4	TDS	-	TDS meter
5	TSS	SNI 6989.3 : 2019	Gravimetri

## 3. Result and Discussion

### 3.1 Water characteristics of coal mines

In Table 2, it shows the test results of coal mine wastewater characteristics in one of the coal mines in East Kalimantan and the characteristics of artificial waste coal mine water

**Table 2.** Synthetic wastewater characteristics

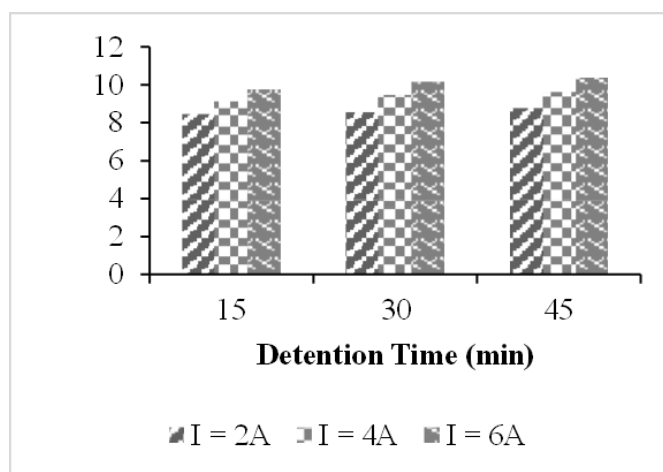
No	Parameters	Unit	Analysis Results		Quality Standards
			Original Wastewater	Artificial Wastewater	
1	pH	-	8	6,65	6-9*)
2	Conductivity	µs/cm	538	310	-
3	Temperature	°C	26,7	24,6	-
4	TDS	mg/L	320	150	1000**)
5	TSS	mg/L	5400	3865	300*)
6	Sulfate	mg/L	49.4	-	300**)
7	Fe metal (total)	mg/L	52	-	7*)
8	Metal Mn (total)	mg/L	0.33	-	4*)
9	Metal Al (total)	mg/L	26.63	-	-

\*) Regional Regulation of East Kalimantan Province Number 02 of 2011 concerning Water Quality Management and Water Pollution Control

\*\*) Government Regulation of the Republic of Indonesia Number 22 of 2021 concerning the Implementation of Environmental Protection and Management (Class 2 Rivers)

### 3.2 pH changes

pH can simply be called the degree of acidity. The pH value in the electrocoagulation process is strongly influenced by changes in current strength. Changes in pH value due to changes in current strength in each discharge variation can be seen in Figure 2.

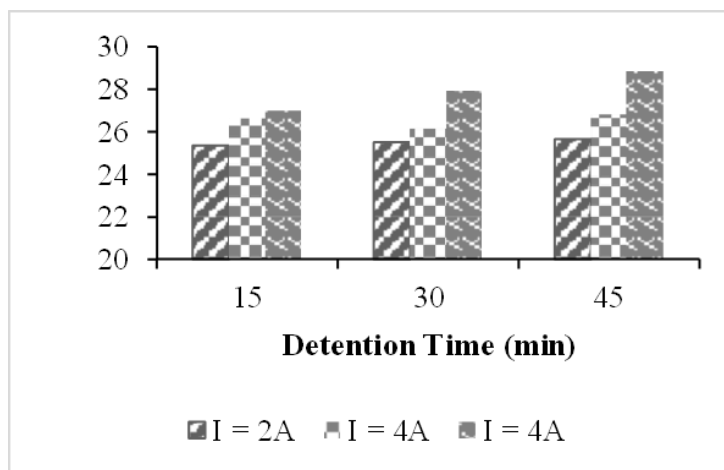


**Figure 2.** Effects of changes in current strength and detention time on pH changes

Based on Figure 2, the highest pH rise was achieved at a strong current variation of 6 Amperes and a detention time of 45 minutes. In this variation, the pH value of the solution reaches 10.37 from the initial pH value of 6.65. The lowest pH rise occurs at a strong current of 2 Amperes and a detention time of 15 minutes. In this variation, the average pH of the solution reaches 8.46 from the initial pH value of 6.65. Therefore, it can be concluded that the higher the current and the longer the detention time given to the system, the higher the pH value in the solution. This phenomenon can occur because  $\text{OH}^-$  ions released from the cathode into the solution multiply (Hudori, 2008).  $\text{OH}^-$  ions have alkaline properties so that they can increase the pH of the solution. The pH value of wastewater will cause the formation of various species of iron compounds in the form of monomer ions and polymers (Mollah et al., 2001).

### 3.3 Temperature changes

The strong influence of current and discharge on temperature changes in the electrocoagulation process can be seen in Figure 3.

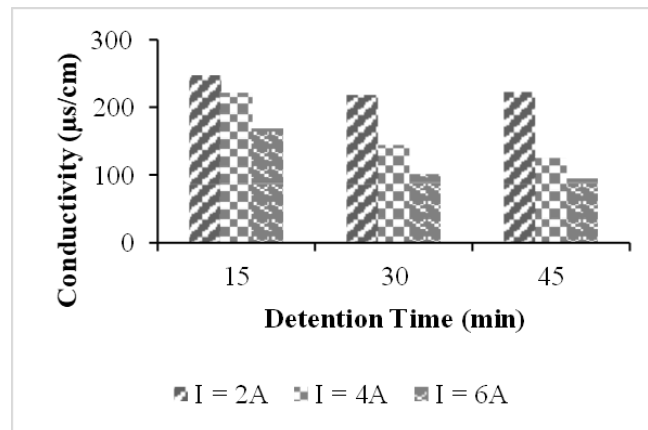


**Figure 3.** The effect of changes in current strength and detention time on temperature changes

Based on Figure 3, the highest temperature increase was achieved with a current strength of 6 Amperes and a detention time of 45 minutes. In this variation, the temperature of the solution reaches 28.85°C from the initial temperature value of 24.3°C. The lowest temperature increase is achieved at a strong current of 2 Amperes and a detention time of 15 minutes, the temperature value of the solution at the variation is 25.35 °C from the initial temperature value of 24.3°C. According to Holt (2002), the increase in temperature occurs due to the release of  $\text{Fe}^{2+}$  metal hydroxide during the electrocoagulation process releasing energy in the form of heat which affects the increase in reaction speed. The increase in temperature promotes the formation of formed metal hydroxides and causes greater particle mobility (Ashtoukhy et al., 2009). Higher temperatures allow the production of larger hydrogen bubbles that increase the flotation speed (Koren & Syversen, 1995).

### 3.4 Conductivity changes

Conductivity is the ability of water to conduct electricity. Changes in conductivity due to the electrocoagulation process can be seen in Figure 4.

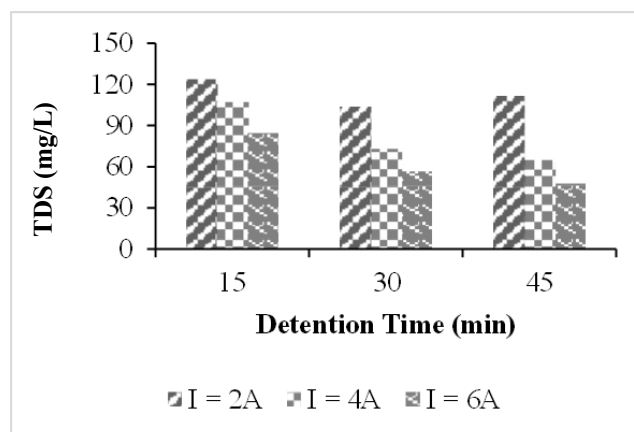


**Figure 4.** Effects of changes in current strength and detention time on changes in conductivity

Based on Figure 4, the highest conductivity decrease is achieved at a strong current variation of 6 Amperes and a detention time of 45. In this variation, the conductivity of the solution reaches 95 µs/cm from the initial conductivity value of 310 µs/cm. The lowest conductivity reduction is achieved at a current strength of 2 Amperes and a detention time of 15 minutes. In these conditions, the conductivity value of the solution reaches 247.5 µs/cm. The decrease occurs because the electrocoagulation process will bind the ions contained in pollutants to form a floc that can be separated (Emamjomeh & Sivakumar, 2009). This is based on Faraday's Law I which states that the amount of chemical change produced will be proportional to the amount of electric charge passing through an electrolysis cell, so that iron ions released from the electrode will bind ions to pollutants to form floc so that it affects the decreasing conductivity value of the solution (Nur & Effendi, 2014).

### 3.5 Changes in total dissolved solids

TDS is the amount of dissolved solids in the form of organic ions, compounds, and colloids in water (WHO, 2003). The change in total dissolved solid to current density can be seen in Figure 5.

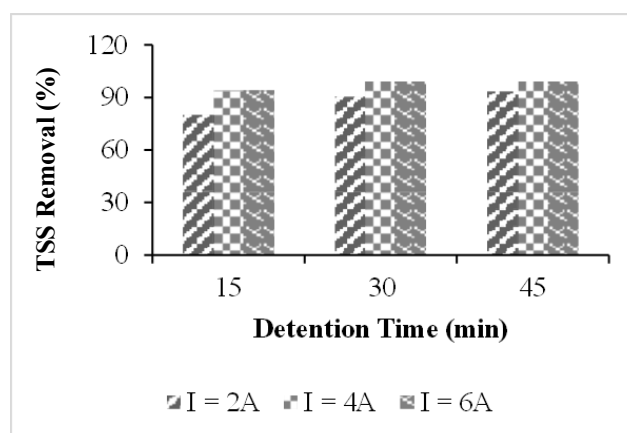


**Figure 5.** Effect of changes in current strength and time of detention on changes in TDS

Based on Figure 5, the highest decrease in TDS was achieved at a strong current variation of 6 Amperes and a detention time of 45 minutes. The TDS value of the solution in this variation reached 47.5 mg/L from the initial TDS of 155 mg/L. The lowest TDS decrease was achieved at a strong variation of 2 Amperes current and a detention time of 15 minutes. The TDS value of the solution in this variation reaches 124 mg/L from the initial TDS value of 155 mg/L. The decrease in TDS levels in the electrocoagulation process is due to higher current strengths, the deposition process of dissolved particles becomes more effective. At higher current strengths, there will be an increase in ions that have different charges from dissolved particles in wastewater, resulting in the formation of floc nuclei which are then agglomerated into larger floc (Nur & Effendi, 2014).

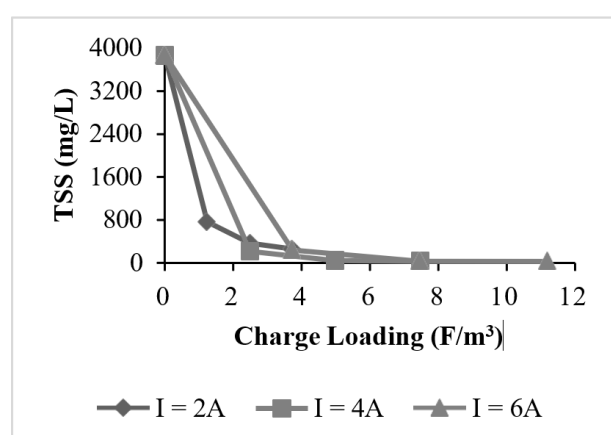
### 3.6 Total suspended solid (TSS)

Total Suspended Solids (TSS) is the part of the total solids of all solids in a liquid held in a sieve with a certain pore size between  $0.45 \mu\text{m}$  –  $2 \mu\text{m}$  (Tchobanoglous et al., 2003). The efficiency of TSS removal due to the electrocoagulation process can be seen in Figure 6.



**Figure 6.** The effect of changes in current strength and detention time on TSS removal efficiency

Based on Figure 6, the highest TSS removal efficiency was achieved at a strong variation of 6 Ampere current and 45 minutes detention time with an average TSS reduction efficiency of 99.18%. The measured TSS concentration in this variation reached 31.4 mg/L from the initial TSS concentration of 3865 mg/L. Then, the lowest TSS removal efficiency was achieved at a strong variation of 2 Amperes current and a detention time of 15 minutes with an efficiency rate of 80.26%. The measured TSS concentration in this variation reached 762.77 mg/L from the initial TSS concentration of 3865 mg/L. Therefore, it can be concluded that the higher the current strength and the longer the detention time given to the system, the higher the TSS concentration allowance. This is because the particles contained in wastewater are generally negatively charged, because similar charges occur repulsive forces between particles that cause particles to be in a stable state. During the electrocoagulation process, positive and negative ions produced by electrodes made of metals such as aluminum will destabilize the particles in wastewater (Yulianto et al., 2009). At the anode electrode will undergo an oxidation reaction against anions (negative ions) to form  $\text{Fe}^{2+}$  and bind OH to form  $\text{Fe}(\text{OH})_2$  compounds that can bind pollutants, while at the cathode will produce gas hydrogen ( $\text{H}_2$ ) which serves to lift the formed floc above the surface, the floc formed over time will increase in size and eventually settle to the bottom of the electrocoagulation bath (Mollah et al., 2001).

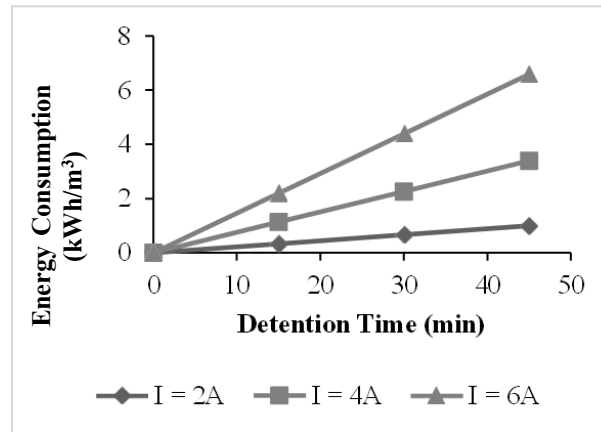


**Figure 7.** The effect of charge loading on TSS reduction

Based on Figure 7 it can be seen that as the current strength increases, the magnitude of the decrease in TSS concentration and the value of charge loading will also be greater. This is because the higher the value of charge loading, the release of  $\text{Fe}^{2+}$  ions which act as coagulant agents in electrocoagulation will increase so that they can set aside TSS levels more optimally. When charge loading applied to the electrocoagulation process is low, the coagulation dose of  $\text{Fe}^{2+}$  is not enough to set aside TSS levels in wastewater. However, not always with high charge loading is able to set aside TSS levels more effectively. In conditions when charge

loading is too high, it can produce more floc iron hydroxide or a higher concentration of  $\text{Fe}^{2+}$  ions than needed and has a direct impact on the concentration of residual iron (Fe) in water that has been treated by the electrocoagulation process. Excessive iron hydroxide globules are difficult to float and separate because they have high density and poor affinity between hydroxide globules and gas bubbles.

Technically efficient wastewater treatment should also be economically viable. Operating costs in the electrocoagulation process are associated with the consumption of electrical energy released during the electrocoagulation process. The electrical energy required to remove TSS levels is calculated in units of  $\text{kWh}/\text{m}^3$



**Figure 8.** The effect of strong effects of current and time of detention on energy consumption

Figure 8 shows that as the current strength and detention time increase in the electrocoagulation process, the energy consumption released will also be higher. This is because the higher the strong current used in the electrocoagulation process, the more particles will be deposited. Then, to be able to precipitate more particles, of course, greater energy is needed. Therefore, by increasing the current strength, energy consumption will also increase. In addition, the electrocoagulation process involves electrodes made of oxidized metal. During the electrocoagulation process, the metal oxidizes and produces gases such as oxygen or hydrogen. The formation of these gases requires additional energy. So, the longer the detention time and the higher the current used, the more gas will be formed and consequently energy consumption also increases.

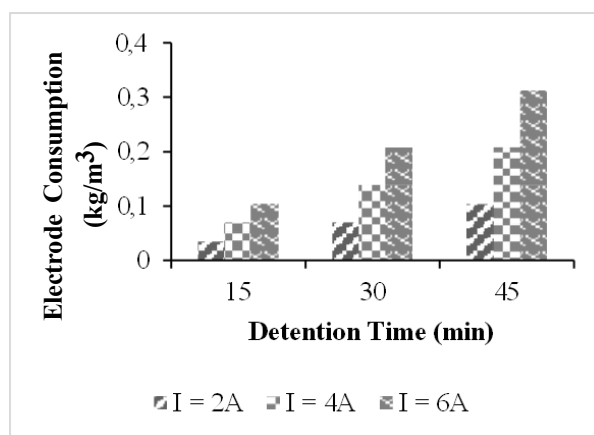
The determination of the optimum variation of the electrocoagulation process in this study was based on the strong influence of current and detention time in setting aside TSS levels. In the electrocoagulation process, the current strength and detention time are the most important parameters that affect the efficiency of TSS removal and control the reaction rate in the electrocoagulation reactor. Therefore, an optimum combination is needed to be able to achieve the highest level of TSS removal efficiency at a low cost. In this study, the optimum condition for TSS removal was achieved at a strong variation of 4 Amperes current and a detention time of 30 minutes. In this variation, it was able to reduce TSS levels by 98.64%. In this variation, the average TSS level was 52.43  $\text{mg}/\text{L}$  from the initial TSS level of 3865  $\text{mg}/\text{L}$ . This value has met the quality standard of TSS parameters, which is 300  $\text{mg}/\text{L}$  based on East Kalimantan Regional Regulation Number 2 of 2011 concerning Water Quality Management and Water Pollution Control. In these variations, the amount of charge loading and energy consumption are 4.97  $\text{F}/\text{m}^3$  and 2.26  $\text{kWh}/\text{m}^3$ , respectively. Then, the values of pH, temperature, conductivity, and TDS in these variations were 9.46, 26.15 $^{\circ}\text{C}$ , 143.5  $\mu\text{s}/\text{cm}$ , and 73  $\text{mg}/\text{L}$ , respectively.

### 3.7 Iron ion release rate

The process of electrocoagulation involves the use of electrodes to produce chemical reactions that help in the deposition of dissolved or suspended particles in wastewater. Then, to find out the mass of the iron plate dissolved in solution can be determined using Faraday's Law.

Based on Figure 9, it can be seen that as the current strength and detention time given to the system increase, the consumption of electrodes will be higher. In the electrocoagulation process, the electrodes involved will undergo oxidation or reduction depending on their polarity. The higher the strong current applied, the greater the rate of oxidation or reduction that occurs on the electrode surface. This process can cause electrode

corrosion, which means the electrodes gradually decompose or erode during the electrocoagulation process. As a result, electrode consumption increases with higher current strength and longer detention time



**Figure 9.** Strong effects of current and time of detention on energy consumption

### 3.8 Cost analysis

In this study, the optimum conditions for removing TSS were achieved at a strong current variation of 4 Amperes and a detention time of 30 minutes. The value of energy consumption in this variation is 2.26 kWh/m<sup>3</sup>. Then, the cost of operating the coal mining industry electricity installation uses the large scale business tariff group (B-3) with power above 200 kVA, which is Rp1,444.00/kWh in accordance with the tariff applied by PLN. Therefore, it can be concluded that the electricity cost needed is Rp3,263.44/m<sup>3</sup>. Then, the price of an iron plate (diameter 2 mm) per kg is Rp16,000.00. The consumption value of iron electrodes dissolved in wastewater is 0.138 kg/m<sup>3</sup>, then the price of iron plates is Rp2,208.00/m<sup>3</sup>. Therefore, the total unit cost required in the electrocoagulation process is the sum of the electricity tariff costs with the price of iron plates, which is Rp5,495.00/m<sup>3</sup>. The price does not include the cost of manufacturing/investing in equipment, operational and maintenance (O/M) and personnel in operations.

## 4. Conclusion

The electrocoagulation process using pairs of iron electrodes is effective in setting aside TSS levels in artificial waste of coal mine water until it is below the quality standards of East Kalimantan Provincial Regulation Number 02 of 2011 concerning Water Quality Management. Therefore, water that has been treated from the electrocoagulation process can be discharged into water bodies when viewed from TSS parameters. The strength of the electric current has an influence on the amount of coagulant produced into the solution. The higher the current given to the system, the more iron ions that act as coagulants released in the solution will be. The anode electrode will undergo an oxidation reaction against anions (negative ions) to form Fe<sup>2+</sup> and bind OH<sup>-</sup> to form Fe(OH)<sub>2</sub> compounds that can bind pollutants, while at the cathode will produce hydrogen gas (H<sub>2</sub>) which serves to lift the floc formed above the surface, the floc formed over time will increase in size and eventually settle to the bottom of the electrocoagulation bath. The optimum condition of Total Suspended Solid removal in this study was achieved at a current strength of 4 Amperes and a detention time of 30 minutes. In this condition, it was able to set aside the level of Total Suspended Solid by 98.64% from the initial concentration of Total Suspended Solid 3865 mg/L to 52.43 mg/L.

### Acknowledgement

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### Reference

- Abfertiawan, M. S., & Tonanga, T. (2017). Mineral lempung dalam peningkatan kekeruhan air. Retrieved May 20, 2023, from <https://www.msonnyabf.id/mineral-lempung-dalam-peningkatan-kekeruhan-air-tambang/>
- Ashtoukhy, N. K., Amin, O., & Abdelwahab. (2009). Treatment of paper mill effluents in batch-stirred electrochemical tank reactor. *Chemical Engineering Journal*, 146, 205–210.
- Chopra, A. K., Sharma, A. K., & Kumar, V. (2001). Overview of electrolytic treatment: An alternative technology for purification of wastewater. *Archives of Applied Science Research*, 2, 191–206.

- Emamjomeh, M. M., & Sivakumar, M. (2009). Fluoride removal by a continuous flow electrocoagulation reactor. *Journal of Environmental Management*, 90(2), 1204–1212.
- Hasan, F. (2022). Total suspended solid (TSS) removal for coal mining water using electrocoagulation (Undergraduate thesis). Environmental Engineering Study Program, Faculty of Civil and Environmental Engineering, Bandung Institute of Technology.
- Hakizimana, B., Gourich, B., Chafi, M., Stiriba, Y., & Vial, C. (2017). Electrocoagulation process in water treatment: A review of electrocoagulation modeling approaches. *Chemosphere*, 200, 631–648. <https://doi.org/10.1016/j.chemosphere.2017.02.151>
- Holt, P. K. (2002). Electrocoagulation: Unravelling and synthesising the mechanism behind a water treatment process (Master's thesis). Department of Chemical Engineering, University of Sydney, Sydney.
- Hudori. (2008). Pengolahan air limbah laundry menggunakan elektrokoagulasi (Master's thesis). Magister Teknik Lingkungan, Fakultas Teknik Sipil dan Lingkungan, Institut Teknologi Bandung.
- Koren, P. P. F., & Syversen, U. (1995). State of the art electroflocculation. *Filtration & Separation*, 32, 153–156.
- Mollah, M. Y. A., Schennach, R., Parga, J. R., & Cocke, D. L. (2001). Electrocoagulation (EC) - Science and applications. *Journal of Hazardous Materials*, 84(1), 29–41.
- Moussa, D. T., El-Naas, M. H., Nasser, M., & Al-Marri, M. J. (2017). A comprehensive review of electrocoagulation for water treatment: Potentials and challenges. *Journal of Environmental Management*, 186, 24–41.
- Nur, A., & Effendi, A. (2014). Aplikasi elektrokoagulasi pasangan elektroda aluminium pada proses daur ulang grey water hotel. *Jurnal Teknik Lingkungan*, 20(1), 58–67. <https://doi.org/10.5614/jtl.2014.20.1.7>
- Septiariva, I. Y. (2014). Pengaruh penggunaan koagulan (air asam tambang, aluminium sulfat) dalam pengolahan air run off pertambangan batu bara (Undergraduate thesis). Institut Teknologi Sepuluh Nopember, Surabaya.
- Tchobanoglous, G., Burton, F. L., & Stensel, H. D. (2003). *Wastewater engineering: Treatment and reuse* (4th ed.). McGraw-Hill.
- Yulianto, A., Hakim, L., Indah, P., & Vidya. (2009). Pengolahan limbah cair industri batik pada skala laboratorium dengan menggunakan metode elektrokoagulasi. *Jurnal Teknik Lingkungan*, Universitas Islam Indonesia, Yogyakarta.