High Total Suspended Solid (TSS) Removal for Coal Mining Water Using Electrocoagulation

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Abstract

Coal mine water contains high concentrations of suspended solids due to clay minerals carried away by surface run-off. Removing it becomes problematic since it requires chemicals, especially in large catchment areas in mining sites. Due to this, Total Suspended Solid (TSS) concentration in coal mining water can reach up to 5,400 mg/L. In Indonesia, it mainly occurs in Kalimantan, which still adopts an open-pit mining system. This research aims to implement the electrocoagulation technique as a potential alternative active treatment to solve high TSS concentration in wastewater of an actual mining site.

Keywords: Total suspended solid, electrocoagulation, mine water, run-off.

Introduction

Open pit mining is done by stripping the topsoil of the mining material. This method results in tiers and basins downward, allowing accumulated rainwater to enter the mining front, erode the mine walls (soil), and form sludge. Sludge entering the mining site's front area can inhibit the mining process and cause equipment damage. Therefore, sludge formed is usually pumped from the front mining area into a settling pond. The goal of 6th Sustainable Development Goals (SDG's) is to improve water quality by reducing pollution, eliminating disposal, minimizing the release of hazardous materials and chemicals, halving the proportion of untreated wastewater, and significantly increasing recycling and reuse of recycled goods that are globally safe are to be concerned. Active treatments such as chemical neutralization and deposition, membranes, and filters have been used at many mine sites to minimize the environmental impact of mining-affected waters (Oncel *et al*. 2013). One of the active treatment technologies developed in mining water treatment is electrocoagulation.

Electrocoagulation is the process of agglomeration or coagulation using electricity. Electric power flowing through the electrodes resulted in an electrolysis process. Electrocoagulation can reduce the concentration of ferrous metal ions from 743.5 mg/L to 0.001 mg/L at 40 minutes of operating conditions and a current density of 500 A/m^2 (Oncel *et al*. 2013). The electrocoagulation process can be done even in remote areas where electricity is unavailable. In this case, energy for the electrocoagulation process can be obtained from solar panels. Solar Powered Electrocoagulation (SPEC) can remove turbidity up to 87% (Sharma *et al*. 2011). Based on these conditions, this study aims to examine coal mining water treatment using the electrocoagulation process of aluminum electrode pairs to meet the quality standards of wastewater from coal mining activities, especially for the High Total Suspended Solid (TSS) parameter.

Methods

This study used actual mining water waste from one of the settling ponds of coal mines

in Kalimantan (Initial TSS of 5,400 mg/L). An electrocoagulation reactor with a batch operating system is used. The reactor was made of acrylic (5 mm) with a capacity of three liters and length, width, and height of 14; 10.5; and 20 cm, respectively. The working volume used was 1000 mL. The electrodes were installed monopolar with 8 electrodes (i.e., 4 anodes and 4 cathodes) with a thickness of 0.2 cm. The dimensions of the electrode plate were 16 by 8 cm. The electrode plate was immersed in the solution for 7.5 cm, producing a total anode wet surface area of 0.024 m^2. The electrodes were installed using a frame with a distance between plates of 1.5 cm and connected to a DC electric current source (MDB 0–60 V and 0–20 A).

Electrocoagulation was done by using a pair of aluminum electrodes (99.9%,) at the Water Quality Laboratory, ITB. The electric current variations used in this study were 0.5, 1, and 2 A, with 15, 30, and 45 minutes of detention time. The treated mining water was analyzed on the supernatant taken at the same depth of 3 cm from the surface of the water samples. Electrical current and voltage measurements were carried out using a multimeter MASDA DT830B. Measurement was done twice (duplo) within the same time of treatment (i.e., same configuration) after 60 minutes of settling time. The process of floc formation and changes in the electrodes were observed. The parameters measured were pH, temperature, Total Dissolved Solid (TDS), and Total Suspended Solid (TSS) using a pH meter, thermometer, TDS meter, and TSS meter with the standard curve of the gravimetric method as follows

Results and Discussion

The steps in electrocoagulation are the formation of coagulants from anode oxidation, destabilizing contaminant particles, and followed by particle aggregation to form flocs (Mollah *et al.* 2004).

The process of floc aggregation into a larger size, which allows the particles to settle, occured in the electrocoagulation process (Figure 3). Furthermore, large-sized floc settled through the sedimentation process (Figure 3c). Floc deposition can also occur during electrocoagulation (Figure 3b) because the production of Al3+ ions from the electrodes is sufficient to form a floc. Therefore, larger flocs can settle before the sedimentation process starts. The following major reaction take place in the electrocoagulation process:

$$2H_2O + 2e^- \rightarrow H_2 + 2OH^- \tag{1}$$

$$Al_{(s)} \rightarrow Al^{3+}_{(aq)} + 3e^-_{(aq)} \tag{2}$$

$$Al^{3+}_{(aq)} + 3OH^-_{(aq)} \rightarrow Al(OH)_{3(s)} \tag{3}$$
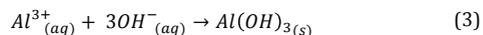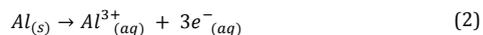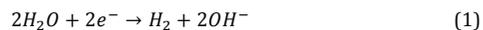
According to Faraday's First Law, the amount of aluminum that dissolves from the electrode is proportional to the current and detention time applied to the system. A greater current and longer detention time will release more Al^{3+} ions (coagulant agent) from the anode and bind strongly to OH-. The particles destabilize and form flocs quickly in large numbers.
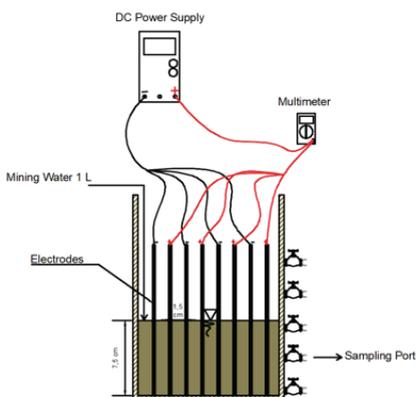
Figure 1 Electrocoagulation reactor scheme (batch)
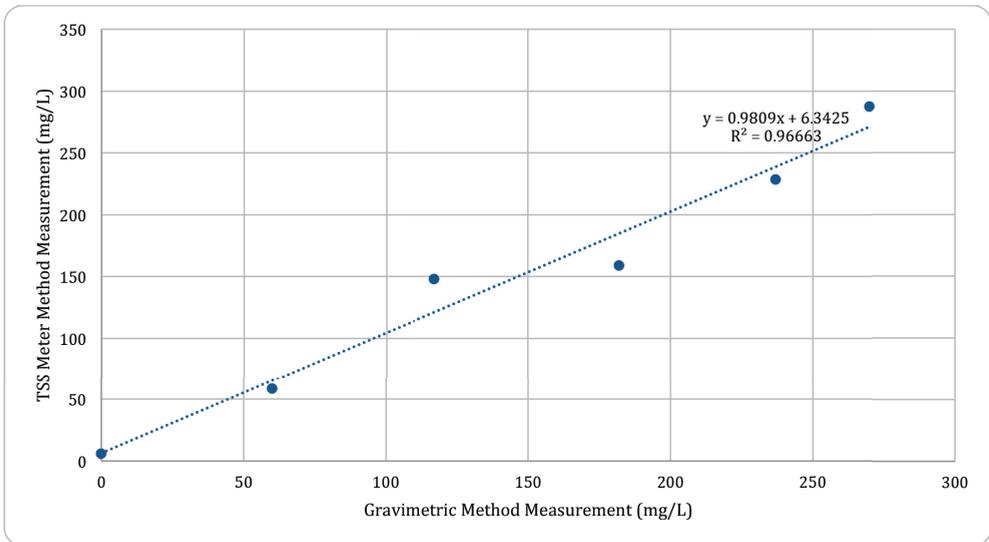
Figure 2 Standard curve of gravimetric method
(y=TSS Meter measurement,x=Gravimetric method measurement)

Figure 3 (a) Electrocoagulation on 15th minute with 0.5 A current (b) electrocoagulation on 45th minute with 2 A current, dan (c) after settling for 60 minutes (tec = 15 minutes, I = 0.5 A)
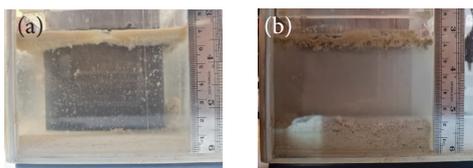
Figure 4 Treated mining water sample after settling for 60 minutes (a) tec = 30 minutes, I = 0.5 A (b) tec = 45 minutes, I = 2 A

Electrocoagulation with a detention time of 30 minutes and a current of 0.5 A resulted in a 1 cm floc forming at the reactor's bottom (Figure 4a). Increasing detention time (45 minutes) and current (2 A) resulted in a higher floc height (2.5 cm) (Figure 4b). The number of coagulant agents formed affects the amount of floc that settles at the bottom of the reactor. Larger currents and longer detention times tend to result in higher floc generation at the bottom of the reactor.

The floc formed in the electrocoagulation process was not only settled to the bottom of the reactor. Bubbles were formed during the electrolysis process, bringing the floc particles to the surface (flotation). The bubbles occurred due to the production of H_2 gas that appears at the cathode. The greater the current applied to the system, the faster the production of hydrogen bubbles occurs (Attour *et al.* 2014). The bubbles are very small and vary from 15 to 80 micrometers and help move pollutant particles to the
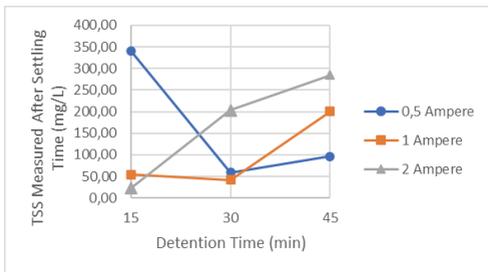
Figure 5 *Measured TSS (mg/L) after settling time*

surface of the liquid (Murugananthan *et al.* 2004). Electrolyte bubbles caused a mixing in solution through an upward momentum flux. Therefore, bubbles can increase the effectiveness of contact between coagulant particles and pollutants (Holt *et al.* 2002).

TSS reflects the amount of organic or inorganic compounds suspended in water. The TSS value in the electrocoagulation process carried out is presented in the graph above.

Only the lowest variation treatment (0.5 A and detention time of 15 minutes) did not meet the Regional Regulation of East Kalimantan Province Number 2 of 2011 concerning Water Quality Management and Water Pollution Control quality standard (300 mg/L). The coagulant produced from the electrodes was possibly insufficient to remove contaminant particles in the wastewater. Variation of 2 Ampere and detention time of 15 minutes resulted in the highest percentage of TSS removal of 99.58% from the initial concentration of 5,400 mg/L to 22.84 mg/L.

Longer detention time in the current of 2 Ampere causes the TSS level to increase to 203.9 mg/L (30 minutes) and 285,10 mg/L (45 minutes). TSS levels increased due to the excess coagulant dose produced from the electrode plate.

The highest variation (I = 2A, t_d = 45 minutes) yields white supernatant, while the lowest variation (I = 0.5 A, td = 15 minutes) yields brown color (Figure 6). In the lowest variation, the coagulant formed cannot remove solids from the mine water due to the lack of the required coagulant dose. The highest variation yields white supernatant, indicating the formation of $Al(OH)_4^-$ compounds. The pH value increased during the electrocoagulation process. The final value of the measured pH was influenced by the current and detention time given to the system. At the highest variation (I = 2A, t_d = 45 minutes), the final measured pH value reached 10.9, indicating a hydrolysis reaction of Al^{3+} into $Al(OH)^{4-}$.

The solubility of metal hydroxide precipitates determines the efficiency of the coagulant. The solubility of alum coagulants was determined by pH. At lower pH (below 4), the solubility of metal hydroxide precipitates produced a positive charge and Al3+ ions, while at higher pH (above 10) negative charge was formed along with Al(OH)4-. The result aligns with a study by Hudori *et al.* (2009) that showed the best pollutant removal in the electrocoagulation process occurs in the pH range of 4-10. PH values below 4 formed Al3+ ions, and at pH above 10 formed Al(OH)4-, which were less effective in coagulation.

Figure 6 *Electrocoagulation supernatant on (a) I = 2 A, t_d = 15 minutes, (b) I = 2 A, t_d = 45 minutes, and (c) I = 0,5 A, t_d = 15 minutes*

Figure 7 *Electrocoagulation reaction in 2 A at 45 minutes detention time*

Apart from the pH solubility, the increase in TSS was possibly due to the bubble produced from the cathode. The bubbles in the electrolyte solution stir the solution through an upward momentum flux. A proper amount of bubbles formed can increase the contact between coagulant and pollutant particles. However, floc cannot develop when bubbles are too much, and particles cannot agglomerate. Only a few floating flocs were found on the surface due to the rapid bubble production (Figure 7). Operation at low currents produces relatively low bubbles, causes gentle agitation, and allows flocculation to occur properly. According to Holt *et al.* (2002), when the current density increases, the bubble production increases, and the upward momentum movement accelerates. This condition will change the mixing, where the shear force from mixing in the solution can damage and break the floc, reducing pollutant removal effectiveness.

Conclusions

There is a relationship between detention time and current on measured TSS results. At currents of 0.5 A and 1 A, the optimum detention time was 30 minutes (TSS 59.04 mg/L and 42.21 mg/L); for a current of 2 A, the optimum detention time was 15 minutes (TSS 22.46 mg/L). The magnitude of electric current and detention time determines the amount of coagulant produced in the solution. An optimum combination is required to achieve the highest TSS removal. The current and detention time lower than the optimum conditions cannot eliminate TSS due to the lack of coagulant produced. In comparison, increasing current and detention time above the optimum condition increased the production of hydrogen bubbles which damage and break up the floc, thereby reducing pollutant removal effectiveness. The optimum variation based on the highest TSS removal was 2 Ampere with a detention time of 15 minutes, reaching TSS removal of 99.58% from the initial concentration of 5,400 mg/L to 22.84 mg/L.

Acknowledgments

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