Comparative study between aluminium sulphate and *Lemna perpusilla* as coagulants for water treatment: case study Lake Cibuntu, West Java

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**Abstract.** Coagulation is a key process in water treatment. The ability of two coagulants, aluminium sulphate (alum) as inorganic coagulant and *Lemna perpusilla* as natural coagulant was assessed using standard jar test measurement. Both coagulants were evaluated with turbidity, Total Organic Matter (TOM) and Total Suspended Solid (TSS) parameters. The results showed that both coagulants were able to remove 100 % of water turbidity with initial turbidity 13.56 NTU. However increasing the coagulants doses, also will increase the concentration of TSS. The use of alum and *L. perpusilla* as a coagulant will increase concentration of TSS by 12.68% and 252.11% respectively. Application of alum tends to reduce the concentration of TOM by 20.25%, while *L. perpusilla* will actually increase the concentration of TOM by 74.85%. Although not as effective as alum, *L. perpusilla* showed sufficient removal capability for treatment of turbid waters from Cibuntu Lake. The optimum dose of *L. perpusilla* should be considered to minimize side effects on produced water such as increasing TOM and TSS concentration.

1. **Introduction**

According to WHO, each person needs around 144 L/day of clean water to fulfill their daily needs. However, clean water could not be accepted by all citizens at the present time. Regional Water Supply Company (*Perusahaan Daerah Air Minum* / PDAM) which is the main provider of drinking water supply in Indonesia is only able to provide 27.05% nationally [1]. PDAM needs sufficient water supply to produce drinking water, however many water supply (such as river water) have been contaminated by industrial waste, thus their water quality was declined. Several water treatment technologies have been applied to produce clean water. The advanced oxidation process is one of the latest technologies that can be used. The disadvantage of this technology is high operating cost. Another technology that can be applied is adsorption using activated carbon. According to Kim [2], this process is relatively expensive and it is difficult to regenerate adsorbent.

The technology that widely used in water treatment is coagulation-flocculation. Coagulation is a chemical process to remove turbidity and color producing material that is mostly colloidal particles (1 to 200 millimicrons, µm) such as algae, bacteria, organic and inorganic substances, and clay particles [3]. Mixing is an important operation for the coagulation process. The coagulation process is usually followed by flocculation to accelerate collisions between particles therefore it becomes easy...
to be sunken and separated. Coagulation is the first stage of the particle aggregation process, by adding coagulants which reduce or eliminate interparticulate forces that function as particle stability (particle destabilization) [4]. The coagulation flocculation process can be seen in figure 1.

![Coagulation flocculation process](image)

**Figure 1.** Coagulation flocculation process [5]

Coagulants are commonly added to the coagulation process. There are two types of coagulants namely inorganic (chemical) and natural coagulants [4]. Chemical coagulants that are commonly used are aluminium sulphate, ferric salts (ferric chloride, ferric sulphate, ferrous sulphate, and lime), and their derivatives (poly aluminium chloride and poly ferric chloride) [3,5]. The most popular coagulant is aluminium sulphate or alum \( \text{Al}_2(\text{SO}_4)_3.18\text{H}_2\text{O} \). It is mainly used in Indonesia because of its effectiveness, accessibility, and low price. Alum is also easy to handle and is utilized in pH values between 5 to 8 for water clearing and in pH values between 9 and 10 for water softening. One of the main drawbacks of using alum is producing a huge amount of sludge. However, the sludge obtained from treatment lead to disposal problems such as aluminium accumulation in the environment. Drinking water containing aluminium affects human health, especially Alzheimer's disease [6].

There has been a lot of interest to investigate natural products that could replace chemical coagulants. Some of the major advantages of these coagulants are less pollution, less dosage precision is required, it is possible to obtain these coagulants in rural areas, where environmental conditions are favorable, and less sludge contamination, among others [7]. Natural coagulants are water-soluble substances from animal or plant constituents, which offer similar properties to inorganic coagulants.

Studies on natural coagulants have been carried out to replace the use of alum. *Moringa oleifera* is a plant that is mostly used as a natural coagulant. *M. oleifera* is used to treat turbid water [8,9,10], peat water [11], and wastewater [12,13,14]. Other natural coagulants like common bean [15], chitosan [16], plantago ovata seed [17], and psyllium husk [18] are proven to have higher efficiency for water turbidity removal. Some of the major advantages of these coagulants are less pollution, biodegradable, cost-effective and low sludge production.

The active component in natural coagulants is protein. *Lemma perpusilla* or duckweed is an aquatic plant that easy to spread. It contains 38.10% of proteins [19] and usually used for the combination of fish feed. *L. perpusilla* can also be used as a phytoremediation agent to adsorb nutrients in aquaculture media [20].

In this current research, *L. perpusilla* and alum were applied to turbid water from Lake Cibuntu, Cibinong. The ability of both coagulants was assessed using standard jar test measurement.
Thus, in this study, the efficiency of *Lemna perpusilla* extract as natural coagulant was compared with aluminium sulphate (alum) as an inorganic coagulant to treat clean water from Lake Cibuntu. The final value of turbidity, Total Organic Matter (TOM) and Total Suspended Solid (TSS) of produced water from Lake Cibuntu are supposed to close to the required standard of Permenkes No 492/2010.

2. Material and Methods

2.1 Preparation of *Lemna perpusilla*

*L. perpusilla* were obtained from integrated multi-trophic aquaculture located in Research Center for Limnology – Indonesian Institute of Sciences, Cibinong. *L. Perpusilla* was washed with water to remove the impurities and were dried. The dried *L. Perpusilla* was crushed and powdered by using a laboratory mill and was sieved through 0.4 mm sieve. The fraction with particle size less than 0.4 mm was used in experiment[21].

Fifty grams of prepared powder was suspended in 1 L of 1 M NaCl solution. The suspension was vigorously shaken for 10 minutes using a magnetic stirrer to accomplish the extraction of coagulant proteins. The suspension was then passed through a rugged filter paper. *L.perpusilla* stock solution prepared in this way was used the same day it was produced and kept in refrigerated[21].

2.2 Preparation of alum

Aluminium sulphate (alum) \([\text{Al}_2(\text{SO}_4)_{3}\cdot18\text{H}_2\text{O}]\) was used in this study as the inorganic coagulant. A 1% stock of alum in tap water was made (1 gram of alum in 100 ml tap water). Alum was thoroughly soluble in this concentration.

2.3 Turbid water samples

Turbid water samples were obtained from Lake Cibuntu. Lake Cibuntu is a small artificial lake, located in Cibinong Science Center. Lake Cibuntu was contaminated by untreated domestic wastewater from the surrounding residential area.

2.4 Experimental design

All tests were carried out in a 600 ml beaker by a standard jar test apparatus. Each beaker was filled with 500 mL turbid water from Lake Cibuntu. A predetermined amount of coagulant was added to each beaker by a pipette and the mixture was stirred at the rapid speed of 200 rpm for 1 min, followed by the slow speed of 60 rpm for 15 min. Then the suspensions were left for sedimentation. After 30 min of sedimentation, cleared samples were collected from the top of the beakers. The turbidity, Total Suspended Solid (TSS) and Total Organic Matter (TOM) of cleared samples were measured. The scheme of experimental design can be seen in figure 2 below.
The turbidity of water samples was measured by turbidimeter (Lutron TU 2016). The efficiency of coagulation was calculated by comparing turbidity before and after treatment. TSS was measured using the gravimetry method. TOM was analyzed by the colour reagent method. The procedures for TOM, TSS, and turbidity were described in the Standard Methods for the Examination of Water and Wastewater [22].

2.5 Coagulation activity
Coagulation activity of alum and L. perpusilla for treating turbid water from Lake Cibuntu was calculated based on the comparison between the amount of compound that is excluded and the initial concentration. The percentage of removal was calculated using the following formula.

\[
\text{Coagulation activity (\%) = \left(\frac{\text{Initial concentration} - \text{Final concentration}}{\text{Initial concentration}}\right) \times 100}
\]

3. Results and Discussion
3.1 Effect of coagulant dose on turbidity removal
There are several parameters to determine the optimization of coagulation. The main parameter is the coagulant dosage. Inappropriate dosage (less or excessive) will produce a poor performance in the flocculation process. The optimum dose was determined to minimize the production costs and sludge formation, and also to obtain the optimum performance in water treatment.

Ozacar [23] claimed that the main coagulation mechanism with alum sulfate coagulant is a combination of adsorption and charge neutralization. Charge neutralization occurs due to charge differences between colloids in wastewater and coagulant.

Coagulation mechanism using natural coagulant was charge neutralization and the formation of interparticle bridging [24,25]. Generally, organic polymer or organic coagulant consists of carboxyl, amino, and sulfunic groups [25]. These groups reacted with groups or reactive sites located on the surface of colloids. Interparticle bridging was built by this reaction. The number of chemical bridges formation would correlate with the number of flocks formed. The effect of coagulant doses was presented in figure 3.

Figure 2. Experimental design
The result showed that alum sulphate was able to reduce turbidity from 13.56 to 0 NTU. It means the efficiency of turbidity removal could achieve 100% by applying 5 mg/l to 30 mg/L alum sulphate. Increasing of alum dose did not affect the coagulation process. Similar result was shown by L. Perpusilla, whereas turbidity removal efficiency also could achieve 100% by applying 5 mg/L to 15 mg/L L. perpusilla. However, increasing L. Perpusilla dose of 20, 25 and 30 mg/L will decrease the turbidity removal efficiency to 98.60%, 98.88%, and 86.24% respectively.

Extraction active component from L. perpusilla using 1 M NaCl solution produced blackish-green solution. The decrease in coagulation efficiency due to the additional dose of L. perpusilla is predicted to be caused by this colour (figure 4).

Previous research conducted by Pritchard [10] and Dalvand [26] also gave the same results. According to Pritchard [10], alum provided 15.8% higher efficiency of turbidity removal than M. oleifera for turbid water treatment. Dalvand used 3 coagulants to remove direct dye from textile wastewater, e.g. alum sulphate, M. stenopetala and M. oleifera, and claimed that alum achieved the highest efficiency [26].

Figure 3. The effect of coagulants dose on turbidity removal

Figure 4. L. perpusilla extract and produced water using 20 mg/L dose of coagulant
3.2 Effect of coagulants on Total Organic Matter (TOM)

Total Organic Matter (TOM), also called Total Organic Material, is defined as the amount of organic matter content in water. Organic materials consist of dissolved organic matter, suspended (particulate) and colloids. The concentration of TOM in the water of Lake Cibuntu after treated by alum sulphate and *L. Perpusilla* were analyzed, the results were shown in figure 5.

![Figure 5. Effect of coagulants on residual Total Organic Matter](image)

The initial concentration of TOM concentration in lake Cibuntu was 6.24 mg/L. TOM concentration reduced until 6.18, 5.41, 5.02, 4.98 mg/L by adding 5, 10, 15 and 20 mg/L of alum dose respectively. Adding 25 and 30 mg/L of alum sulphate did not reduce concentration of TOM even further, but it remained at 4.98 mg/L. It means the efficiency of TOM removal could achieve 20.25% by applying 20 mg/L to 30 mg/L alum sulphate.

Application of *L. perpusilla* as a natural coagulant for treating turbid water from Lake Cibuntu would lead to the increase of TOM concentration in produced water. The concentration of TOM in produced water increase from 6.24 mg/L to 8.95 mg/L, 9.77 mg/L, 9.74 mg/L, and 10.91 mg/L in the *L. perpusilla* dose of 15, 20, 25 and 30 mg/L respectively. *L. perpusilla* consists of organic matter. The addition of *L. perpusilla* thus increased the concentration of organic matter. As a result, the concentration of TOM in produced water also increased. However, increasing *L. perpusilla* dose of 20, 25 and 30 mg/L will increase the TOM removal efficiency to 56.50%, 56.17%, and 74.85% respectively.

The current investigation results are supported by a previous research study conducted by Ali[27]. That research used 4 coagulants viz alum as inorganic coagulant; de-oiled Jatropha curcas cake, *M. oleifera* seed and Neem seeds (*Azadirachta indica*). That research verified that alum obtained the highest efficiency of microalgae removal.

3.3 Effect of coagulants on Total Suspended Solid

Total Suspended Solids (TSS) are defined as solid particles in water that can be trapped by a filter with a maximum particle size of 2μm or larger than colloidal particles'size. TSS is correlated with turbidity. Generally increasing TSS will increase turbidity value.
Figure 6. Effect of coagulants on TSS concentration of produced water

The use of alum sulphate and *L. perpusilla* as coagulants on water treatment had an effect on TSS concentration of produced water. Application of 5, 10 and 15 mg/L alum sulphate increased TSS concentration by 1.5 mg/L from initial concentration (35.5 mg/L). TSS increased by 4.23% by applying those doses. Furthermore, the addition of 20, 25 and 30 mg/L alum sulphate increased TSS concentration until 2.5, 3.5 and 4.56 mg/L from initial TSS concentration, as shown in figure 5. It means the efficiency of TSS increase could achieve 7.04%, 9.86% and 12.68% by applying 20 mg/l, 25 mg/l and 30 mg/l alum sulphate respectively.

Different results are shown by *L. Perpusilla* as the natural coagulant. TSS concentration increased from 35.5 mg/L to 51.5, 66, 78, 92, 106 and 125 mg/L on the application of 5, 10, 15, 20, 25 and 30 mg/l *L. Perpusilla*, respectively. The TSS increase reached 45.07%, 85.92%, 119.72%, 159.15%, 198.59% and 252.11% by applying 5, 10, 15, 20, 25 and 30 mg/l this coagulant, respectively. TSS concentration increased two times after applied 15 mg/l of *L. perpusilla* and 3.5 times after applied 30 mg/l of *L. perpusilla*. Application of *L. perpusilla* as a natural coagulant in water treatment increased TSS concentration significantly.

4. Conclusion

Alum and *L. perpusilla* were able to remove turbidity of water from Lake Cibuntu. The addition of coagulants increased the concentration of Total Suspended Solid (TSS). TSS concentration increased due to the addition of *L. perpusilla* and alum sulfate. Alum reduced concentration of Total Organic Matter (TOM), while *L. perpusilla* vice versa. Although not as effective as alum, *L. perpusilla* showed sufficient removal capability for the treatment of turbid water from Lake Cibuntu, the optimum dose should be considered to minimize side effects such as increasing TOM and TSS concentration.

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