Study of coagulant effective dose for water treatment plant in Semarang City

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Abstract. Water is an important component which community need, especially for clean water consumption. Water treatment plant is one of the solutions as fulfilment of clean water needs that guaranteed quality, quantity and continuity. Determination of the effectiveness of the type of coagulant is used to guarantee the quality of raw water according to the requirements of water quality of drinking of health minister of Republic Indonesia 492/2010 law. Blorong River is one of the water sources in Semarang City which has characteristics of turbidity of 41.1 NTU; pH 7.11 and TSS 110 mg/L. The aim of this study is to determinate effective type and dose from several coagulants. The method uses the Jar Test method with a variety of velocity gradients. The first variation is 550/sec and 100/sec, the second variation is 650/sec and 80/sec, and a third variation 700/sec and 60/sec. The types of coagulants used are Poly Aluminium Chloride (PAC), Aluminium Sulphate and Chemical Mixing Alum with parameters observed are turbidity, pH, total suspended solids (TSS), and flock size. This study resulted coagulant PAC as an effective coagulant with an optimal dose of 10 ppm resulting in a pH of 6.71, turbidity 1.65 NTU, TSS 34 mg/L and flock size 1.7 cm at the third velocity gradient. Based on the planning discharge of 200 L/sec, the PAC coagulant costs IDR100,000 L/day.

1. Introduction

Water is an important component on earth which is the main need of the community both in urban and rural areas, one of which is Blorong River water in Semarang City. Drinking water needs in the city of Semarang increases along with high population growth. River water is one of the raw water sources that can be used to supply clean water needs. Generally, river water contains organic and solids which cause turbidity in the water [1,2]. Therefore, water treatment is needed to fulfil the water quality to established quality standards. The quality standard refers to the water quality of drinking of health minister of Republic Indonesia 492/2010 law [3]. Water treatment is carried out by three methods such as physical, chemical and biological processing [4] Physical processing aims to reduce turbidity and rough solids carried by water by using filters or sedimentation [5], biological treatment aims to removing bacteria by giving disinfectants [6], and chemical processing with the addition of coagulants such as Poly Aluminium Chloride (PAC) coagulant [7], Aluminium Sulphate (alum) coagulant [4], and Chemical Mix Alum (CMA) coagulant.

The three types of coagulants are often used for water purification processes [6,8]. In this case water treatment using chemical processing to determines the effectiveness of the coagulant which aims to reduce the parameters that exceed the quality standard [2,3]. Parameters observed were decreases in
turbidity, pH, TSS and flock size. From this research, it will produce a type of coagulant with the ability to decrease water quality requirements and have an affordable price.

2. Materials and method

2.1. Materials

This research uses samples from the Blorong River Semarang near from intake location of the water treatment plant in Jatisari with total samples used as much as 90 liters. Sampling was carried out on March 18, 2019 with physical and chemical parameters as the initial analysis (table 1).

![Figure 1. Location of water sampling.](image)

**Table 1. Blorong river analysis**

| No | Parameter          | Units | Value |
|----|--------------------|-------|-------|
| 1  | Temperature        | °C    | 22.3  |
| 2  | Color              | TCU   | 54    |
| 3  | Electrical Conductivity | µohm/cm | 186.5 |
| 4  | Dissolved Solids   | mg/L  | 93    |
| 5  | Turbidity          | NTU   | 41.1  |
| 6  | pH                 |       | 7.11  |
| 7  | Suspended Solids   | mg/L  | 110   |

Water purification process use three types of coagulants that have different specifications (table 2).

**Table 2. Coagulant type specifications.**

| Spesifikasi | Poly Aluminium Chloride | Coagulant Type | Aluminium Sulphate |
|-------------|-------------------------|----------------|--------------------|
| pH          | 3.5 - 5                 | 3.63           | 2.6 – 3.3          |
| Al₂O₃ Content | 30%                    | 8.09%          | 0.41%              |
| Solubility | 98.5%                   | -              | 99.49%             |
| Spesific Gravity | -          | 1.31           | 1.32-1.34          |

2.2. Method

The method used is the Jar Test method test and turbidity analysis with Hellige Turbidimeter, pH analysis with pHmeter, the size of the floc with Imhoff Cone or mistar to measuring the height that is deposited and TSS analysis by examining suspended/non-dissolved solids [9,10].

Jar Test method used to determine the optimum coagulant dose in reducing water turbidity value [11]. The 30% PAC coagulant solution was diluted by adding 3.3 grams of PAC powder into a 1000 mL volumetric flask; Liquid CMA coagulant solution was diluted by adding 0.75 mL liquid CMA to a 100 mL volumetric flask; and 2% Alum coagulant solution was diluted by adding 2 grams of alum powder into a 100 mL volumetric flask. The coagulant is mixed in 1 L of raw water with five different doses for each type of coagulant [12].
Jar test can be set stirring speed and stirring time [13,14] so that the stirring speed is based on gradient velocity variation with 1 minute for rapid mixing, 15 minutes for slow mixing and deposited for 20 minutes. Then turbidity, pH, TSS and flock size were determined based on coagulant doses and different velocity gradients in one type of coagulant.

3. Result and discussion
Based on research conducted jar test experiments with velocity gradient variations is 550/sec (164 rps) and 100/sec (53 rps) as first variation; 650/sec (184 rps) and 80/sec (45 rps) as second variation; 700/sec (202 rps) and 60/sec (33 rps) as third variation. Variations in gradients velocity were applied to the jar test experiment on different types of coagulants.

3.1. Effect of Poly Aluminium Chloride dose on turbidity, pH, flock size and TSS
The addition of PAC coagulant resulted in turbidity and pH values which were getting lower by giving higher coagulant doses, this was similar in previous research [11,15]. In processing water purification turbidity values are based on quality standards for a maximum of 5 NTU and the pH value is between 8.00-6.00 [3] so this experiment fulfils these criteria.

The effect of giving coagulants by figure 2. and figure 3 shows that the greater the coagulant value of turbidity and pH will be lower [16]. The 10 ppm coagulant dose was chosen as the optimum dose with turbidity value is 1.45 NTU with a pH value is 6.71. PAC compounds contain small amounts of acid compared to other coagulants and PAC are able to react perfectly and do not caused corrosion effects on the pipe [17].

\[
2AlCl_3 + 5OH^- + 5Na^+ \rightarrow Al_2(OH)_3Cl_5 + 5Na^+ + 5Cl^-
\]

\[
Al_2(OH)_3Cl_5 + H_2O \rightarrow 2Al(OH)_3 + H^+
\]

The PAC coagulant affects the size of the flock formed, the precipitation produced by the PAC coagulant are bigger [18] as the largest flock size is a good size for precipitation.

![Figure 2. Effect of PAC coagulant dose on turbidity.](image)

![Figure 3. Effect of PAC coagulant dose on pH.](image)

![Figure 4. Effect of PAC coagulant dose on TSS.](image)

![Figure 5. Effect of PAC coagulant dose on flock size.](image)
TSS parameters by figure 4 showed that the PAC coagulant dose of 10 ppm with gradient velocity three variations had a TSS decrease is 69% and the height of the flock size formed was 1.7 cm. The largest size of flock by figure 5 is at a dose of 18 ppm, but at that dose the pH of the formed water becomes more acidic.

The advantages of PAC coagulant are able to reduce turbidity more and not caused corrosive in water treatment plants. The disadvantage is the cost relative more expensive. Based on the planning discharge of 200 L/sec at a dose of 10 ppm, PAC coagulant costs IDR100,000 L/day.

3.2. Effect of chemical mixing Alum dose on turbidity, pH, flock size and TSS

Chemical Mixing Alum (CMA) has a dose range of 40 ppm to 60 ppm resulting in a percentage of turbidity allowance of 93% - 96% and a pH value of 6.1-6.49. The optimum coagulant dose by figure 6 is 50 ppm with 95% turbidity allowance or 1.99 NTU with pH value by figure 7 is 6.49.

![Figure 6. Effect of CMA Coagulant Dose on Turbidity.](image1)

![Figure 7. Effect of CMA Coagulant Dose on pH.](image2)

Velocity gradients affect the selection of the optimum dose, even though the changes that occur are not significant because in this study still use the same mixer design [19]. The effect of the velocity gradient on the CMA coagulant has succeeded in reducing TSS parameters. On the velocity gradient variation one and two obtained 85% decrease in TSS while at the velocity gradient variation three obtained 84% decrease in TSS.

![Figure 8. Effect of CMA coagulant dose on TSS.](image3)

![Figure 9. Effect of CMA coagulant dose on flock size.](image4)

Figure 9 shows the largest flock size at a dose of 60 ppm. High coagulant doses cause high flock size to be large because in alkaline conditions it causes a greater flock growth rate [14,20]. The optimum dose for CMA coagulant is 50 ppm with a three variation speed gradient with 95% turbidity allowance, TSS decrease by 78%; 0.7 cm high flock size and pH values is 6.49. The CMA coagulant has a cost of IDR3,741.85./kg cheaper than the PAC coagulant cost [21]. Based on the planning discharge of 200 L/sec at a dose of 50 ppm, PAC coagulant costs IDR187.050 L/day.
Figure 10. Effect of CMA coagulant dose on flock size.

3.3. Effect of Aluminium Sulphate on turbidity, pH, flock size and TSS
Aluminium Sulphate coagulant has a dosage range of 10 ppm - 30 ppm. At a dose of 10 ppm in each variation the speed gradient has a pH of 6.7 with allowance for turbidity 94%, while at a dose of 20 ppm it can reduce turbidity up to 96% with pH value 6.5. Alum when dissolved in water will produce H₂SO₄ compounds which will reduce the pH of water [2,22].

\[ \text{Al}_2(\text{SO}_4)_3 + \text{H}_2\text{O} \rightarrow 2\text{Al(OH)}_3 + 3\text{H}_2\text{SO}_4 \]

Figure 11. Effect of alum coagulant dose on turbidity.

Based on the TSS chart shown by figure 13 the more alum coagulant doses are added, the more decrease TTS concentration. This is because the positively charged colloidal disperse binds fine particles and neutralizes the charge, which is similar to previous research Firra and Mirwan then form small flock and settle.

\[ \text{Al}_2(\text{SO}_4)_3 + 3\text{Ca(OH)}_2 \rightarrow 2\text{Al(OH)}_3 + 3\text{CaSO}_4 \]

Figure 13. Effect of alum coagulant dose on TSS.

The effect of alum coagulant doses formed the height of flock size of 1.4 cm in variation one which is the largest size among the other three variations. In this experiment the alum coagulant dose was 20 ppm.

Figure 14. Effect of alum coagulant dose on flock size.
with velocity gradient variation one. The alum coagulant has a cost of IDR 5,000. -kg. Based on the planning discharge of 200 L/sec at a dose of 20 ppm, PAC coagulant costs IDR 100,000. -L/day

4. Conclusion
Effective coagulant for processing drinking water with raw water sources from the Blorong River is a PAC coagulant at a dose of 10 ppm. A 10 ppm PAC can produce pH 6.71; turbidity of 1.65 NTU and TSS 34 mg / L with velocity gradient in variation 3 which resulted in a 1.7 cm flock size at a cost of IDR 100,000 L / day. Although the cost of the PAC coagulant is more expensive and is equivalent to the alum coagulant but the PAC coagulant is effective in reducing turbidity and TSS.

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