

# Application of aerated submerged sponged bed biofilter for raw water pre-treatment in drinking water installation

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**Abstract.** Pesanggrahan River has been contaminated by domestic wastewater. High contamination of Pesanggrahan River with the maximum observed TSS (243,8 mg/L), COD (165,2 mg/L), Total Phosphate (0,74 mg/L), and NH<sub>3</sub>-N (1,04 mg/L) has exceeded the Raw Water for Drinking Water standard based on Government Regulation Number 82 the Year 2001. Aerated Submerged Sponge-bed Biofilter can be proposed as pre-treatment recommendation for Drinking Water Treatment Plant processing due to its environment-friendly property and ability to reduce the organic pollutant. A lab-scale experiment with the modified volume of 15% media was applied in a 6L reactor with 7 L/min oxygen supply. Retention time variation was evaluated at 1, 1,5, and 2 hours. It was found that the highest removal efficiency occurred at HRT 1,5 hours with the reduction capability of 75,5±0,12% TSS; 59,1±0,14% COD; 57,1±0,27% Total Phosphate; and 45,5±0,37% NH<sub>3</sub>-N. On the same HRT (1,5 hours), ammonia reduction obtained at  $k_{(0-order)} = 0,005$  g/m<sup>2</sup>day. This biofilter also decreased the optimum coagulant (PAC) concentration needed.

## 1 Introduction

The crisis in clean water is one of the major issues in Jakarta. The clean water service in this capital city of Indonesia only able to cover around 60% of the whole clean water needs of Jakarta citizens. Limited water resources from groundwater and surface water is a serious warning for Jakarta. According to a report from a drinking water supply company (PAM Jaya), Jakarta only has ±3% water reserves, which means that DKI Jakarta has a clean water deficit around 9.100 liters per second for more than 10 million citizens [1]. The issue of land subsidence in Jakarta makes represents the condition that Jakarta might need the new water source from surface water. But the primary issue about the surface water source is its quality. The Government Regulation Number 82 Year 2001 set the water class standard, according to the purpose of surface water resource [2]. Among all the rivers that flow through Jakarta, Pesanggrahan river has the second biggest minimum flowrate as 10,14 m<sup>3</sup>/sec [3]. However, the water quality of Pesanggrahan river is still the biggest issue because it contains the contamination from a domestic source around the water body [3], [4].

Biological treatment is one of the most commonly used technology because it doesn't need the chemical compound in addition to run the treatment process. Therefore, the operational cost is relatively cheaper than the common physic-chemical treatment [5]. Pre-treatment using biological system can be the most suitable option to increase the efficiency of drinking water treatment

installation. Biofiltration can be the most suitable treatment due to its ability to remove pollutant contaminant that can't be naturally removed by the conventional treatment, such as organic compounds, ammonia, detergent, and pesticide [6]. The research about biofilter as pre-treatment for polluted water as drinking water supply had been done and found that on 2 h HRT the removal efficiency reached 78% for organic load, 82% for ammonium, and 91% for TSS [7]. Treatment using submerged sponge-bed with fraction volume of 20% was able to remove phosphate from wastewater up to 99% [8], [9]. The research about membrane fouling proof that the submerged sponge-membrane reactor produces less membrane barrier layer that inhibits the nitrification process in the biofilm layer also has stronger pore resistance [10]. The combination of submerged biofilter technology and sponge-bed as an attached growth media is potentially the best alternative to treat the quality of Pesanggrahan river water that's research-worthy. This study aims to discover the potential performance of aerated submerged sponge-bed biofilter as the pre-treatment of Pesanggrahan river water quality according to the class I standard of Government Regulation Number 82 Year 2001.

## 2 Research methodology

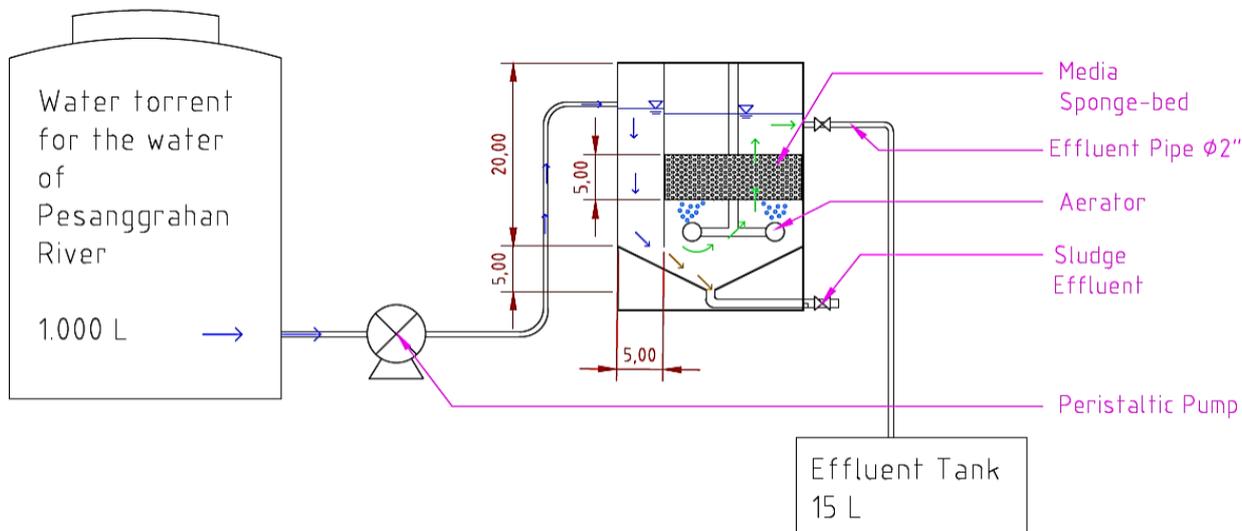
The experiment was held in situ at Cinere spot with the raw water taken from Pesanggrahan River. The

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experimental equipment consisted of a raw water tank, peristaltic pump, and one unit of biofilter.

The biofilter unit was made of Plexiglas with the working volume of 6 L, filled with Sponge-bed as the media for attached growth, equipped with an air supply and water faucet at the effluent. The volume of the Sponge-bed was 15% of the biofilter fraction volume. The aerator was equipped with four branches to channel the

air and therefore minimize the possibility of dead zones to appear. The biofilter was operated with combined flow, where the influent enters the bioreactor with downflow then went with the up-flow with the aid from aerator's airflow. The schematic diagram of the biofilter experiment system can be seen in Fig. 1.



**Fig. 1.** Biofilter reactor operation scheme

### 2.1. Characterization of raw water

The characteristic of the raw water was determined with the physical and chemical parameters, such as TSS, COD, Total Phosphate, and NH<sub>3</sub>-N. The experiment was held during February until May 2018. Table 1. shows the raw water characteristic from Pesanggrahan River during the experimental.

**Table 1.** Raw water characteristics

Parameter	Amount <sup>1)</sup>
TSS	7 - 243,8
COD	31,4 - 165,2
Total Phosphate	0,12 - 74
NH <sub>3</sub> -N	0,08 - 1,04

1) unit : mg/L

### 2.2 Sponge-bed

The study of sponge-bed's competency to reduce pollutant has been conducted in several studies. Biomass flocs were less easily broken up with the suggest addition of relative light and large-sized carriers with larger surface area ([10]–[12]). Sponge is one of the most used

material due to its high porosity property [13]. Polyethylene fiber sponge is used to remove COD in wastewater (0,4 kg/m<sup>3</sup>-day) with the pore size of 0,1 μm and surface area of 0,195 m<sup>2</sup> [8].

### 2.3 Seeding and acclimatization process

The seeding process was done with the bacteria inoculum using activated sludge from the Aeration Pond of Jababeka's Wastewater Treatment Plant (the biggest industrial zone in Jakarta) in aim to hasten the biofilm formation. The seeding was held for 17 days until the bacteria has its own removal pattern, then the process continued with the acclimatization that was held for 10 days. This process was intended to achieve the steady state for microorganisms' growth. The COD removal ability was used to indicate the acclimatization condition and the stable removal rate.

### 2.4 Effect of hydraulic retention time

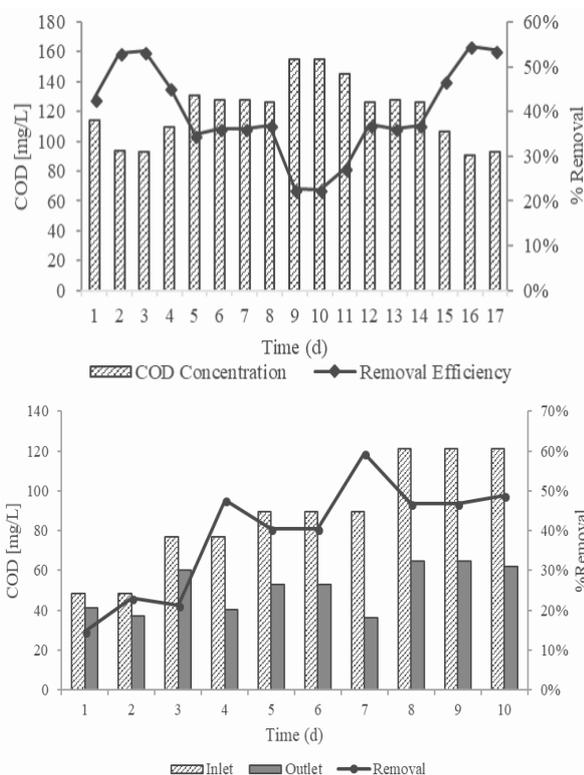
After achieving the growth phase, the experiment then continued with feeding process to evaluate the effect of hydraulic retention time variation to the pollutants removal efficiency. The experiment was conducted in three levels of hydraulic retention time, that is 1 h; 1,5 h; and 2 h where each one was run for six days.

The performance of biofilter was evaluated with both physical and chemical parameters (TSS, COD, Total Phosphate, and NH<sub>3</sub>-N). Samples from the influent and effluent was taken daily for each variation of hydraulic retention time. Laboratory analysis was held to measure the water quality, whereas minor variables such as dissolved oxygen, pH, and temperature were also measured directly.

### 3 Results and discussion

#### 3.1 Pollutants removal

The seeding and acclimatization process was conducted using recirculation flow with the diluted activated sludge as the inoculum to ignite the growth of biofilm on the media, so that the inoculum can get enough nutrition to do metabolism, growths, and productions. All the bacteria in biofilm will always compete each other and try to adapt the new environment condition to get the nutrition require and energy for its growth production [14]. The hydraulic retention time variation was analysed by setting the flowrate. The start-up process was conducted with the lowest hydraulic retention time with flowrate 100 ml/min, so that the bacteria will adapt the fast contact time to the media. Excessive oxygen supply was given at 7 L/min. The aeration process helps the microorganisms to reduce organic pollutant better [15]. Fig. 2 shows the removal efficiency at the seeding and acclimatization process. The bacterial biofilm layers were observed visually attaching the media, indicated biofilm formation and development. After 17 days of operation, the organic removal efficiency relatively increased gradually, achieving its steady-state condition. The next step was to acclimate the bacterial growth, which was held for 10 d.



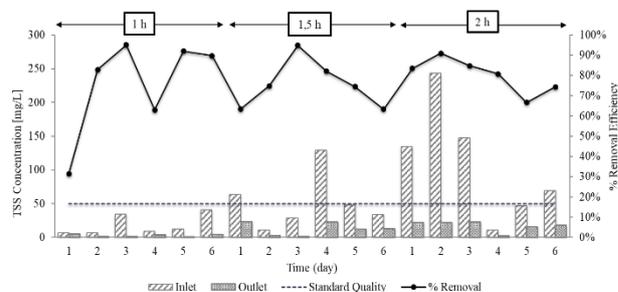
**Fig. 2.** Seeding and acclimatization process

Experiments were then conducted in aim to evaluate the most optimum hydraulic retention time to remove organic pollutant. The hydraulic retention time was then increased to 1,5 h and followed by the 2 h operation, which each was held for 6 d running operation. The increasing hydraulic retention time was held to minimize

the potential of shock load. The following paragraphs discuss about the biofilter performance during the experiment.

#### 3.1.1. Total suspended solids

TSS is the most common parameter used in observation for domestic water treatment usage. High TSS affects the taste of water, usually giving laxative effect, and often causing disease if the body is not get used to high contamination [16]. A low concentration of TSS in water will lead to reduced coagulant consumption in the subsequent raw water treatment [7]. The inlet concentration of TSS that goes into the reactor varies between 7 to 243,8 mg/L. This variation possibly occurs due to the weather conditions such as rains. The flow model operation of the biofilter can significantly reduce TSS. The performance of TSS removal efficiency can be seen in Fig. 3., showing the removal rates ranged from 31% to 95% within all variation from 1 h; 1,5 h; and 2 h of hydraulic retention time.



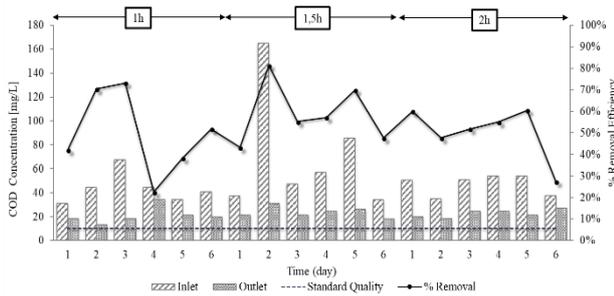
**Fig. 3.** TSS removal efficiency graph

Based on Fig. 3., the high removal efficiency for TSS obtained owing to the shape of the reactor with the room to collect the solids before the water was streamed *upflow*, resulting the solids to settle down. This *upflow* system has caused the particle velocity in the treated water decreased, so that the particles that is not carried by the *upflow* will settle in the bottom of the biofilter reactor [17]. The biofilter performance with a combined flow like this experiment achieved the reduction averagely for hydraulic retention time of 1; 1,5; and 2 h for 75,7%; 75,5%; and 80,2% respectively. Pre-treatment using aerated submerged sponge-bed biofilter was able to decrease the TSS value until below the class I quality standard for drinking water based on Government Regulation No. 82 Year 2001.

#### 3.1.2. Chemical oxygen demand

COD is one of the main parameters based on Government Regulation No. 82 Year 2001 with the threshold's value for class I is 10 mg/L on raw water for drinking water. COD represents the oxygen needs for bacteria's metabolisms, in means that the higher oxygen needs represents higher microbial activities [16]. The COD concentration in the water that goes into the reactor varies

between 31,4 to 165,4 mg/L. Fig. 4. Shows the COD removal in all variant of HRT.

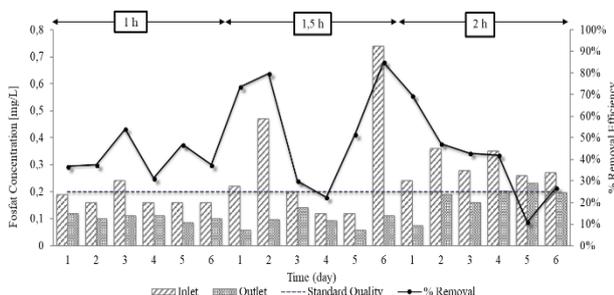


**Fig. 4.** COD removal efficiency graph

Fig. 4. shows the removal efficiency of COD which the rate ranged from 23% to 81%. The average value of COD removal at the hydraulic retention time of 1; 1,5; and 2 hours were 49,7%; 59,1%; and 50,4% respectively. Highest removal efficiency was achieved at the operation with 1,5 h hydraulic retention time. In COD removal, oxygen plays a big part, due to the operation that ran aerobically, and therefore needs enough supply of oxygen. This is proved when *Pearson*-correlation test was held, showing strong bond between low dissolved oxygen level with low COD removal. Bacteria's biochemical metabolism uses those amounts of oxygen to extract organic substrate become two simpler form: CO<sub>2</sub> and H<sub>2</sub>O. The raw water pre-treatment using aerated submerged sponge-bed biofilter was able to degrade the value of COD significantly below the value of standard water quality class II based on Government Regulation No. 81 Year 2001. Therefore, this reduction can lighten the process load of drinking water treatment to fulfil the required class I standard for drinking water.

### 3.1.3. Total phosphate

Total phosphate is the main source for undissolved potassium and nitrogen in water. Exceeded phosphate in the water can trigger nutrient dispersion in water or known as eutrophication [18]. Biofilter performance in Total Phosphate removal can be seen on Fig. 5.



**Fig. 5.** Total phosphate removal efficiency graph

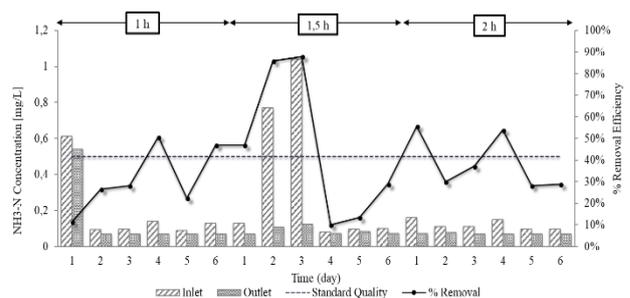
Fig. 5. shows the phosphate removal variation. While occurred in aerobic condition, dissolved phosphorous will be absorbed by bacteria then synthesized by organic

compounds oxidation [17]. Phosphate removal is closely related to DO dynamics variation. Some bacteria are able to accumulate excess amount of P in the form of polyphosphate, those bacteria are called polyphosphate accumulating organisms (PAO) [13]. These bacteria have the ability to remove simple substrate products and store it inside their cells. The strong correlation between phosphate removal and dissolved oxygen represents that the living bacteria needs enough oxygen supply to metabolize and grow themselves.

The experiment showed that the Sponge-bed biofilter with the hydraulic retention time of 1; 1,5; and 2 h was able to remove averagely 40,7%; 57,1%; and 39,9% total phosphate in the water, respectively. Hydraulic retention operation for 1,5 h explained that the organic load influent affects about 64,74% increase in removal efficiency. The standard quality for Class I water based on Government Regulation No. 82 Year 2001 for total phosphate is 0,2 mg/L. Raw water pre-treatment using sponge-bed biofilter was able to increase the water quality and degrade the total phosphate contamination with the average of 0,12 mg/L that meets the threshold.

### 3.1.4. NH<sub>3</sub>-N

Nitrogen derivatives are usually found in the water in the form of ammonia, nitrite, and nitrate even though those components are not desired in drinking water due to its toxicity property for living organisms. Ammonia can be biologically oxidized in biofilter system by nitrification [7]. The most common bacteria to convert ammonia into nitrite is *Nitrosomonas*, while the one converting nitrite into nitrate is *Nitrobacter*. Fig. 6. shows ammonia removal during all variation of hydraulic retention time.



**Fig. 6.** NH<sub>3</sub>-N removal efficiency graph

From Fig. 6., the removal efficiency of ammonia for the hydraulic retention time of 1; 1,5; and 2 h was averagely 31,3%; 45,6%; and 39,0% respectively. The removal of ammonia depends on the nitrification process that's held during the experiment. Therefore, a source of oxygen supply is necessary. The pH condition in the environment also takes a big role into this process, making a strong connection with the removal efficiency. The performance of biofilter is also possibly affected by the amount of TSS that goes into the reactor, especially increasing the clog possibility for sponge-bed media which have small pores.

Hydraulic retention time of 1,5 h operation indicates the strong bond of organic load influent with 95,28%

removal rate. It is explaining that the higher ammonia load that goes into the reactor, the higher bacteria's organic load removal ability. The most optimum ammonia removal that could be reduced is 0,001 to 0,016 kg/day.m<sup>3</sup>. The removal rate also affected by organic removal when the microorganism oxide the organic and inorganic material to produce energy for growth, heighten the growth of heterotroph bacteria and decreasing the nutrition supply for autotroph bacteria's growth [16]. Under aerobic condition, the removal efficiency will degrade when the biofilm layer on media thicken. The nitrification process will be inhibited because both type of bacteria will compete each other to get the oxygen and nutrition needs.

### 3.2 NH<sub>3</sub>-N removal kinetics

This experiment also delved into the removal kinetics of NH<sub>3</sub>-N by observing the removal efficiency trend by the biofilter. The data of observed experiment result is shown on Fig. 7.

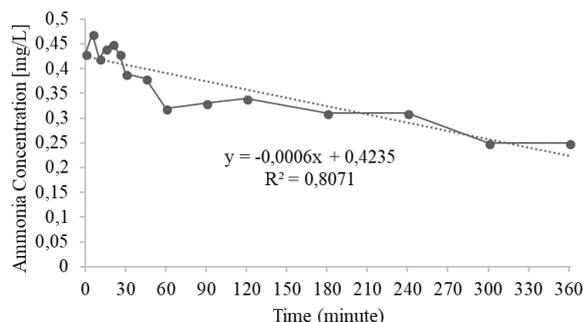


Fig. 7. NH<sub>3</sub>-N Decrease per time (minute)

Fig. 7. shows the removal kinetics of ammonia in zero order reaction with  $r^2$  0,807. Removal ammonia is observed with linear equation  $y = -0,0006x + 0,4235$ . From calculation, it is found that the removal rate as 0,005 g NH<sub>3</sub>-N/m<sup>2</sup>-day. Nitrate value from before and after observation decrease from 2,5 to 0,25 mg/L; while the Nitrite value increase from 1 to 2 mg/L due to the reaction that occurred.

It is stated that the ammonia pattern where nitrite constantly formed as a direct compound during ammonia oxidation to change into nitrate. In other words, this indicates how easy it is for ammonia to make a chemical bond with oxygen, creating nitrite [19]. The NH<sub>3</sub>-N result from aerated submerged sponge-bed biofilter has met the standard quality of class I water resource purpose based on Government Regulation Number 82 Year 2001 of Raw Water for Drinking Water. The effluent quality for NH<sub>3</sub>-N after the treatment averagely 0,1 mg/L; showing the water has reached the quality below the standard level which is 0,5 mg/L.

### 3.3 Most optimum HRT

All the results data is then used to determine the most optimum hydraulic retention time for biofilter pre-

treatment. The data was assessed by comparing the HRT operation with the highest average removal efficiency. The overall removal efficiency resulted of HRT variation for each parameter can be seen in Fig. 8.

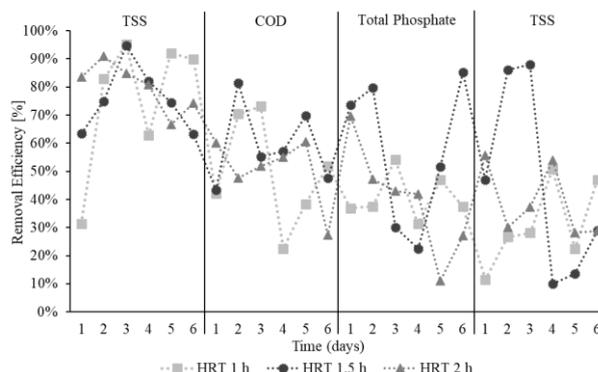


Fig. 8. Overall removal efficiency of HRT variation for each parameters

From Fig. 8., we can see all data variations of removal ability to decrease the pollutants varies for all HRT and parameters. Then those variations show us that the median of each HRT variation is different. Statistical descriptive approach shows that the 1,5 hours of HRT operation resulting the highest median, followed by 2 hours then 1 hour of HRT pre-treatment operation. Observation in the range of 1,5 hours HRT pre-treatment resulting the pollutant removal ability that can be relied upon. It is believed that with a better conditioning environment, removal potency with 1,5 hours contact time can be stabilized during on field application.

Pollutant removal ability with 1,5 hours contact time ranged around 75,5±0,12% for TSS; 59,1±0,14% for COD; 57,1±0,27% for Total Phosphate, and 45,5±0,37% for NH<sub>3</sub>-N. Observation using biofilter pre-treatment resulted in a significant reduction of contaminants. From each parameter and overall removal ability observation, it is resulted that 1,5 hours of pre-treatment operation is the most optimum contact time between the water and the media. This assessment was done according to reach the threshold of Class I Drinking Water Purpose of The Government Regulation Number 82 Year 2001.

### 3.4 Post-treatment advantages

The experiment was continued with jarrest to know the effects of sponge-bed biofilter pre-treatment towards optimum coagulant dose, compared to the water without any pre-treatment. Coagulant addition in water treatment is purposed to destabilize the colloids, hence forming flocs to be settled down. The type of coagulant that's been used in the experiment was PAC with optimum work at pH of 6 to 9. Jar test experiment was done with coagulant dose variations to get the most optimum dose for pollutant degradation in the water.

The initial measurement resulted in water characteristic of 33 mg/L COD. Then jarrest simulation was done and found that the most optimum dose of

coagulant ranged around 50 ppm to decrease the COD concentration to 19 mg/L. This shows the need of coagulants if the water does not run into pre-treatment. Meanwhile, the initial measurement of the water that has been ran into pre-treatment using sponge-bed biofilter resulted in 24 mg/L COD. Water pre-treatment was held with the most optimum HRT obtained from the experiment: 1,5 hours. The same jarrest simulation was done and resulted that the most optimum dose of coagulant needed declined into the range around 5 ppm. Using that little dose of coagulant, COD concentration was able to be decreased to 14 mg/L.

The optimum dose of coagulant that is needed to treat the water is decreasing. Therefore, this pre-treatment will be able to give advantages to water treatment plant from three sides: (1) decreasing the optimum coagulant concentration needs, followed by (2) decreasing the cost of PAC purchase; also (3) convenience in secondary drinking water treatment thanks to low COD concentration.

## 4 Conclusion

A water pretreatment using Aerated Submerged Sponge-bed Biofilter can significantly improve the water quality and decrease the pollutant concentrations, as shown by the decreased value of TSS, COD, Total Phosphate, and NH<sub>3</sub>-N. Boxplot assessment is used to see the tendency of highest removal efficiency of all parameters. Most optimum hydraulic retention time of 1,5 hours was found with removal efficiency for TSS, COD, Total Phosphate, and NH<sub>3</sub>-N respectively as 75,5±0,12%; 59,1±0,14%; 57,1±0,27%; and 45,5±0,37%. This pre-treatment has resulted in pollutants concentration fulfilling the requirement of Class I Water Quality of the Government Regulation No. 82 year 2001 in terms of TSS, Total Phosphate, and NH<sub>3</sub>-N. Whereas the concentration of COD can be decreased significantly. This pre-treatment using Sponge-bed biofilter can be an effective recommendation to lighten the load of drinking water treatment plant's conventional process and therefore decreasing the coagulant purchase costs.

The authors are indebted to Environmental Engineering Laboratory Universitas Indonesia for allowing us operating and testing the reactor in the lab. The authors are thankful for the financial support of Hibah Publikasi Internasional Terindeks Untuk Tugas Akhir Mahasiswa UI (PITTA UI) No. 2529/UN2.R3.1/HKP.05.00/2018.

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