

Bench scale study of moving bed biofilm reactor application as pre-treatment of raw water for water treatment plant (Case study: Pesanggrahan River)

Rhefa Fauza Setiani¹, Setyo Sarwanto Moersidik^{2,*}, and Sandyanto Adityosulindro²

¹Environmental Engineering Study Program, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia

²Department of Civil Engineering, Faculty of Engineering, Universitas Indonesia, Depok, Indonesia

Abstract. The quality of surface water in Jakarta is on a serious polluted status. In order to reduce the Water Treatment processing load, a pre-treatment process is needed to eliminate parameters such as organic matter, ammonia, color, taste, and odor. This treatment generally uses chemical and physical processes, such as chlorination and activated carbon that produce harmful byproducts. Moving Bed Biofilm Reactor (MBBR) is one of the solutions developed to reduce the nutrient and organic levels in raw water. This study aims to improve the quality of raw water, by reducing the concentration of COD, NH₃-N, Phosphate, and TSS before entering the conventional process. Reactor performance is assessed based on contaminant removal efficiency with variation of residence time (1 hour, 1.5 hours, 2 hours). The reactor is operated by using Kaldness K1 as the medium and oxygen supply of 7 L/min. The optimum residence time is 1,5 hours with the ability to remove COD, NH₃-N, Phosphate, TSS 51.8% ± 0.2; 54.3% ± 0.28; 52.6% ± 0.19; and 77.7% ± 0.14 respectively. Based on the optimum residence time, the kinetics of the ammonia removal rate in MBBR takes place at zero order, with a rate constant removal of 0.0056 g/m².day. The results showed that the higher concentration of ammonia, and organic contaminants treated, the higher the efficiency of MBBR. Apart from water quality improvement, pre-treatment process using MBBR can reduce coagulant dose from 50 mg/L to 9 mg/L, to decrease raw water turbidity from 135 NTU to 0.68 NTU before entering the coagulation-flocculation unit.

1 Introduction

According to water quality monitoring conducted by the Ministry of Environment and Forestry in 2015, it was known that 68% of river conditions in Indonesia were heavily polluted. In addition, based on the evaluation of the Jakarta river water quality conducted by Regional Environmental Agency in 2015, most of river in Jakarta were classified as heavily polluted. Pesanggrahan River is one of the surface water that still has the potential to be used as a source of clean water with quality improvements 1. Pesanggrahan River has not meet the requirements of the quality standard, based on the research of Regional Environmental Agency in 2015 the river included in the C category of water body, that is more suitable for use as fisheries and livestock water sources because they have pollutant levels that exceed drinking water parameters. The contamination is produced by domestic waste due to activities in the Pesanggrahan watershed area, which is dominated by agricultural and residential activities 2.

The concentration of organic pollutants, and ammonia which exceeded the environmental threshold based on Government Regulation No. 82 of 2001 about raw water quality standards will make it difficult for water treatment

plants to treat raw water 3. Since conventional water treatment plant (WTP) is generally not designed to remove organic parameters and ammonia, a pre-treatment process is required. So far, pre-chlorination has been used in most of WTP to remove organics and other contaminants in raw water (*i.e.* manganese, ammonia, and detergent). Nevertheless, the disadvantage of this process is the high cost and could produce carcinogenic by-products such as trihalomethane and chlorophenol 3.

To overcome the limitation of pre-chlorination, biological processes come with environmentally benign technologies which offer organics and ammonia removal without using chemicals and expensive operational costs. Moving Bed Biofilm Reactor (MBBR) is one of the solutions developed to reduce nutrient and organic levels in raw water and wastewater. This system has advantages over other biological pre-treatment process, such as Aerated Filter, Biological Contact Oxidation, and Membrane Bioreactor because the cost is cheap, does not require a lot of space and is quite efficient in removing pollutant 4. Research on the use of MBBR as a pre-treatment unit for surface water treatment was carried out using a pilot-scale reactor, the system was raising a good

* Corresponding author: ssarwanto@eng.ui.ac.id

interest because it could remove ammonia concentrations from the Yellow River sample water in China by 61.6% and COD 11, 53% respectively. Another study also carried out for micro polluted water, using the Taihu River sample water in China. The study proved that the level of ammonia removal efficiency in the reactor reached $71.4 \pm 26.9\%$ depending on the influence of temperature, organic load, and residence time 4.

Based on the description above, the purpose of this research is to prove that Pesanggrahan River is adequate to be considered as a source of clean water by using the MBBR system as the pre-treatment process in order to meet the class I water quality standard based on Government Regulations No. 82 of 2001. This research will be conducted on a laboratory scale, only focusing on variables COD, NH₃-N, Phosphate, and TSS.

2 Material and methods

2.1 Raw water characteristics

Surface water was obtained from Pesanggrahan River in Cinere monitoring point. Characteristics of the raw water varies depend on environment condition. Influent characteristics throughout the research shown on table 1

Table 1. Characteristic of pesanggrahan river

Parameter	Concentration Range
COD	24.3 – 106.2 mg/L
NH ₃ -N	0.08 – 1.04 mg/L
Phosphate	0.12 – 0.74 mg/L
TSS	7 – 243.8 mg/L
DO	4.2 – 8.1 mg/L
pH	7.01 – 7.53

2.2 MBBR configuration and operation

The study was conducted using MBBR bench scale with a volume of 6 L (20 x 15 x 25 cm) fabricated from plexiglass. The design of the reactor refers to the previous study 6 with the modification of the addition of the pre-sedimentation zone (fig 1). Pre-sedimentation zone were made to reduce TSS concentrations before water was treated using media. The high TSS will reduce pollutant removal efficiency in biofilm systems, because it can clog media so that it inhibits biofilm growth 3.

MBBR is filled with Kaldness K1 as the media with a density of 0.95 g/cm³, which allows the media to move freely in the reactor. Media is made of polyethylene with a diameter of 10 mm, height 7 mm, and a specific surface area of 500 m²/m³. The filling of the media in the reactor is set at 40% volume, because the higher the percentage of the media, the removal efficiency will gradually decrease 6. Aeration is given through diffusor with a capacity of 7 L/minute. The water flowing process during the study was carried out continuously by downflow using

a peristaltic pump with a flow rate of 100, 66.7, and 50 mL/minute. This research was conducted with three variations of detention time, which were 1, 1.5, and 2 hours.

2.3 System start-up and experimental procedure

Seeding process was carried out to grow bacteria in the media, by adding an inoculum in the form of activated sludge from the oxidation ditch unit of the Jababeka WWTP, with an MLVSS concentration of 6232.1 mg/L. The system was operated by a batch method to support the formation of a biofilm layer, with a flow discharge of 100 mL/min. During the seeding process, a control over DO concentration above 2 mg/L was carried out 8, pH of 6.5 - 8.5, and temperature of 25 - 35°C 11 to support bacterial growth. The inoculation process was completed in 17 days, marked by the formation of a biofilm layer and the reach of steady state condition as indicated by the increase in removal efficiency from 34-55% (days 10-17).

After the seeding process was completed, an acclimatization process was carried out as a process of microbial adaptation to the water of Pesanggrahan river. The process was carried out gradually for 10 days until 100% of the reactor volume was filled with Pesanggrahan river water. The acclimatization process was divided into four stages based on the composition of the reactor loading. Phasing was carried out with a loading percentage of 25%, then it was continued with an increase of multiples of 25% every two or three days. Changes in load were carried out when the percentage of efficiency had increased because it was assumed that the bacteria in the reactor were familiar with the load given. The same treatment was given as it was given during the seeding process, to optimize the bacterial growth. The steady state condition was achieved when there is a steady increase from 25% to 33%. This indicates that microorganisms have succeeded in adjusting to the new load, which is indicated by the formation of thicker layers of biofilm due to multiple layers of growth, rapid cell division, and stable metabolism of microorganisms.

2.4 Analytical methods

The laboratory tests conducted to determine the concentration of COD, NH₃-N, Phosphate, and TSS from reactor's effluent, according to the National Standard of Indonesia (SNI 6989.72:2009). While both parameters, DO and pH were measured by DO and pH meter according to (SNI 06-6989.23: 2005). Each running of detention time is conducted within one week, with the process of monitoring water quality every day. One week's time was chosen to observe the tendency of the contaminant removal in a long period of time, besides that it was also adjusted to the operational time of the WTP that operated for a full week.

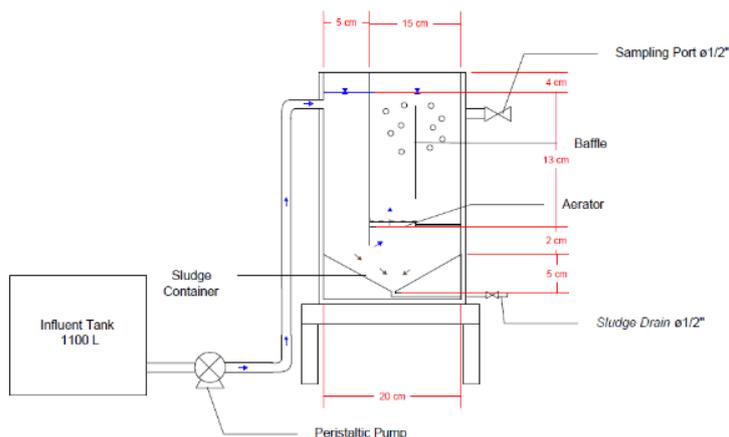


Fig. 1. Schematic of the Bench Scale Moving Bed Biofilm Reactor (MBBR).

3 Result and discussion

3.1. COD Removal

As shown in fig. 2, COD concentration varies depends on the operational condition. The study showed that by providing contaminants with high concentrations, the reactor could achieve higher removal efficiency. With an organic load of 2.6 kg/m³ the reactor can reach an efficiency level of 88.3%. Previous research explained that the higher the organic load was, the higher the COD removal efficiency became 11. This was due to the consumption of carbon material by bacteria which caused an increase in removal efficiency as the organic load was increased. Organic substances that can be removed biologically are influenced by several variables, namely dissolved oxygen (DO), contact time, and the type and number of decomposing microorganisms 12.

Removal efficiency at 1 hour was seen to decrease from 63.4 to 38.4% when there was an increase in DO concentrations of 7.7-8.1 mg/L. Likewise with the level of efficiency at 2 hours, the level of efficiency has decreased from 47.7 to 44% when DO concentration has increased by 7.1-8 mg/L. Meanwhile, the efficiency level tended to be stable at 1.5 hours of residence with the highest removal of 81.7% and the DO concentration range of 7.45-7.7 mg L. This increase in concentration indicates a low level of oxygen consumption, due to death by substrate-decomposing bacteria 10.

Based on this research, pH and efficiency level has a proportional relationship, which is characterized by an increase in pH and efficiency simultaneously. At 1 hour residence time, optimum efficiency was achieved at 63.4% with a pH of 8.3. While at 1.5 hours HRT was achieved when the efficiency was 81.2% with a pH of 8.33. As well as 2-hour HRT with an efficiency level of 47.7% and pH 8.29. Based on a previous research, pH conditions had a significant effect on COD removal. Therefore, it was necessary to maintain pH because heterotrophic bacteria grew optimally in the pH range 7-8.13.

The experiment showed that the effluent from MBBR has not met Class I Quality standard based on Government Regulation No.82 of 2001. The average concentration of the effluent is 49.41 mg/L which only meet the Class III Quality standard, with a maximum concentration limit of 50 mg/L.

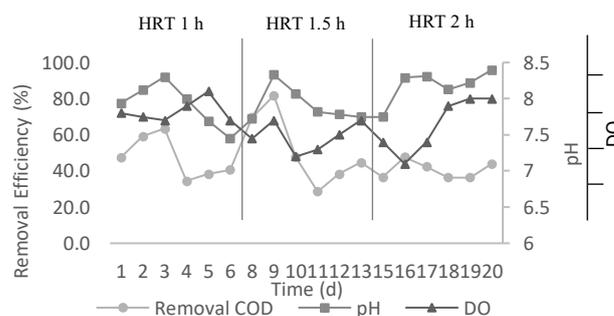


Fig. 2. COD removal efficiency, DO, and pH during operational period

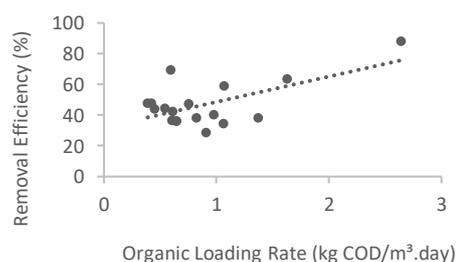


Fig. 3. COD removal rates versus COD loading rates in the MBBR system

3.2. NH₃-N removal

The nitrification rate in MBBR is influenced by three factors, which are organic load, ammonia load, and oxygen concentration. In order for the nitrification process to take place, a load of more than 4 g/m².day and a concentration of oxygen above 6 mg/L can take place 11. In addition, the research also showed that with a load range of 0.1 - 4.43 g-N/m².d the highest removal was achieved at 93%.

* Corresponding author: ssarwanto@eng.ui.ac.id

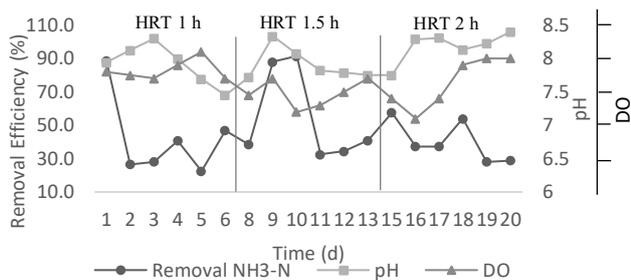


Fig. 4. NH₃-N removal efficiency, DO, and pH during operational period

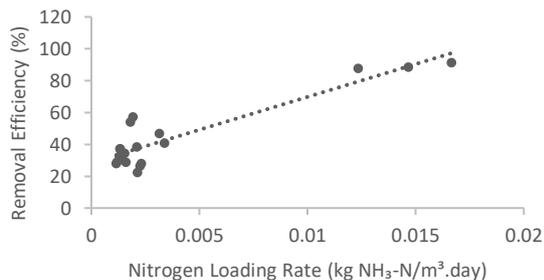


Fig. 5. NH₃-N removal rates versus ammonia loading rates in the MBBR system

In this study, the pH range was kept at 7 to 8.5 because the nitrification rate decreased significantly when the pH was below 6.8. Specifically, the optimum pH range for *Nitrosomonas* and *Nitrobacter* bacteria is 7.9–8.8 and 7.2–7.6 respectively. On the first three days, it was seen that the pH decreased, this was because at the initial stage of the nitrification process consumed alkalinity, which caused a decrease in pH. The nitrification process involves the release of H⁺ ions, the higher the nitrification rate, the more acidic the pH of the solution. Therefore the condition of the pH of the reactor is very dependent on the buffer capacity of the water, to maintain pH conditions in the nitrification process.

For NH₃-N removal, bacteria were very dependent on DO concentration. This was because DO was a co-substrate in the nitrification process, because it was able to carry out the nitrification process, an oxygen concentration of more than 1 mg/L was needed. If the oxygen concentration was lower, it would be the limiting factor and the nitrification could run slower.

The effluent from MBBR has already met the Class I Quality standard based on Government Regulation No.82 of 2001. The average concentration of the effluent was 0.07 mg/L which is still far compared to the Class I Quality Standard, which is 0.5 mg/L. That means the treated water is suitable to be used as a source of drinking water.

3.3. Phosphate removal

The experimental results showed phosphate loading rate about 0.00192-0.01184 kg P/m³.day could achieve phosphate removal efficiency up to 87.23%. Previous research has also explained this condition, the highest

phosphate removal rate is reached when the load was given more than 0.2 kg P/m³.day, with efficiency removal of 98% [11]. Apart from the loading rate given, efficiency removal also dependent on the operational conditions of the reactor. DO concentration needs to be given continuously to ensure that there is oxygen in the biofilm layer. The process of phosphate removal in water is affected by bacterial polyphosphate accumulating organisms (PAO) under aerobic conditions [14]. The microorganisms consume phosphate, so the phosphate content in the water decreases gradually. The process of phosphate removal is inhibited by the accumulation of nitrite, therefore it is necessary to have an adequate aerobic phase to achieve the perfect nitrification process. Apart from DO, PAO bacteria also need to maintain pH conditions during the operational process. In order to gain an optimal removal efficiency, pH was maintained by range of 7-8 for optimum growth of PAO bacteria. Previous research showed that PAO bacterial population has decreased when there is a decrease in pH from 8 to 6.5 [15]. The effluent from MBBR has already met the Class I Quality standard based on Government Regulation No.82 of 2001. The system managed to decrease the phosphate concentration until it reached 0.106 mg/L, while the threshold has the limit concentration of 0.2 mg/L.

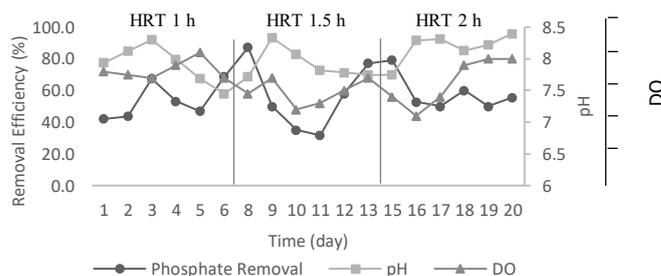


Fig. 6. Phosphate removal efficiency, DO, and pH during operational period

3.4. TSS Removal

Based on the performance of each residence time, the level of TSS removal efficiency from 1 hour, 1.5 hours, and 2 was 50.6%-80%; 57.5%-88.9%; and 53.6–89.2% respectively. The high removal rate was obtained from the flow model and addition of the pre-sedimentation zone. The flowing process causes suspended solids in the water to settle in the pre-sedimentation zone, due to a decrease in the water velocity. The research showed that the optimum performance of TSS parameter removal were obtained at 2 hours residence time. The longer the contact time, the higher the level of TSS removal. Because it has more time to settle at the bottom of the reactor [17]. MBBR as a pre-treatment process managed to decrease the concentration of TSS until it reached 12.8 mg/L, while the threshold has the limit concentration of 50 mg/L.

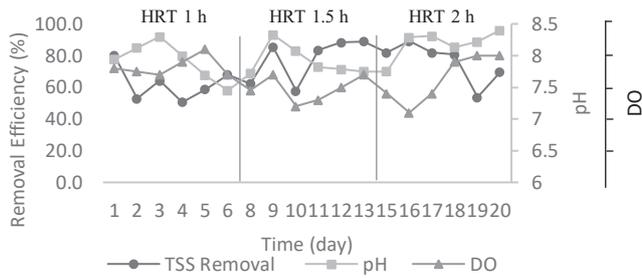


Fig. 8. TSS removal efficiency, DO, and pH during operational period

3.5. Optimum HRT for MBBR as pre-treatment process

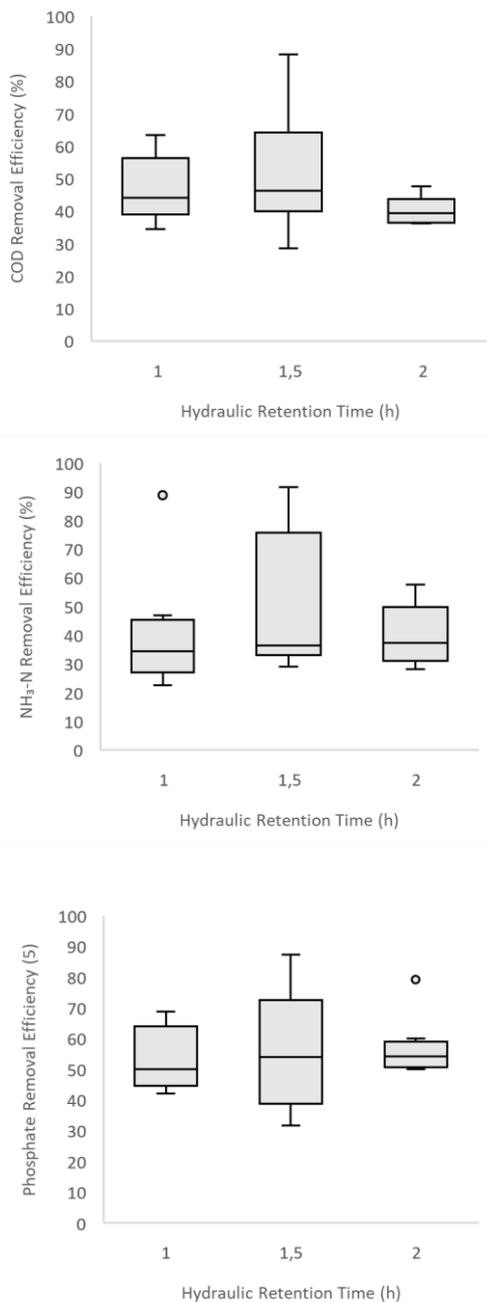


Fig. 9. Box Plot removal efficiency of a) COD, b) NH₃-N, c) Phosphate, and d) TSS on MBBR

Determination of optimal detention time referred to the removal efficiency of COD, NH₃-N, Phosphate, and TSS with variations in HRT. In order to identify the data distribution and minimum allowance, boxplots were used to adjust the effluent to quality standard. When viewed from ANOVA test, there is no significant differences occurred in each parameter removals ($P > 0.05$), so the decision-making continued by using box plots. Box plots also used to see the minimum removal, whether it has met with the environmental threshold or not.

When viewed from the median, there was no significant difference between COD, NH₃-N, and Phosphate. If the median value had similarities, the comparison would be seen from Q3 and whisker length at the top of the box. For the COD removal efficiency, 1.5 hours of HRT had a Q3 value and the maximum value was higher when compared to 2 hours of HRT. This indicates that the removal rate of 1.5 hours of HRT could reach a high value of 81.7%. In addition, the average HRT effluent of 1.5 hours was closer to the target of class I Government Regulations No. 82 of 2001. At NH₃-N removal rate, there was also a median similarity, so that the comparison seen from Q3 and whisker length at the top of the box was determined to be 1.5 hours as optimal detention time. At 1.5 h HRT, whiskers had a considerable range with a bottom line at 32.97% removal with effluent concentration 0.054 mg/L which is beyond the standard quality limit (0.5 mg/L). As for phosphate removal efficiency, the optimal detention time reached by 1h because of the lower whiskers had a higher removal rates than the others which were 44.53% with the effluent concentration of 0.09 mg/L, exceeding the quality standard. Meanwhile for the TSS optimal detention time, 2h HRT was chosen because of the highest median and Q₁ than the others (84.52% and 67.65% respectively). Based on the results of these statistics analysis, COD, NH₃-N, Phosphate, and TSS effluents has already meet the quality standards. Therefore, HRT 1.5 h was chosen as the optimum detention time to removes pollutants from the Pesanggrahan River.

3.5. Nitrification kinetics

After obtaining the optimum detention time of MBBR, a batch experiment was conducted to determine the NH₃-N removal kinetics on MBBR. During this experiment, the same treatment was given to the system as it was given during continuous trials with a detention time of 1.5 hours. At the start of the batch trial, tests were carried out on the concentrations of NH₃-N to determine the initial concentration of ammonia nitrogen in water sample used. The observation was carried out for 4 hours with initial NH₃-N concentration level of 0.44 mg/L.

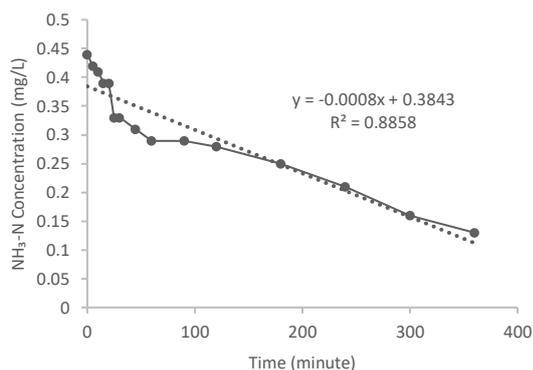


Fig. 10. Nitrification kinetics on MBBR system

Based on figure 11, it is known that the kinetics of ammonia removal rate in MBBR takes place at zero order, with a removal rate constant of 0.0056 g/m².day. Zero-order removal rate constant would increase significantly as the load was being processed, hence the zero-order removal rate constant reflected the maximum reaction rate limited by bacteria metabolism 19. Previous research had also explained this condition, the nitrification rate showed a strong relation to the ammonium loading rate in aerobic conditions 10.

3.6. Coagulant demand

This study also analyzed the coagulant dosage to treat the Pesanggrahan Surface Water. MBBR as pre-treatment process is expected to reduce the processing load from the Coagulation and Flocculation unit in WTP, which is characterized by increase in coagulant demand. The coagulant used in this study is liquid PAC which content 10% alumina, with a dose range of 30-70 mg/L. The dosage refers to the coagulant demand for raw water processing with turbidity 60-90 NTU, while the Pesanggrahan River water only has turbidity concentration of 135 NTU.

Based on the jar test, it was found that before using MBBR technology, WTP needed a coagulant dosage of 50 mg/L to reduce the raw water turbidity from 135 to 0.28 NTU, and COD concentration from 33 to 19 mg/L. After using MBBR as pre-treatment, the coagulant needed to achieve the same effluent condition is 9 mg/L. The dose was able to reduce COD concentration from 40.5 mg/L to 22 mg/L, and turbidity from 7.69 NTU to 0.68 NTU. Based on these tests, it is known that MBBR technology

can reduce the coagulant usage by 84% in WTP, hence minimizing the costs incurred for coagulant materials.

4 Conclusion

The study shows that Pesanggrahan River could be used as a source of clean water by using MBBR as the pre-treatment process. The raw water treated has improved in quality, marked by decrease in concentration in each parameter. The determination of the performance of MBBR is seen from the parameter removal efficiency with a variety of residence times, which were 1 hour, 1.5 hours, and 2 hours. Based on statistical analysis, the optimum detention time obtained to treat Pesanggrahan river water is 1.5 hours. With this detention time, MBBR was able to reach the level of COD, NH₃-N, Phosphate, and TSS 51.8% ± 0.2; 54.3% ± 0.28; 52.6% ± 0.19; and 77.7% ± 0.14 respectively. During the research, effluent concentration had met the class I quality standards based on PP 82 of 2001 for the categories of Ammonia, Phosphate, and TSS. For COD, concentration only meets class III quality standards, so it is necessary to carry out an advanced treatment process to reduce the COD concentration. During the research process, DO concentrations are always above 4 mg/L. This concentration is sufficient to provide conditions where there is a perfect nitrification process, so that ammonia nitrogen contained in river water will be converted into nitrite and nitrate. pH range was also kept at 6.5 to 8.5 in order to optimize the bacterial growth, and also prevent competition between autotrophic and heterotrophic bacteria. Apart from water quality improvement, pre-treatment process using MBBR can reduce coagulant dose from 50 mg/L to 9 mg/L, to decrease raw water turbidity from 135 NTU to 0.68 NTU and COD from 33 mg/L to 22 mg/L before entering the coagulation-flocculation unit.

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