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Optimizing the Performance of Type U Ultrafiltration Membrane with Variations in Flow Rate and Filtration Time

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ABSTRACT

Ultrafiltration is one of the membrane technologies widely applied to remove nanoparticles (NPs) and colloids, producing drinking water from raw water such as river water, rainwater, etc. In this research, a Type U ultrafiltration membrane was applied. The research parameters, including filtration time and flow rate are varied at 80-720 mins and 1-2 L/s, respectively and optimized to determine the optimum condition of membrane performance. The raw water originates from the Sei Harapan Batam reservoir. The operating parameters, including turbidity and pH, are monitored. After being processed using a U-type ultrafiltration system, the pH and turbidity parameters decreased from 6-8.5 to 6-7 and 6-12 NTU to 0.1-0.5 NTU, respectively at a filtration time of 720 minutes and a flow rate of 2 L/s. Under these conditions, the efficiency of turbidity reduction is relatively high, ranging from 95-99% with an average of 96%. It can be concluded that the turbidity of the effluent water from the membrane system reached the Indonesian drinking water standard of below 3.0 NTU. The U-type ultrafiltration is a low cost and environmentally friendly drinking water production process due to the absence of any chemical.

1. INTRODUCTION

Access to clean water resource is one of the human rights. However, population growth increases the demand for clean water, leading to insufficient clean water distribution [1]. Clean water scarcity affects public health negatively, people's quality of life, urban environment quality, and the socio-economic development of the country [2]. WHO and UNICEF reported that about 38 million Indonesian people do not have access to sanitation water and about 22 million people do not have access to clean drinking water [3]. Commonly, dams and water reservoirs are purposely built for irrigation, power plants, and clean water resources [4]. Generally, raw water from the water reservoir still contains suspended solid matter that comes from sediments on the bottom floor. Some of the particles are large enough to be settled via sedimentation, and some of them are very small and remain suspended in the water during the sedimentation process [5]. Therefore, the Indonesian Ministry of Health set a turbidity standard for drinking water of less than 3 NTU [6].

Membrane technology is one of effective methods to remove suspended particles and dissolved solid fractions, including microorganisms, colloids, organic matter, and organic particles from water [7]. Le Hir et al. [8] and Pansare et al. [9] reported that ultrafiltration method using a hollow membrane was successfully applied to remove nanoparticles and colloids [8, 9]. Ultrafiltration systems apply a hollow membrane which has a 0.005-10μm porous diameter with 0.1-0.8MPa operating pressure [10]. The application of membrane ultrafiltration has some advantages such as low operation cost and high efficiency [11]. On the other hand, the low occupational area and high recovery efficiency make the membrane technology more competitive compared to conventional technology [12]. However, membrane fouling, which may occur during the membrane operation, remains a significant challenge [13]. Fouling is indicated by the increase of transmembrane pressure (TMP) in a constant flux operation or the decrease of flux in a constant pressure operation. Membrane fouling can be originated from the deposited fouling constituent on the membrane surface. Fouling can be classified as reversible and irreversible fouling. Reversible fouling can be removed by physical backwash or chemical cleaning. Meanwhile, irreversible fouling only can be removed by extensive chemical cleaning or replacing the membrane [14]. Backwash is the most common physical method to remove the fouling cake from the membrane surface. Regular backwash process, disinfection, and chemical cleaning can be applied for membrane maintenance to maintain the membrane flux of 50-100 L/h.m^2 [15, 16]. The backwash process should be carefully scheduled to prevent irreversible fouling and increase the membrane durability [17].

In this study, the performance of a U-type ultrafiltration membrane was tested to answer the research questions as follows: 1) Does filtration time affect the water product quality? and 2) Does the flow rate affect the water quality? The raw water was taken from the Sei Harapan Batam Water Reservoir. Backwash time and backwash flow rate were fixed at a specific value; however, filtration flow rate and filtration time were varied. The main operating variables, including turbidity and water pH, were investigated to obtain suitable ultrafiltration operation conditions. Other water parameters including BOD_5, COD, TSS, and Ammonia concentration were also analyzed at the suitable operating conditions. The objective of the study is to investigate the filtration-backwash cycle and fouling control to increase the membrane effectivity. On the other hand, the suitable filtration time and flow rate of U-type membrane ultrafiltration are also investigated. The ultrafiltration process offers a promising method to treat raw water to produce clean water with low operation cost and high operational efficiency.

2. MATERIALS AND METHOD

2.1 Materials

The raw water feed was taken in situ from Sei Harapan Water Reservoir in Batam, Indonesia. The research was also conducted in a water treatment facility near the reservoir. Usually, the water from the reservoir is used by local people as a clean water source. However, the untreated water does not satisfy the water standard.

2.2 Experimental procedure

Table 1. Experimental parameters

No.	Filtration Time (Minutes)	Flowrate (LPS)	pH	Turbidity
1	80	2	Monitored	Monitored
2	240	1.5	Monitored	Monitored
3	720	1	Monitored	Monitored

The experiment was conducted in a U-type membrane ultrafiltration system. The membrane is made from PVDF (Polyvinylidene Difluoride), 3000mm in length and 2mm in diameter. The membrane was arranged to become a bundle consisting of 420 strands of membrane with a total flux rate capacity of 30 L/h.m^2. There are three different membrane systems named systems 1, 2, and 3 that were differentiated by their filtration time of 80, 240, and 720 minutes, respectively. The maximum filtration time of 720 mins was set to imitate the common maximum shift office hour in an industry. Meanwhile, three different flow rates of 1.0, 1.5, and 2.0 L/s were introduced to each system. The maximum flow rate was set at 2 L/s due to the designated maximum capacity of the UF device of 2 L/s. The systematic parameter design can be observed in Table 1. Two parameters were monitored during the research, including pH and turbidity. The solution pH and turbidity were monitored to make sure that two parameters in outlet water were still in the required value of 6.5 to 8.5 and 3.0, respectively based on the drinking water standard from the Indonesian Ministry of Health [6]. The detailed optimization research design is shown in Table 2.

Table 2. Research parameter design for optimization study of U-type membrane ultrafiltration performance

No.	UF Membrane System	Filtration Time (Minutes)	Flowrate (LPS)
1	System 1	80	2
2	System 1	80	1.5
3	System 1	80	1
4	System 2	240	2
5	System 2	240	1.5
6	System 2	240	1
7	System 3	720	2
8	System 3	720	1.5
9	System 3	720	1

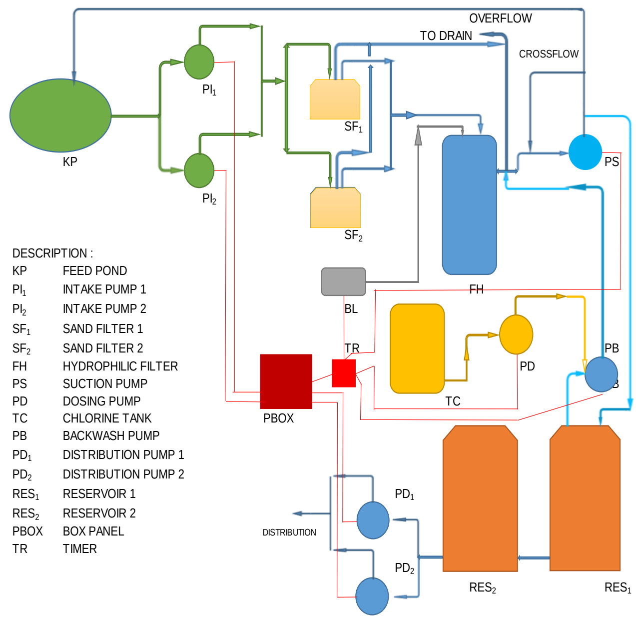


Figure 1. Schematic flow chart of water treatment process using U-type ultrafiltration system

Figure 2. Actual picture of U-type membrane ultrafiltration system installation

Figure 1 shows the schematic process of the membrane ultrafiltration system. Meanwhile, Figure 2 shows the actual installation picture of the membrane ultrafiltration system that was placed near the Sei Harapan Water Reservoir. The research was conducted for about 1 month (30 days). The experiment procedure was conducted as follows:

Filtration Process

(1). The water from Sei Harapan Reservoir was pumped into the sand filter (SF1 and SF2) using intake pumps of Pin 1 and Pin 2, which operated alternately every 2 hours.

(2). After the filtration process in sand filters SF1 and SF2, the water was then transferred into a UF membrane tank containing a hydrophilic filter (HF). The operating parameters were controlled in the UF membrane tank.

(3). The water was then pumped using a suction pump (PS) so that it could be filtered by a hydrophilic filter and transferred to the clean water reservoir (RES 1 and 2).

(4). The water in reservoir RES 1 and 2 was then distributed into the pipeline network using distribution pumps (PD1 and PD2), which were alternately operated every 2 hours.

Backwash Process

(1). The sand filter backwash was scheduled daily for 10 minutes, recycling the treated water as the backwash cleaning solution.

(2). The backwash process of the hydrophilic filter membrane was automatically turned on after a specific operation time interval. The regular backwash process lasted for 3 minutes, using a blower (BL) to blow air into the hydrophilic filter, referred to as the 'push-blow process,' to remove deposits on the membrane surface. A chemical backwash using a chlorine solution was only introduced when the internal pressure increased significantly, indicating the membrane clogging.

(3). 4000 ppm chlorine solution was injected by dosing pump (PDOS) at 120 L/h during the chemical backwash process. The backwash process was required to prevent the membrane clogging that may lower the flowrate and increase the internal pressure.

3. RESULTS AND DISCUSSION

In this research, the effect of filtration time and flow rate on the pH and turbidity removal efficiency was investigated. Other parameters, including BOD_5, COD, TSS, oil, grease, and ammonia, were also analyzed at the chosen condition.

3.1 Effect of filtration time and flowrate to water effluent pH

pH is one of the master variables to determine the water quality that may affect directly human health [18]. The high pH may weaken the chlorination process efficiency due to the speciation of chlorine compounds in the water. On the other hand, a high pH stimulated the precipitation of fouling constituents. However, the low pH may enhance the corrosion rate of the pipe.

The previous report indicated that the pH value of raw water feed from Sei Harapan Water Reservoir fluctuated within a range of 6.0 to 8.5 over approximately 1 year of monitoring. As shown in Figure 3, the pH value is decreased to about 6-7 in every system at every flow rate. The value is still acceptable since the permissible pH value for clean water is 6 to 9. The pH drop is possibly caused by concentrated organic matter, high acidity compounds, and other impurities that are rejected by the membrane system and deposited onto the membrane inlet surface. The deposited compound may acidify the water that passes through the membrane.

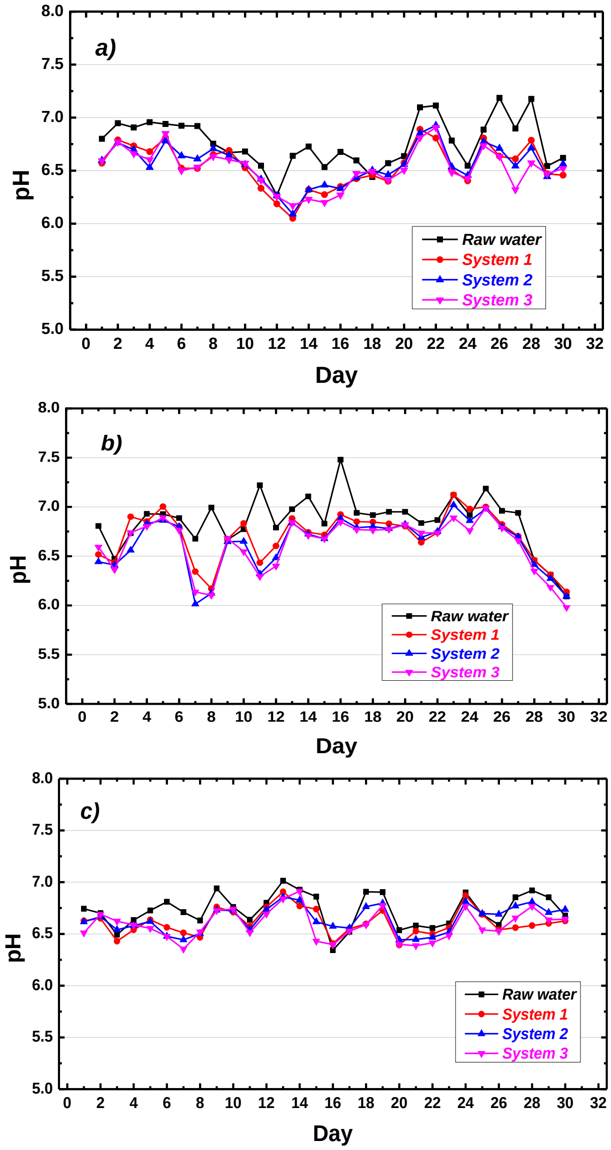


Figure 3. The effect of filtration time and filtration flowrate to pH: a) flowrate 2 L/s; b) flowrate 1.5 L/s; c) flowrate 1 L/s

3.2 Effect of filtration time and flowrate to water effluent turbidity

Turbidity can be observed as a cloud in the water or reduced water transparency due to the presence of insoluble particulate matter. The turbid water blocks sunlight and causes ecosystem damage to aquatic life. Furthermore, the insoluble matter intake may pose a risk to human body. It was observed that the turbidity of the raw water from Sei Harapan Water Reservoir was relatively stable at 6 to 12 NTU.

Most suspended particles, colloids, bacteria, and macromolecule organic matter can be removed from the water by the membrane ultrafiltration process combined with another physical separation process [19]. As the big particulate can be removed completely from the water using the ultrafiltration process, the turbidity will be automatically decreased significantly. As shown in Figure 4, the system successfully decreased the turbidity of the raw water from about 6-12 to become 0.1-0.5 NTU. The turbidity is far below the standard turbidity for drinking water that was set by the Indonesian Ministry of Health of below 3.0 NTU [6].

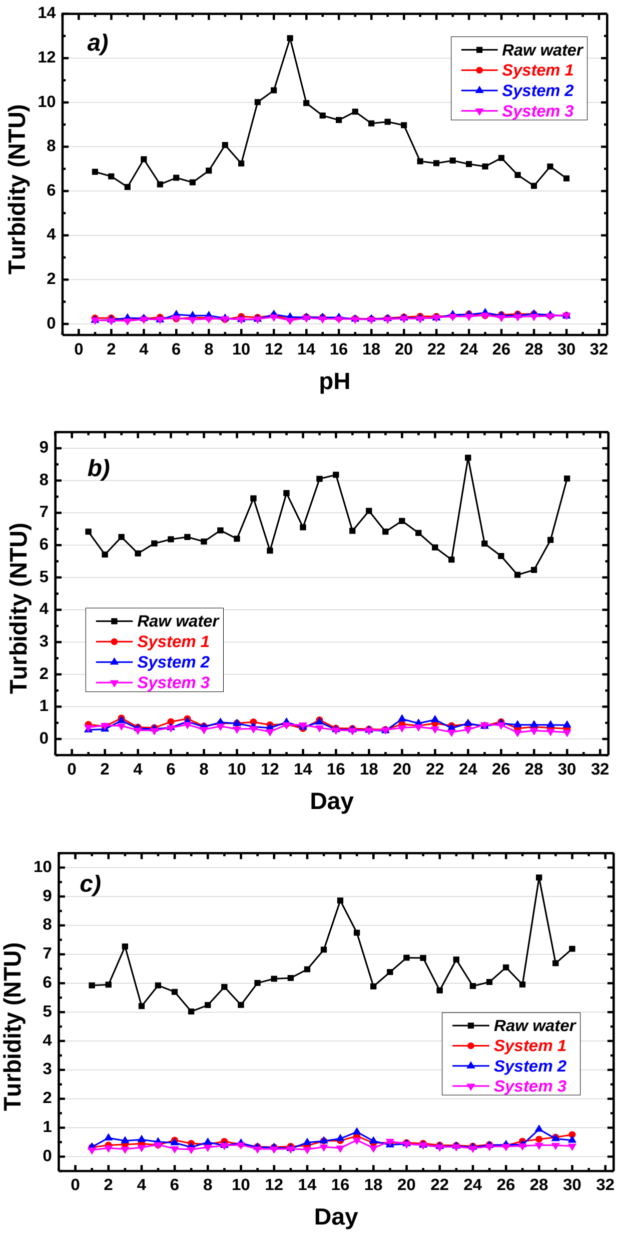


Figure 4. The effect of filtration time and filtration flowrate to turbidity: a) flowrate 2 L/s; b) flowrate 1.5 L/s; c) flowrate 1 L/s

3.3 Turbidity removal efficiency

Figure 5 shows the turbidity removal efficiency in all of the systems under 3 different flow rates of 1, 1.5, and 2 L/s. It can be listed that the turbidity removal efficiency reaches about 80%-97%, 90%-98%, and 91-99% for flowrate 1, 1.5, and 2 L/s, respectively with the best value reached by the operation under system 3 or filtration time of 720 minutes. The data of system 3 operation is recompiled and depicted in Figure 6. As observed from Figure 6, the turbidity removal efficiency reaches its highest value at a flowrate of 2 L/s that can be confirmed by the magenta color that lay stably above both of flowrate 1 L/s and 1.5 L/s. The flow rate of 2 L/s under 720 minutes filtration time is considered to be the best condition to remove turbidity from the raw water of Sei Harapan Water Reservoir to obtain the turbidity removal efficiency of (96.13±1.43)%.

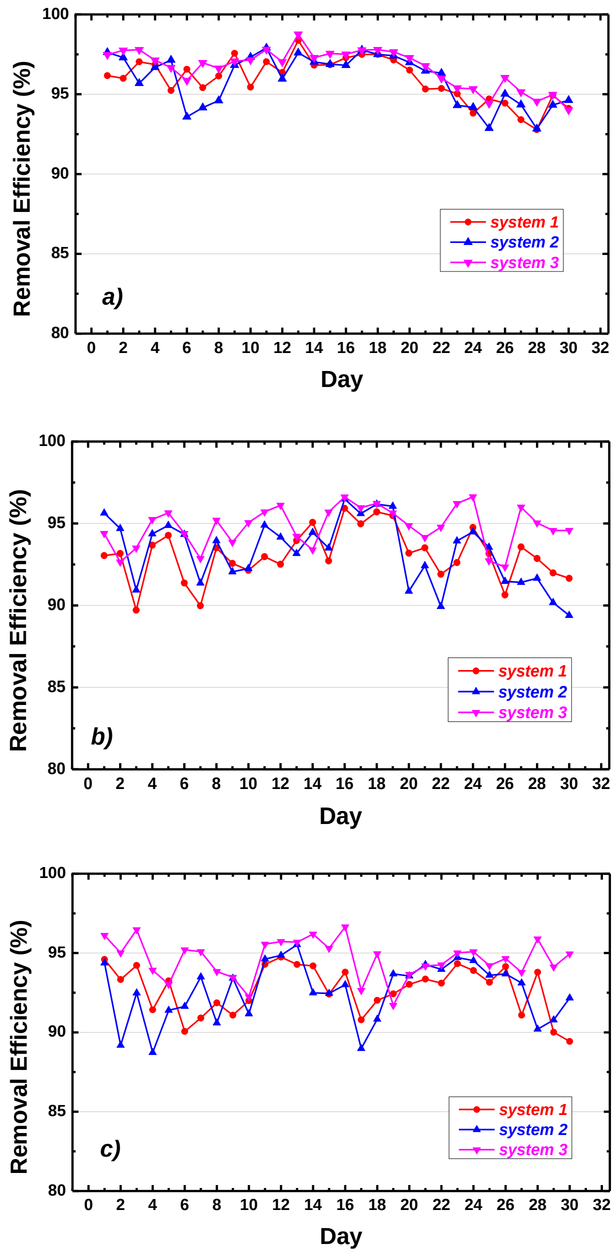


Figure 5. The effect of filtration time and filtration flowrate to turbidity removal efficiency: a) flowrate 2 L/s; b) flowrate 1.5 L/s; c) flowrate 1 L/s

3.4 Effluent water quality

The sample from the best condition of flowrate of 2 L/s was analyzed to measure other water parameters of BOD_5, COD, TSS, oil and grease, and ammonia. As shown in Figures 7(a) and 7(b), the BOD_5 and COD are drastically removed from the raw water. It is indicated that the organic matter was rejected by the membrane ultrafiltration system. However, the BOD_5/COD ratio was insignificantly changed at about 0.3 to 0.35 (Figure 7(c)). The minimum BOD_5/COD ratio to show the high biodegradability should be 0.4 or higher [20]. However, since both actual BOD_5 and COD levels were removed from the raw water significantly, it can be concluded that the membrane ultrafiltration system was unselectively removing the organic matter from the raw water.

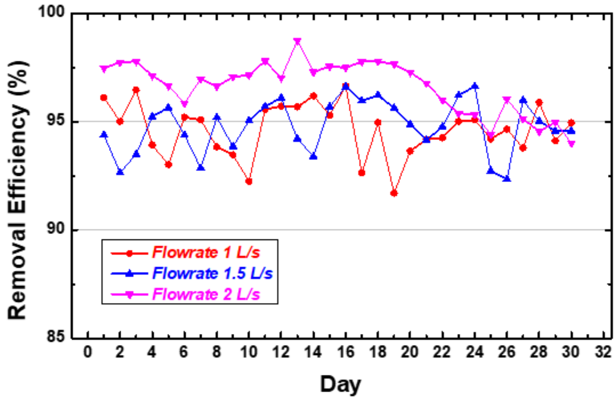
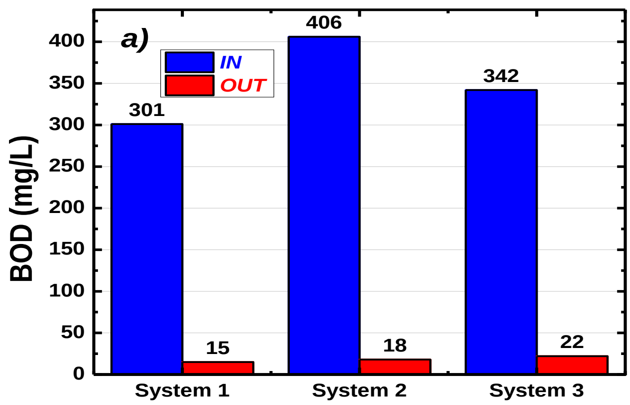
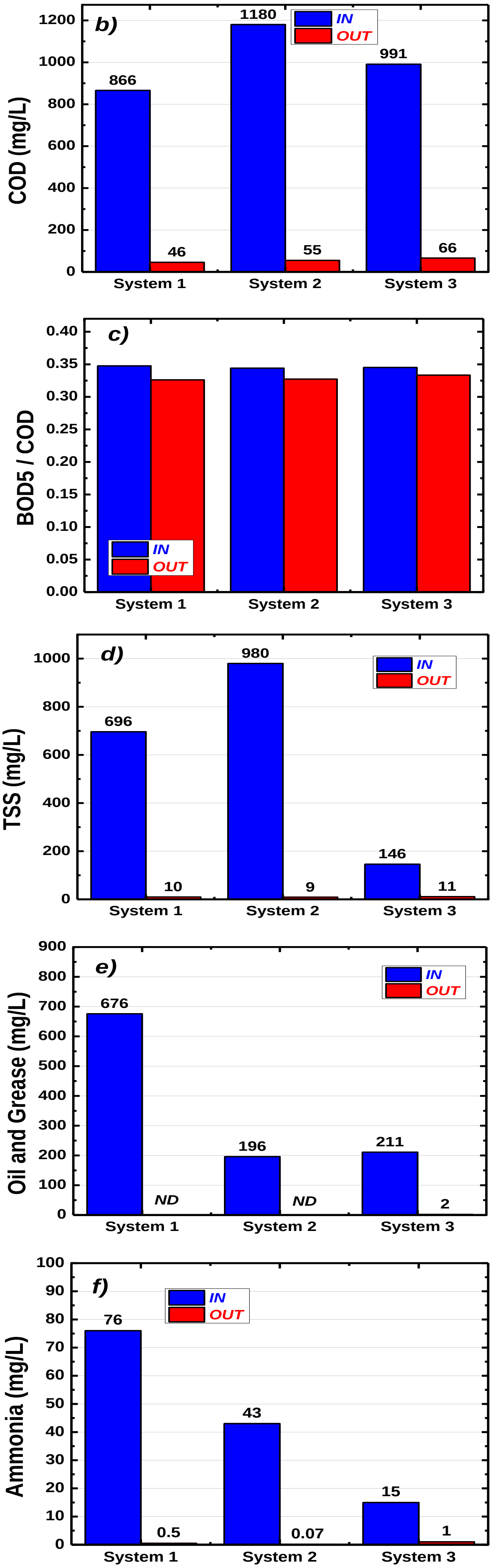


Figure 6. The effect of filtration flowrate to turbidity removal efficiency in system 3 (filtration time 720 minutes)

The high turbidity removal efficiency can be confirmed by the reduction of TSS concentration from about 146-980 mg/L to only about 9-11 mg/L, as shown in Figure 7(d). Membrane ultrafiltration also successfully removed oil and grease components from 196-676 to below 2 mg/L (Figure 7(e)). Moreover, at System 1 and System 2, there is no oil and grease pollutants were detected. It is caused by the big molecules of oil and grease as they are present in the form of polymerized molecules. It is also can be observed that dissolved ammonia was successfully removed from the raw water from about 15-76 mg/L to about 0.07-1 mg/L in the membrane ultrafiltration system (Figure 7(f)). Meanwhile, as shown in Figure 7(g), the total coliform was removed completely from raw water from 700-6000 MPN/100 mL to undetectable levels. The U-type membrane filtration system was proven to be an alternative process for treating raw water from a lake or water reservoir, demonstrating good performance in removing turbidity, BOD_5, COD, TSS, oil and grease, and total coliform.

Membrane ultrafiltration process is widely applied for treating drinking water and wastewater process [10] due to its relatively lower energy consumption compared to another membrane filtration methods [18]. It is caused by the low pressure needed to remove the pollutant from the water. However, in this study, the U-type membrane was proven to be successfully treated raw water from the lake become the clean water. The transfer of the water across the membrane was only driven by gravity force and there was no external pressure needed.





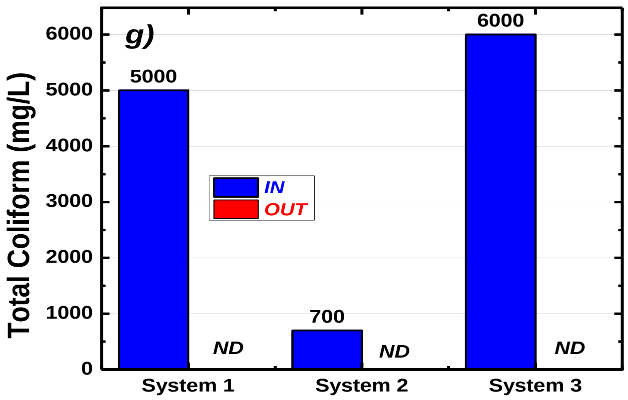


Figure 7. Effect of filtration time at flowrate 2 L/s to: a) BOD_5; b) COD; c) BOD_5/COD; d) TSS; e) Oil and grease; f) Ammonia; g) Total coliform

4. CONCLUSION

In this study, U-type membrane ultrafiltration performance in the treatment process of raw water from Sei Harapan Water Reservoir in Batam, Indonesia, was investigated. The decrease of water pH during the operation of about 0.2-0.6 will not become a problem since it is still satisfying the water pH standard of 6 to 9. The turbidity of the water was almost completely removed at a filtration time of 720 minutes and a filtration flowrate of 2 L/s with a removal efficiency of 90-99% that was consistent with the TSS removal from 146-980 mg/L to about 9-11 mg/L. The U-type membrane ultrafiltration system also successfully removed BOD_5, COD, TSS, oil and grease, dissolved ammonia, and total coliform under a flow rate of 2 L/s. The capacity of the water product can be calculated as 173m^3/day, which can be classified as a pilot scale system that can provide a clean water product for about 100 people in a day. On the other hand, the absence of external pressure and the application of the gravity force to drive the water transfer through the membrane makes the U-type ultrafiltration membrane has a big economic advantage.

U-type membrane ultrafiltration system has been successfully applied to treat the raw water from Sei Harapan Water Reservoir and has a big potential to be utilized to treat the raw water from another source such as a river or natural lake. For the further research, it is recommended to integrate the U-type ultrafiltration system to produce the 'ready-to-drink' water product.

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REFERENCES

[1] Leveque, B., Irakiza, A., Ndong, M., Jalbert, J., Burnet, B., Kammoun, R., Dorner, S., Bichai, F. (2024). Assessing the vulnerability of urban drinking water intakes to water scarcity under global change: A bottom-up approach. Environmental Challenges, 15: 100885. https://doi.org/10.1016/j.envc.2024.100885

[2] Wu, F., Yang, X., Cui, Z., Ren, L., Jiang, S., Liu, Y., Yuan, S. (2024). The impact of human activities on blue-green water resources and quantification of water resource scarcity in the Yangtze River Basin. Science of the Total Environment, 909(2023): 168550. https://doi.org/10.1016/j.scitotenv.2023.168550

[3] Cameron, L., Chase, C., Contreras Suarez, D. (2021). Relationship between water and sanitation and maternal health: Evidence from Indonesia. World Development, 147: 105637. https://doi.org/10.1016/j.worlddev.2021.105637

[4] Weber, M., Rinke, K., Hipsey, M.R., Boehrer, B. (2017). Optimizing withdrawal from drinking water reservoirs to reduce downstream temperature pollution and reservoir hypoxia. Journal of Environmental Management, 197: 96-105. https://doi.org/10.1016/j.jenvman.2017.03.020

[5] Singh, M., Kishor, B. (2020). A review on removal of turbidity and tds from water by using natural coagulants. International Research Journal of Modernization in Engineering Technology and Science, 521(2): 521-525.

[6] Kementrian Kesehatan Republik Indonesia. (2023). Peraturan menteri kesehatan republik Indonesia nomor 2 tahun 2023 tentang: Peraturan Pelaksanaan Peraturan Pemerintah Nomor 66 Tahun 2014 Tentang Kesehatan Lingkungan. https://p2p.kemkes.go.id/wp-content/uploads/2023/12/pmkno.2th2023-signed.pdf.

[7] Trzaskus, K.W., Lee, S.L., de Vos, W.M., Kemperman, A., Nijmeijer, K. (2017). Fouling behavior of silica nanoparticle-surfactant mixtures during constant flux dead-end ultrafiltration. Journal of Colloid and Interface Science, 506: 308-318. https://doi.org/10.1016/j.jcis.2017.07.043

[8] Le Hir, M., Wyart, Y., Georges, G., Siozade, L., Moulin, P. (2018). Nanoparticles retention potential of multichannel hollow fiber drinking water production membrane. Journal of Membrane Science and Research, 4(2): 74-84. https://doi.org/10.22079/JMSR.2017.69079.1150

[9] Pansare, V.J., Tien, D., Thoniyot, P., Prud'homme, R.K. (2017). Ultrafiltration of nanoparticle colloids. Journal of Membrane Science, 538: 41-49. https://doi.org/10.1016/j.memsci.2017.03.041

[10] Li, X., Jiang, L., Li, H. (2018). Application of ultrafiltration technology in water treatment. IOP Conference Series: Earth and Environmental Science. IOP Publishing, 186: 012009. https://doi.org/10.1088/1755-1315/186/3/012009

[11] Yang, Y.X., Chen, J. (2013). Advanced treatment of drinking water by ultrafiltration membrane. Advanced Materials Research, 647: 543-547. https://doi.org/10.4028/www.scientific.net/AMR.647.543

[12] Crini, G., Lichtfouse, E. (2019). Advantages and disadvantages of techniques used for wastewater treatment. Environmental Chemistry Letters, 17: 145-155. https://doi.org/10.1007/s10311-018-0785-9

[13] Shi, X., Tal, G., Hankins, N.P., Gitis, V. (2014). Fouling and cleaning of ultrafiltration membranes: A review. Journal of Water Process Engineering, 1: 121-138. https://doi.org/10.1016/j.jwpe.2014.04.003

[14] Guo, W., Ngo, H.H., Li, J. (2012). A mini-review on membrane fouling. Bioresource Technology, 122: 27-34.

https://doi.org/10.1016/j.biortech.2012.04.089
[15] Peter-Varbanets, M., Margot, J., Traber, J., Pronk, W. (2011). Mechanisms of membrane fouling during ultra-low pressure ultrafiltration. Journal of Membrane Science, 377(1-2): 42-53. https://doi.org/10.1016/j.memsci.2011.03.029
[16] Ellouze, F., Kammoun, Y., Kalboussi, N., Rapaport, A., Harmand, J., Nasr, S., Amar, N.B. (2023). Optimal control of backwash scheduling for pumping energy saving: Application to the treatment of urban wastewater. Journal of Water Process Engineering, 56: 104378. https://doi.org/10.1016/j.jwpe.2023.104378
[17] Mahmud, R.N. (2005). Kinetika fouling membran ultrafiltrasi (UF) pada pengolahan air berwarna: Pengaruh interval dan lamanya pencucian balik (Backwashing) Membran. Jurnal Info Teknik, 6(1): 62-69. http://doi.org/10.20527/infotek.v6i1.1674
[18] Zhang, L., Zhang, P., Wang, M., Yang, K., Liu, J. (2016). Research on the experiment of reservoir water treatment applying ultrafiltration membrane technology of different processes. Journal of Environmental Biology, 37(5): 1007-1012.
[19] Al Aani, S., Mustafa, T.N., Hilal, N. (2020). Ultrafiltration membranes for wastewater and water process engineering: A comprehensive statistical review over the past decade. Journal of Water Process Engineering, 35: 101241. https://doi.org/10.1016/j.jwpe.2020.101241
[20] Andrio, D., Asmura, J., Yenie, E., Putri, K. (2019). Enhancing BOD5/COD ratio co-substrate tofu wastewater and cow dung during ozone pretreatment. In MATEC Web of Conferences. EDP Sciences, 276: 06027. https://doi.org/10.1051/matecconf/201927606027

NOMENCLATURE

pH	Potential Hydrogen, dimensionless
COD	Chemical Oxygen Demand, mg/L
BOD_5	Biochemical Oxygen Demand after 5 days, $mg.L^{-1}$
TSS	Total Suspended Solid, mg/L

ABBREVIATIONS

NPs	Nanoparticles
UF	Ultrafiltration
TMP	Transmembrane Pressure
PVDF	Polyvinylidene Difluoride
HF	Hydrophilic Filter
SF	Sand Filter