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Analysis the Effect of Flux and Water Characteristics on Polyethersulfone Ultrafiltration Membrane Performance as Pre-Treatment of SWRO

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ABSTRAK

Meningkatnya populasi manusia mengakibatkan bertambahnya kebutuhan air bersih yang tinggi. Dengan terbatasnya sumber air tawar, air laut dipergunakan sebagai alternatif sumber utama air bersih dengan teknologi Seawater Reverse Osmosis (SWRO). Permasalahan utama dari SWRO adalah penyumbatan pada pori membrane, yang berdampak terhadap menurunnya kinerja membran. Solusi alternatif untuk masalah ini adalah dengan menggunakan membran ultrafiltrasi sebagai pra-pengolahan. Identifikasi terkait efisiensi penyisihan untuk karakteristik air laut terhadap parameter TDS, COD, konduktivitas, dan UV-Vis pada fluks yang berbeda dan investigasi laju filtrasi serta pengaruh variasi tersebut terhadap kinerja membran ultrafiltrasi PES ukuran pori 50 kDa MWCO perlu dilakukan. Percobaan Filtrasi dilakukan pada skala laboratorium dengan pengoperasian fluks konstan 120 L/m^2·jam dan 180 L/m^2·jam dengan filtrasi *dead-end*. Membran PES secara efektif mampu menghilangkan parameter kekeruhan, TDS, UV-Vis, konduktivitas, dan COD sebesar 63±6%; 37±19%; 7±4%; 33±33%; dan 97,86%. Berdasarkan kinerja membran, filtrasi fluks 120 L/m^2·jam menunjukan laju performa yang umum ditemukan pada pengoperasian membrane, sedangkan filtrasi dengan fluks 180 L/m^2·jam menghasilkan performa lebih buruk yang berdampak terhadap kemampuan *backwash* dan umur pakai membran menjadi lebih pendek. pengoperasi fluks optimum sebagai pre-treatment dari SWRO adalah 120 L/m^2·jam dimana proses filtrasi bisa berlangsung lebih lama dan mengurangi beban kerja serta meningkatkan performa pada unit SWRO.

Kata kunci: Ultrafiltrasi membran, Flux konstan, Fouling, Material organik, Pre-treatment SWRO

ABSTRACT

Increasing human population resulted in higher demand for potable freshwater, while freshwater sources were limited. As an alternative solution, seawater was necessarily to be employed as a main source of water supply and necessarily treated with Seawater Reverse Osmosis (SWRO). However, membrane fouling of SWRO was occurred. Therefore, implementation of ultrafiltration membranes as pre-treatment were necessary. In this study, identification of removal efficiency seawater characteristics of TDS, COD, conductivity, and UV-Vis parameters at different flux and investigation of the fouling rate at variations filtration performance of the 50 kDa MWCO pore size PES ultrafiltration membrane was performed. Filtration of laboratory scale experiment with constant flux of 120 L/m^2·h and 180 L/m^2·h at dead-end operation was performed. Filtration of 50 kDa PES ultrafiltration membrane was able to remove effectively turbidity, TDS, UV-Vis, conductivity, and COD with 63±6%; 37±19%; 7±4%; 33±33%; dan 97.86%, respectively. Furthermore, related to membrane performance, filtration at 120 L/m^2·h flux operation was found as the common fouling mechanisms, while flux operation at 180 L/m^2·h resulted different behavior resulted for severe membrane performance. The suitable operation of fluxes 120 L/m^2·h was recommended to increase the performance and membrane lifespan as well as to decrease the load of SWRO unit.

Keywords: Ultrafiltration membrane, Constant flux, Fouling, Organic matter, SWRO Pre-treatment

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1. INTRODUCTION

The increase of water supply demand caused a problem due to exponential growth of the population and currently occurred in Indonesia. Water usage in DKI Jakarta reaches up to 25.000 L / sec or 1.2 billion m3/year, while the amount of Private sector in water sector can provided only 633 million m3/year (BPS DKI Jakarta, 2022). Ground water was found as a solution as a water supply. However, excessive groundwater use causes negative impacts, such as contamination, seawater intrusion, and land subsidence. Meanwhile, water sources derived from surface water now have significant problems due to high levels of pollution, fluctuating water quality and quantity, and lack of continuity (Duvert et al., 2019). These conditions indicate that a clean water crisis is imminent. Thus, an alternative source of raw water is needed to meet the need for clean water in the long term, namely using seawater.

As one of the archipelagic countries, Indonesia has great potential to become the world's maritime axis with the most significant sea area. Along with the development of science, a well-known technology for processing seawater into fresh water was developed. Sea Water Reverse Osmosis (SWRO) which uses reverse osmosis (RO) membranes is one of the technologies. Currently, SWRO production capacity produces 45 million m3 / day (Elsaid et al., 2020). Despite efficient, during the process, pre-treatment is necessary required using ultrafiltration (UF) membranes as an alternative to reduce RO performance load. UF membranes had a pore size in range of 0.01-0.1 µm and was able to remove suspended solids, microorganisms, organic compounds, and colloids from seawater (Darwish et al., 2014). Polyethersulfone (PES) membranes were an alternative because they are most often used in SWRO installations and have advantages that are superior to other polymeric materials, such as hydrophilicity, strength, and durability, and are readily available (Yildiz Töre & Kirhan Sesler, 2021).

Several studies have been conducted to identify membrane performance on certain materials. One study showed that a membrane with 48 nm pore size ceramic material and a filtration area of 10 m2 under constant flux conditions of 80-150 L/m2.h was able to remove turbidity in lake water by 99%, CODMn by 58%, DOC by 49%, and UV254 by 45% (Yang et al., 2022). In addition, another study using UF polyethersulfone (PES-10) flat sheet membranes with a mixture of foulant latex bead suspensions and soybean oil emulsion at 200 ppm aims to determine the mechanism of fouling on the membrane under constant flux conditions ranging from 20-130 L/m2·h. This study obtained results in the form of characterization of fouling models in the form of intermediate pore blocking and cake filtration with a removal rate of 100% for latex bead suspensions and >98% for soybean oil emulsion and showed that flux influences fouling rates (Kirschner et al., 2019).

Another study discussing the removal of organic compounds (DOC) and UV254 on a PVDF-material UF membrane with a pore size of 0.04 µm and operating flux of 25 L/m2·h resulted in removal efficiencies of 25% and 73%, respectively (Marais et al., 2018). Each flux operating mode and different membrane materials have different removal efficiency levels, so further research needs to be done, especially on PES membranes.

Previous studies have discussed the utilization of ultrafiltration to treat lake water and seawater with various filtration modes. However, research on the effectiveness of ultrafiltration membranes against PES membrane material for seawater treatment has yet to be widely conducted. in this study, PES material flat sheet membrane using seawater from Sea Water Reverse Osmosis (SWRO) Installation in North Jakarta was performed. The aim of this study is to identify the removal efficiency for each operating flux to obtain the most optimal flux of ultrafiltration membrane as pretreatment. The research is conducted at a laboratory-scale experimental configuration made using a peristaltic pump. Additionally, the effect of flux and water characteristics in seawater on the performance of PES (Polyethersulfone) membranes through the resulting fouling rate, as well as the efficiency level of TDS, COD, conductivity, and UV-Vis removal in the filtration process was investigated. Furthermore, the output of the study might provide recommendations for optimum operating methods and performance of 50 kDa MWCO pore size PES membranes as pre-treatment for SWRO and decrease performance energy and loading on the Reverse Osmosis (RO) unit.

2. MATERIAL AND METHODS

2.1. Feed Water Quality

Laboratory scale test was conducted using real seawater collected from North Jakarta. Two types of water collected directly from raw water tank from Muara Ancol (as untreated water) and DAF outlet water (as pre-treated water) collected from Sea Water Reverse Osmosis (SWRO) unit were employed. Both feed water was further characterized using several parameters i.e., pH, Temperature, Turbidity, Dissolved Oxygen (DO), Total Dissolved Solid (TDS), organic carbon (UV-Vis), conductivity, chemical oxygen demand (COD) (see Table 1). Both untreated and pre-treated water had different concentrations; A higher concentration of Turbidity, UV-Vis and COD, while lower concentration of TDS and Conductivity was exhibited in untreated water in comparison to pre-treated water.

Table 1. Sample Water Quality

Sample Water Location	pH	Temperature (°C)	Turbidity (NTU)	DO (mg/L)	TDS (mg/L)	UV-Vis (ABS)	Conductivity (ms/cm)	COD (mg/L)
Raw Water Tank	7-7.8	27.6-28.1	6.45-7.22	6,47-8.42	3,720-3,860	0.352-1.237	6.31-6.54	546
Storage Tank after the DAF Unit	6.6-7.5	25.9-27.9	0.71-3.13	7.54-8.19	7,210-17,180	0.121-0.349	11.74-26.1	140

2.2 Experiment Setups

The schematic diagram of the lab scale experiment setup for membrane filtration system was shown in Figure 1. The system consists of a feed tank, a peristaltic pump (BT300-2J, LongerPump, China), a magnetic stirrer, a millipore membrane holder, a digital scale, a manual valve, a digital pressure gauge, and pipes. The membrane module consisted of a piece of modified flat sheet PES membranes 50 kDa MWCO (provided from Germany) with a diameter of 47 mm and a membrance sufcare area of 1,735.6 mm2. The filtration mode was performed at dead end configuration and operated at constant flux. Constant flux was controlled by a peristaltic pump flow rate at 2 and 3 RPM, equal to operation at the constant flux of 120 and 180 L/m2.h respectively.

2.3 Ultrafiltration Experiment Procedure

The experiment was conducted by preparation of membrane through soaking process with natrium hypochorite (NaOCl) at 200 ppm solution. Prior use, the membrane was rinsed with distilled water. The treated membrane was installed into the Millipore membrane holder for filtration process. Furthermore, the experiment was started by measuring membrane pure water permeability (PWP) using distilled water to ensure the entire configuration can run adequately and stabilize the membrane for 5 minutes. Afterwards, the ultrafiltration process was performed according to the variation of sample water characteristics (untreated water and Pre-treated Water) and flux (120 and 180 L/m2·h). During ultrafiltration, the resulting permeate flux and transmembrane pressure (TMP) were recorded. At the first 20 minutes, the mass of the digital scale and digital pressure gauge values was measured every 1 minutes and followed by observation every 5 minutes. Different duration data recorded due to limitation of the measurement device. Furthermore, during filtration process, the important filtration data is the earlier phase of filtration performance. During the filtration test, permeated water was collected and furtherly measured including turbidity, COD, UV-Vis, TDS, and conductivity to determine the water quality.

2.4 Analytical Instruments and Methods

The COD value was determined using a spectrophotometer (DR2000, Hach, USA). The UV-Vis value was obtained by an ultraviolet–visible spectrophotometer (DR6000, Hach, USA) with 200-400 nm wavelength. The total dissolved solids (TDS) and conductivity was measured with a multi-parameter meter (HQ40d, Hach, USA). Turbidity was measured with a turbidity meter (TU-2016, Lutron, Taiwan). In parallel, the PES membrane was characterized by measuring the surface morphology of the PES membranes was examined by a SEM-EDS (Quanta FEG 650, FEI, USA).

2.5 Analysis of Membrane Performance

General equations to analyze the membrane performance were used (see Table 2). Membrane permeability is the ability of solution (i.e., water) through the membrane pore and indicates the membrane capacity. This permeability is linearly correlated with permeate flux and inversely proportional with transmembrane pressure (TMP). At a certain filtration condition, the permeability will be reduced compare to intial membrane permeability, which indicates fouling behavior. The decrease of the permeability due to filtration was called membrane fouling. The membrane fouling was strongly correlated to the amount of water through the membrane (specific filtered volume). To compare the performance at different flux, normalization of permeability was necessary to be conducted by comparing the current permeability with initial permeability. Related to the selectivity, the membrane retention was observed by measuring both feed and permeate with the mentioned parameters.

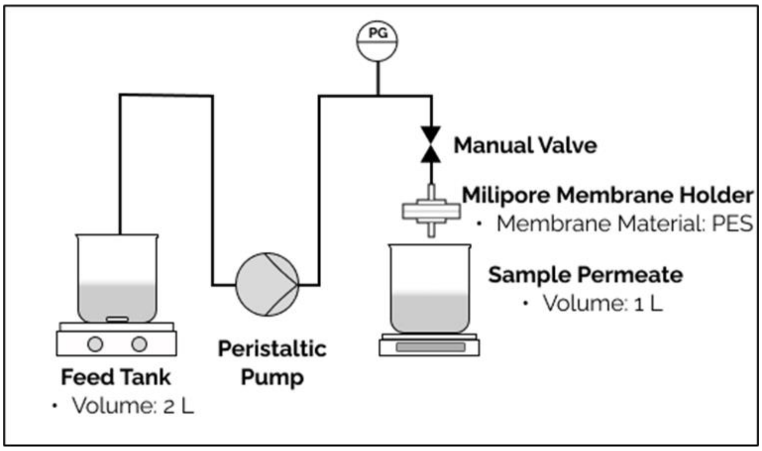


Figure 1. Schematic diagram of the PES membrane ultrafiltration system

Table 2. Membrane filtration equations

No.	Equation	Description
(1)	Membrane Permeability: $W = \frac{\dot{V}}{A \times \Delta P} = \frac{J_w}{\Delta P}$	J_w: permeate flux (L/m²·h), W: membrane permeability (L/m²·h·bar), A: surface area (m²), $\dot{V}$: volumetric flowrate (L/hr), ΔP: transmembrane pressure (bar), where P_0 is the pressure on the initial and P_f is the pressure on the measurement.
(2)	Specific Filtered Volume: $V_{sp} = J_w \times t$	V_{sp}: specific filtered volume (L/m²), J_w: permeate flux (L/m²·h), t: filtration time (h).
(3)	Normalized Pure Water: $W' = \frac{W_{Vsp}}{W_o}$	W': normalized pure water permeability ratio, W_{Vsp}: specific filtered volume permeability (L/m²·h·bar), W_0: virgin membrane permeability (L/m²·h·bar)
(4)	Membrane Retention: $R = \left(1 - \frac{C_p}{C_f}\right) \times 100\%$	R: membrane retention (%), C_p: solute concentration in permeate, and C_f: solute concentration in sample water

3. RESULT AND DISCUSSION

3.1. PES Membrane Retention on Water Characterization Variation

Membrane retention of parameters for both untreated water and pre-treated water feed were shown in Figure 2. The efficiency results show that the PES 50 kDa ultrafiltration membrane has variations in reducing the levels of several parameters in the water. For instance, the turbidity parameter, the 50 kDa PES ultrafiltration membrane was able to reduce turbidity levels with a removal efficiency level for both untreated and pre-treated water feed in the range of 43.58 ± 13.08% with an average concentration decrease of 2.97 NTU and range of 60.56 ± 25.95% with an average concentration decrease of 1.13 NTU for all flux variations, respectively. The high removal efficiency level of turbidity is because ultrafiltration membranes are maximally able to remove higher turbidity levels in compounds that have a size greater than 7 nm (corresponding to the average membrane pore size) (de Pinho & Minhalma, 2019b). This result is supported by Huang's research (2022), which shows that the level of turbidity rejection carried out by ultrafiltration membranes is relatively high. In addition, the removal efficiency level of DAF outlet water (pre-treated water) was found to be higher than untreated water feed. This condition can be explained due to the high concentration in the feed water that accelerated the fouling rate on the membrane and resulted in less effective turbidity removal. On the other hand, in pre-treated water, the water has undergone pre-treatment so that the concentration level is lower than the untreated water.

In term of organic compounds in water, measured by UV-VIS parameter at a wavelength of 274 nm, the PES 50 kDa ultrafiltration membrane was able to decrease organic concentration with removal efficiency levels of untreated feed water and pre-treated water in the range of 38.6 ± 23.9% with an average concentration decrease of 0.22 ABS and 24.35 ± 20.70% with an average concentration decrease of 0.04 ABS for all flux operation variations, respectively. Higher deviation of membrane retention in all parameter was resulted from inhomogeneity of membrane material (Goebel et al., 2019). Furthermore, the comparison was made between the two water characteristics; the removal efficiency obtained for the pre-treated water was lower than that of the untreated water. However, the removal efficiency level tended to be high enough to show that the 50 kDa PES ultrafiltration membrane can remove organic compounds significantly in water. This study supported Marais's research (2018) that the UV254 rejection rate in dam water using PVDF membranes reaches up to 73%. The difference in results shows that the membrane material used affects the level of rejection produced, especially for the 50 kDa PES membrane.

For COD parameter, PES 50 kDa ultrafiltration membrane was able to reduce COD with removal efficiency levels in untreated feed water and pre-treated feed water in the range of 96.89 ± 1.9% with an average concentration decrease of 529 mg/L and 97.86% with an average concentration decrease of 137 mg/L for all flux operation variations, respectively. In terms of efficiency comparison, the efficiency level of Pre-treated water (DAF outlet water) was lower than untreated water. Nevertheless, in terms of concentration value, COD concentration level was approximately less than 3 mg/L. This value was lower than COD concentration in untreated water feed. In other words, the removal efficiency was very high and supports the statement that PES 50 kDa ultrafiltration membrane able to remove organic compounds significantly in water. This study supported Yang's research (2022) that the COD rejection rate in river water using ceramic material membranes reaches up to 58%. Thus, the PES 50 kDa ultrafiltration membrane can remove COD with a better rejection rate than other membrane materials. This condition also showed that one of the critical factors in removing organic compounds was the appropriate pore size and high membrane selectivity (Elma et al., 2022). Therefore, it can be concluded that PES 50 kDa ultrafiltration membrane can effectively remove turbidity and organic compounds (through UV-VIS and COD parameters) at different concentration variations.

Respect to salt concentration parameters (TDS and conductivity), the PES 50 kDa ultrafiltration membrane was not able to reduce the levels of salt concentration with removal efficiency respectively against untreated feed in the range of 4.04 ± 2.28% with an average concentration decrease of 155 mg/L and 3.61 ± 1.83% with an average concentration decrease of 0.24 ms/cm for all flux operation variations. As for the Pre-treated water, the TDS and conductivity removal efficiency levels were in the range of 19.13 ± 9.5% with an average concentration decrease of 1,515 mg/L and 17.04 ± 16.35% with an average concentration decrease of 2.18 ms/cm for all flux operation variations, respectively. The level of removal efficiency is considered insignificant to the quality of water filtration results. This result is contrary to the research conducted by Notodarmojo (2014), that the level of TDS rejection in CA-material membranes reaches up to 80%. However, this phenomenon can be caused by many ions and dissolved inorganic compounds in the feed water. This condition aligns with the theory that ultrafiltration membranes had limitations in the process of filtering these compounds, especially for particles that have a size smaller than the PES membrane pore size of 50 kDa. In the treatment process, UF is a pre-treatment process of RO which is more instrumental in removing organic compounds (abror et al, 2023). In addition, Ultrafiltration as a pre-treatment was able increase the performance of Reverse Osmosis at optium condition. Reverse osmosis is the only treatment unit capable of rejecting ions and dissolved inorganic compounds in water due to its smaller pore size and different mechanism from the ultrafiltration (UF) process.

3.2. PES Membrane Retention on Flux Variation

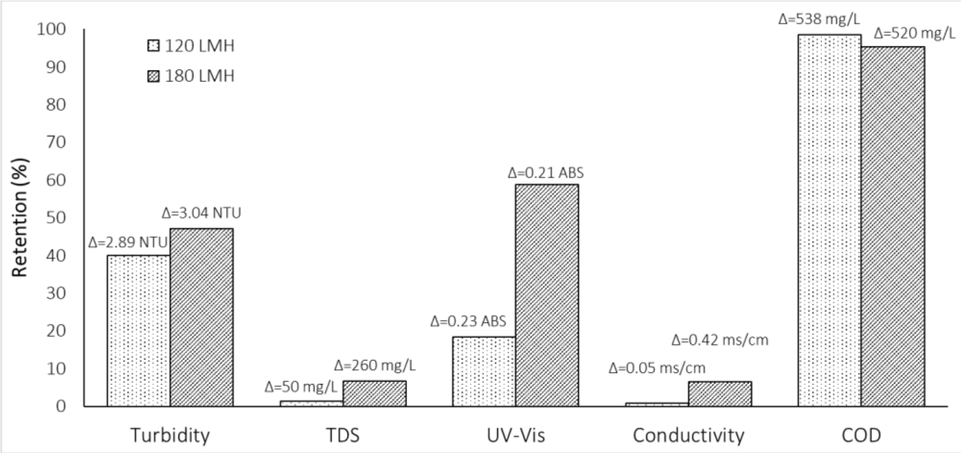
In comparison of flux variation with membrane retention, it was revealed that the operating flux at 180 L/m2·h provided a better removal efficiency level than operating flux at 120 L/m2·h for both untreated and pre-treated water characteristics. In the case of untreated water, it was indicated by the highest removal efficiency for turbidity, TDS, UV-VIS, and conductivity parameters with average concentration decrease of 3.04 NTU, 260 mg/L, 0.21 ABS, and 0.42 ms/cm, respectively. On the other hand, the operating flux of 120 L/m2·h had the highest removal efficiency level for COD parameters with an average concentration decrease of 538 mg/L.

Results the pre-treated water (DAF outlet water) was indicated the highest level of removal efficiency for turbidity, TDS, conductivity, and COD parameters with an average decrease in the concentration of 0.45 NTU, 2,935 mg/L, 4.2 ms/cm, and 137 mg/L, respectively. While, at the flux operation of 120 L/m2·h had the highest removal efficiency level for UV-VIS parameters with an average concentration decrease of 0.08 ABS. These results indicate that operating a flux of 180 L/m2·h is more effective for both water characteristics retention due to faster filtration rate and resulted for retention of substance by a cake layer formation on the surface of the PES 50 kDa ultrafiltration membrane. This result aligns with the research that has been conducted that the amount of foulant load at higher fluxes will also result in higher fouling rates (Kirschner et al., 2019). Therefore, flux significantly influences the operation of the PES 50 kDa ultrafiltration membrane.

3.3. PES Membrane Performance on Fouling Behavior

The performance of the PES 50 kDa ultrafiltration membrane can be seen from the fouling rate generated from the tendency of the graph generated against the untreated water and pre-treated water (see Figure 3). The graph has a different pattern decreasing due to foulant buildup over time. In general point of view by comparing untreated water with pre-treated water, it could be seen that pre-treated water resulted in severe membrane fouling than untreated water. For instance, in case of 120 $L/m^2·h$, despite comparable filterability with 300 L/m^2, stronger permeability decline in case of pretreated with the decrease of 0.85 was observed, while less permeability decline in case of untreated water with 0,73. In parallel, similar behavior was found during filtration at 180 $L/m^2·h$. Stronger membrane fouling was occurred during filtration of pre-treated water with 0,95 and untreated water with 0,9. Stronger fouling in pretreated water was related to the characteristics (Figure 2). It might be explained that larger organic substances resulted for surface fouling in case of untreated water, while smaller organic substances might be attributed to internal membranes fouling that responsible for severe membrane fouling (Laksono et al., 2021).

Observation of the details of the filtration could be performed employing membrane fouling mechanisms. For the operation flux with 120 $L/m^2·h$, rapid decline was found in the earlier phase until specific filtered volume of 180 L/m^2 in case of untreated water. In case of pretreated water, steeper and faster decline was observed until specific filtered volume of 200 L/m^2. Despite different, the trend of the permeability decline was found to be similar. For the further phase, the slower permeability decline was observed that indicates the cake layer at the later phase was formed. This condition is linear to the theory that the main mechanisms of fouling in membranes are intermediate pore blocking and cake filtration (Kirschner et al., 2019).



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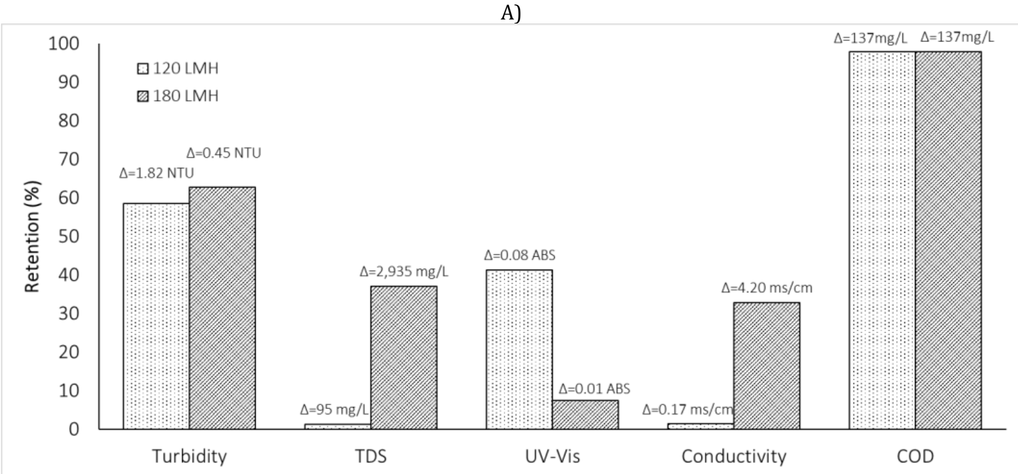
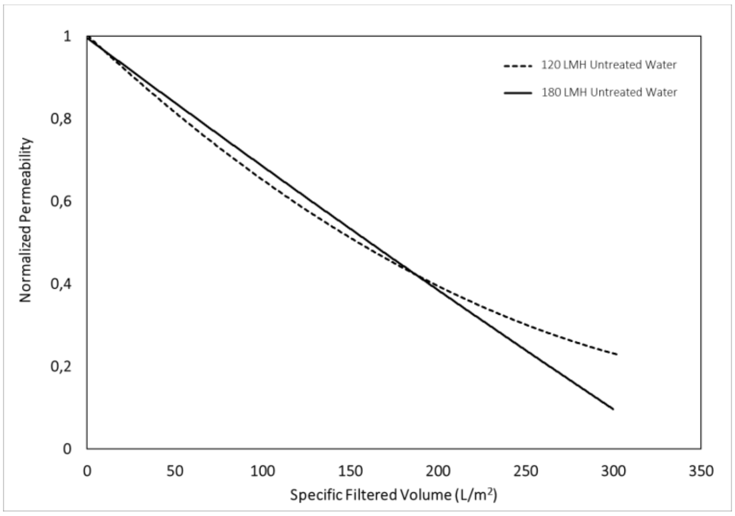


B)

Figure 2. Retention Membrane with Variation Flux in A) Untreated Water and B) Pre-treated Water

Interesting results was found in case of filtration employed flux 180 L/m²·h using both pre-treated water and untreated water. Different permeability decline curves in comparison with flux 120 L/m²·h was observed (see Figure 3). There are several phases of permeability reduction, namely the phase of rapid permeability reduction in the early-stage slow permeability reduction in the middle period, and rapid permeability reduction (compression) in the late stage (Yang et al., 2022). In these cases, the curves reflected different fouling behavior, whereas steep permeability decline until end of filtration cycle occurred. In the case of untreated water, one might say that the permeability decline curves tended to be linear from the first filtration until end filtration. In parallel, for pre-treated water, a decreasing concave permeability curve was seen. Related to the fouling mechanisms models, the liner and decreasing concave permeability could be interpreted that high flux forces the water and substance through the membrane so the particle and substance could not deposit properly on membrane surface (Laksono, 2020). Another possibility that high flux also resulted the substance was forced inside the membrane and blocked internal part of the membrane. This phenomenon could be explained by the linear decrease of the permeability at the end of filtration cycle. It is worth mentioning that this fouling behavior can be also caused by the influence of the PES membrane, namely the pore size and membrane coating. The inhomogeneous pore size of the membrane can cause differences in the resulting performance (Bera et al., 2021). Second, the 50 kDa PES membrane used in this experiment had its membrane coating modified by the vendor, potentially affecting the performance of the membrane used. Thus, the difference in fouling rates produced in each flux variation shows that flux affects fouling in PES 50 kDa ultrafiltration membranes (Sioutopoulos & Karabelas, 2016). Based on the experimental results, it was found that different the flux operation of 180 L/m2.h resulted higher water production of ultrafiltration for both water characteristics on the PES 50 kDa ultrafiltration membrane (Brover et al., 2022). Furthermore, different fouling performance at different flux not only resulted from different flux but also different organic concentration in particular to cake layer filtration (Wu et al., 2023) However, it was unclear whether the membrane was backwashable and sustainable at multiple filtration cycle test.



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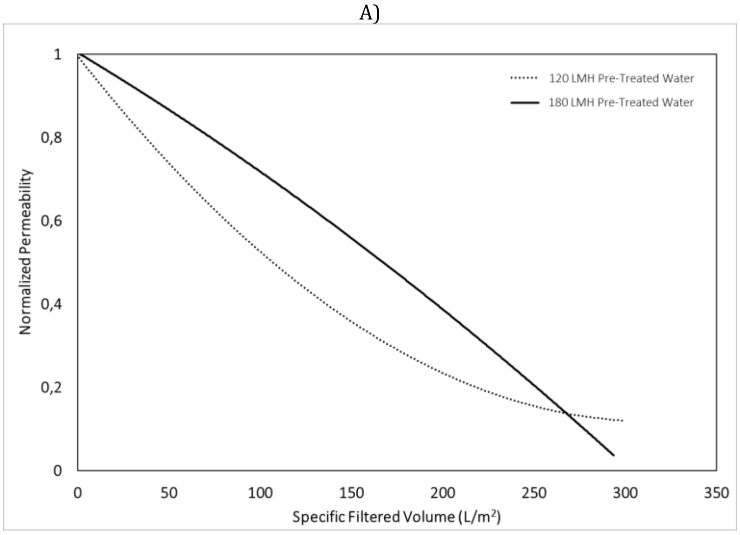
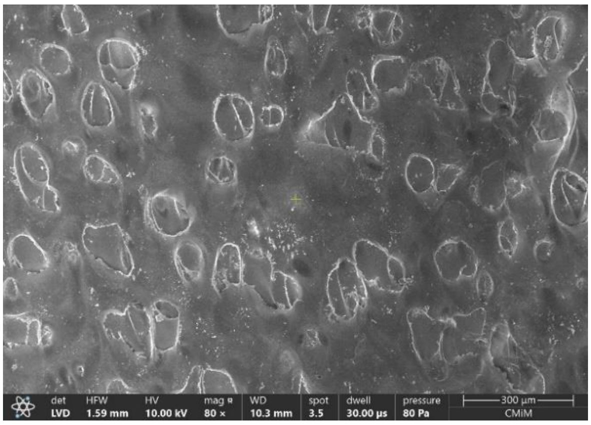


B)

Figure 3. Membrane filtration performance with Variation Flux in A) Untreated Water and B) Pre-Treated Water



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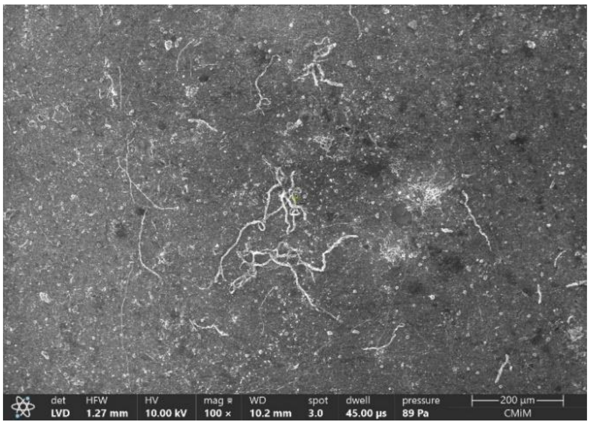

B)

Figure 4. Scanning Electron Microscope (SEM) of PES Membrane by A) Before and B) After Ultrafiltration

3.4. Fouling Characteristics of PES Membrane

The characterization of the PES 50 kDa ultrafiltration membrane was performed through SEM analysis (see Figure 4). SEM analysis was conducted on the PES 50 kDa for virgin membrane and filtered ultrafiltration membrane, with two magnifications of 80 and 100 times. In the case of virgin membrane (before ultrafiltration), it can be seen there is no foulant covering the membrane surface layer (see Figure 4a). simultaneously, after ultrafiltration, the membrane shows many foulants on the top of the surface. Moreover, it can also be seen that the foulant buildup covers the pores of the PES 50 kDa ultrafiltration membrane. Generally, these foulants are suspended particles, microorganisms, and dissolved organic and inorganic compounds that form a thick cake layer (Alsawaftah et al., 2021).

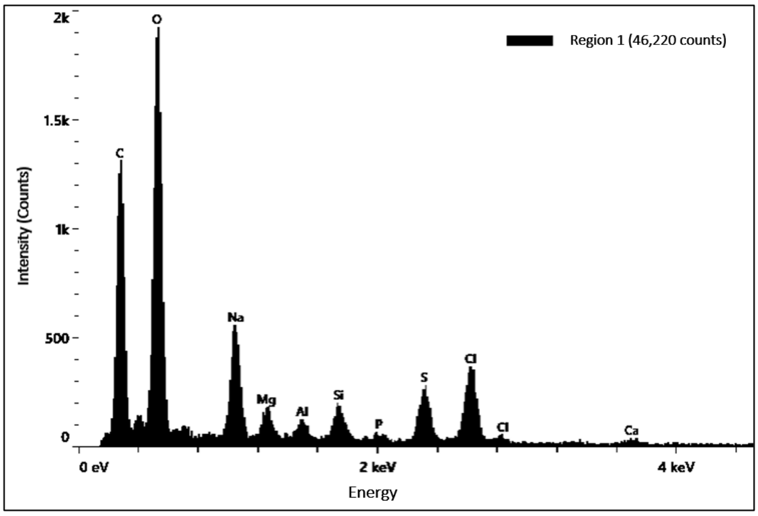

Figure 5. Energy Dispersive X-ray Spectroscopy (EDS) of PES Membrane After Ultrafiltration

Furthermore, an analysis using EDS (Energy Dispersive X-Ray Spectroscopy) related to the components of the PES 50 kDa ultrafiltration membrane (See.Figure 5). It can be analyzed that the layer cake on the PES 50 kDa ultrafiltration membrane contains several components, such as organic compounds (C, O, and S) and inorganic compounds (Ca, Na, and Mg). The highest percentage of components on the PES 50 kDa ultrafiltration membrane surface is C at 40.1% and O at 39.2%. These results show that organic compounds are the main components of the cause of fouling on the membrane. During ultrafiltration, these organic compounds can change shape to settle and solidify on the membrane surface. Thus, the cake layer reduces organic compounds and improves permeate water quality.

Furthermore, it can be assumed that the cake layer contains a complex mixture of polymers, such as extracellular polymeric substances (EPS) and soluble microbial products (SMP). The main constituent components of EPS and SMP are proteins, polysaccharides, humus, and organic compounds (Laksono et al., 2021). The complex polymer mixture can adsorb on the membrane surface and cause irreversible fouling and indicates that the fouling state of the membrane is caused by the polarization effect of the enhanced protein concentration (Yue et al., 2021). Concentration polarization is greatly affected by the variation of operating flux. The higher the operating flux, the lower the potential for concentration polarization. This condition happens because the faster stirring process in the water results in higher diffusion (Sadr & Saroj, 2015). In this experiment, concentration polarization tends to have more potential to occur when operating a flux of 120 LMH than when operating a flux of 180 LMH.

4. CONCLUSION

Differences in flux operation and water characteristics affected the fouling mechanism on the membrane i.e., the fouling rate and removal efficiency level of the PES 50 kDa ultrafiltration membrane. Related to characteristic of water, PES membrane was effectively able to remove turbidity, TDS, UV-Vis, conductivity, and COD parameters for both untreated and pretreated water. In parallel, in the case of membrane performance, The filtration of flux operation of 120 $L/m^2 \cdot h$ revealed less membrane fouling in comparison to flux operation of 180 $L/m^2 \cdot h$. Severe membrane fouling mechanisms in particular at flux 180 $L/m^2 \cdot h$ might influence the backwash ability and influenced the for shorter life span despite higher production water was performed. Therefore, the suitable operation of fluxes for recommendation is 120 $L/m^2 \cdot h$ to decrease performance energy and loading on the reverse osmosis unit. Despite clear results, further analysis of organic concentration with other methods shall be conducted in order to minimize disruption for high salt concentration of seawater. Furthermore, an investigation at pilot scale might reflected the real application of membrane filtration process and fouling mechanism.

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