PENGOLAHAN AIR GAMBUT MENJADI AIR BERSIH MENGGUNAKAN TEKNOLOGI NANOFILTRASI MEMBRAN KERAMIK

PEAT WATER TREATMENT INTO CLEAN WATER USING COMPOSITE CERAMIC MEMBRANE NANOFILTRATION TECHNOLOGY

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Diterima: 18 Maret 2022; Direvisi: 8 Juni 2022 – 9 Juni 2022; Disetujui: 27 Agustus 2022

Abstrak

Pengadaan air bersih merupakan salah kebutuhan mendesak yang harus diwujudkan guna menyelesaikan persoalan yang terus dihadapi oleh masyarakat yang hidup di lahan gambut. Tujuan penelitian ini adalah mengolah air gambut menjadi air bersih menggunakan metode nanofiltrasi dengan membran keramik berbasis *clay*, nanopartikel karbon aktif Tandan Kosong Kelapa Sawit (TKKS) sebagai bahan aditif dan serbuk besi sebagai penguatnya. Air gambut terlebih dahulu dinetralkan dengan penambahan kapur tohor kemudian diolah melalui berbagai metode mikrofiltrasi dengan sponge filter dengan ukuran pori 0,3 dan 0,1 µm, selanjutnya difiltrasi kembali dengan karbon aktif, dan yang terakhir difiltrasi dengan membran keramik berbahan aditif nanopartikel karbon aktif TKKS. Tekanan diatur pada 1 bar, 1,5 bar, dan 2 bar. Bahan baku air gambut berasal dari Sungai Telang yang bersifat asam dengan nilai pH 4,1 dan mengandung TSS 147.5 mg/L, Fe 0,33 mg/L, Mn 0,56 mg/L, Zn 0,02 mg/L, NH_3-N 0,58 mg/L, NO_2^- of 0,19 mg/L, PO_4^{-3} of 0,264 mg/L, dan BOD_5 of 12,1 mg/L. Dapat dilihat bahwa semakin besar perbedaan tekanan *transmembrane* dan semakin lama waktu operasi yang digunakan, maka akan semakin baik hasil permeat yang dihasilkan. Perbedaan tekanan sebesar 2 bar memberikan hasil yang paling baik dalam menurunkan kadar senyawa kontaminan yang terdapat dalam air gambut dengan rerata persen rejeksi reduksi TSS 91,89%, Fe 70%, Mn 93,2%, Zn 95%, NH_3-N 68,6%, NO_2^- 70%, PO_4^{-3} 38,14%, dan BOD_5 91,99%.

Kata kunci: air gambut, membran keramik, nanofiltrasi, tandan kosong kelapa sawit

Abstract

The provision of clean water is an urgent need that must be acknowledged in order to solve the problems that are continuously faced by people who live on peatlands. The purpose of this research is to process peat water into clean water using the nanofiltration method by a composite ceramic membrane made of clay, activated carbon nanoparticles from oil palm empty fruits bunch (OPEFB) as an additive, and iron powder as a reinforcement. Peat water is neutralized first by adding quicklime, afterward, it is processed using various microfiltration methods using sponge filters with pore sizes of 0.3 and 0.1 µm, and then continued with filtration using an activated carbon filter, and lastly, filtration using ceramic membranes made of OPEFB activated carbon nanoparticle additive as the final step. The pressures used are 1 bar, 1.5 bars, and 2 bars. The acidic peat water used is from the Telang River with pH of 4.1, TSS of 147.5 mg/L, Fe of 0.33 mg/L, Mn of 0.56 mg/L, Zn of 0.02 mg/L, NH_3-N of 0.58 mg/L, NO_2^- of 0.19 mg/L, PO_4^{-3} of 0.264 mg/L, and BOD_5 of 12.1 mg/L. It was found that the greater the transmembrane pressure difference and the longer operating time used, the better permeate yield achieved. The pressure difference of 2 bars gives the best results in reducing the levels of contaminants contained in peat water, with an average percentage of rejection reduction of TSS is 91.89%, Fe is 70%, Mn is 93.2%, Zn is 95%, NH_3-N is 68, 6%, NO_2^- is 70%, PO_4^{-3} is 38.14%, and BOD_5 is 91.99%.

Keywords: peat water, ceramic membrane, nanofiltration, oil palm empty fruit bunch

INTRODUCTION

The need for clean water continues to increase along with the increase in population. However, not all residents can easily obtain clean water, one of which is people who live in peatland areas (Ali et al., 2021). The supply of clean water is one of the main problems faced by people living on peatlands (Permana et al., 2021). Banyuasin region has a peatland area of 283,000 ha out of 1.2 million ha in South Sumatra (Badan Restorasi Gambut, 2019). In this area, people generally still use rainwater as a source of clean water (Kunarso et al., 2022). However, if the rainwater supply runs out, people will still use surface water to fulfill their daily needs even though its quality is not suitable for use (Safitri et al., 2020). This condition is because this rural peatland area is not supplied by any drinking water companies, which causes clean water unavailability (Putri et al., 2021).

Peat water is a source of water available on peatlands (Taufik et al., 2019). Peat water has the characteristic of containing high organic matter, reddish-brown in color, and acidic with a pH ranging from 3 to 5 (Herawati et al., 2021). Peat water also contains high TSS, TDS, BOD, and COD (Said et al., 2019). The organic matter contained in peat water is Humic and Fulvic acid (Jarukas et al., 2021). In addition, peat water also contains high levels of iron (Fe) and manganese (Mn), so it has a negative impact if it is consumed, that it will cause tooth decay, digestive disorders, allergies, skin irritation, and cancer (Rusdianasari et al., 2019). Therefore, the condition of peat water like this does not meet the clean water quality requirements stipulated by South Sumatra Governor Regulation No. 16 the Year 2005. In order for peat water can be used for daily purposes, it must be treated properly. Therefore, an important mitigation measure in order to prevent further impacts should be done right (Martini et al., 2021).

The methods used for peat water treatment are coagulation-flocculation, disinfection-oxidation, and filtration methods (Mulyadi et al., 2020). The method used in this research is filtration using a ceramic membrane. Organic compounds and metals dissolved in peat water can be separated using a filtration process using a ceramic membrane with high density (Saifuddin et al., 2020). This method has been chosen because ceramic membranes have high stability against chemicals, are resistant to high temperatures, resistant to acid and alkaline conditions, have good mechanical strength, and low energy consumption (Sisnayati et al., 2018), The performance of ceramic membranes can be influenced by the membrane constituent materials, the particle size of the membrane materials, the shape or dimensions of the ceramic membrane, the pressure, and the firing temperature used in the making process of the ceramic membrane (Yanu et al., 2020).

Membrane materials are based on alumina, titania, zirconia, and silica and have limited resources, so their prices are high (Abdullayev et al., 2019). Clay is a membrane-building material that is easier to obtain and cheaper (Abdullayev et al., 2019). Clay is a porous material and contains hydrous aluminum silicate (Elgamouz & Tijani, 2018). The use of oil palm empty fruits bunch (OPEFB) activated carbon as a ceramic membrane additive is because it is usually unused and piled up in the palm oil mill industrial area. It has not been utilized optimally (Yanti & Hutasuhut, 2020).

Research conducted by Saifuddin et al., (2020) made ceramic membranes from clay, zeolite, and activated carbon as filters by varying the composition of the membrane constituents and the combustion temperature. This study resulted in the highest Fe^{2+} removal efficiency of 100%, the highest Mn^{2+} removal of 99.94%, the removal efficiency of 82.58%, and the turbidity of 95.65% (Saifuddin et al., 2020).

A study to remove BOD in peat water was carried out by Elma et al., (2022), which investigated the effect of coagulation-adsorption as an ultrafiltration pretreatment using polysulfone-based membranes. This method can remove 95% of BOD in peat water with a filtration flux of up to 92.4 L/m^{2}h (Elma et al., 2022).

The research was conducted by Ayunata et al., 2020 to determine the effectiveness of ceramic membranes made of eggshell, zeolite, and polyvinyl alcohol (PVA) in peat water treatment. This method can increase the pH of peat water from 5.67 to 6.84 with an effectiveness percentage of 17% and can reduce 77% BOD, 48% TSS, and 53.12% Fe. From the various efforts above to treat peat water into clean water and drinking water using ceramic membranes, the percentage reduction in Fe, Mn, BOD, and TSS is quite large, which means that these methods still require special treatment (washing and heating) of the membrane raw materials, and also require a complicated initial pretreatment before the peat water is filtered with a ceramic membrane. Besides, the raw materials for making the membrane are not cheap, so these efforts are relatively more expensive.

In this study, the method used is the nanofiltration using a composite ceramic membrane with activated carbon OPEFB as an additive and iron powder as a reinforcement. This method utilizes easy-to-obtain membrane raw materials, which is a kind of unused solid waste and does not require complicated initial pretreatment, so it is hoped that this method can be a good alternative for peat water treatment.

MATERIALS AND METHODS

The materials used are quicklime, peat water, activated carbon nanoparticles made from OPEFB with iron powder, membrane housing, 0.3 m, and 0.1 m sponge filter.

The tools used are composite ceramic membranes, a PVC tank of 500 L, PVC pipe, 1 unit of water pump, an activated carbon filter, a measuring cup, and glass beakers.

In this study, the composite ceramic membrane used was adopted from the research of Sisnayati et al., (2017), who made a ceramic membrane with a composition of 87.5% clay and 10% OPEFB activated carbon nanoparticles, and 2.5% iron powder. The analysis of this membrane shows the average pore diameter is 298 nm, respectively.

The research begins by analyzing peat water first. After that, the peat water was coagulated-flocculated using quicklime as a coagulant using the jar test method. After that, the peat water is put into a 500 L tank. Then by using a pressure pump, the peat water flowed from the storage tank to housing-1, which contains a sponge filter with a pore diameter of 0.3 μm. The pump pressure is set to 1 bar, 1.5 bars, and 2 bars by adjusting the feed flow rate using a feed flowmeter. Then the peat water that has been filtered by the 0.3 μm sponge filter flows into housing-2 and housing-3, each of which contains a sponge filter with a pore diameter of 0.1 μm and activated carbon. Then the peat water has passed through the sponge filter and activated carbon filters. Then the peat water flowed into housing-4, which contains a ceramic membrane made from an additive of OPEFB activated carbon nanoparticles. Peat water that has passed the filtration process was stored in a container as the permeate. A sampling of peat water was carried out every 25 minutes, 30 minutes, 45 minutes, 60 minutes, 75 minutes, and 90 minutes. Each permeate produced measured in volume. Then the permeate was analyzed for physical parameters such as TDS and TSS, as well as chemical parameters such as pH, Fe. M. Zn, $SO4^{2-}$, BOD5, NH_3-N, NO_2^-, and PO_4^{3-}.

The research flow chart can be seen in Figure 1.

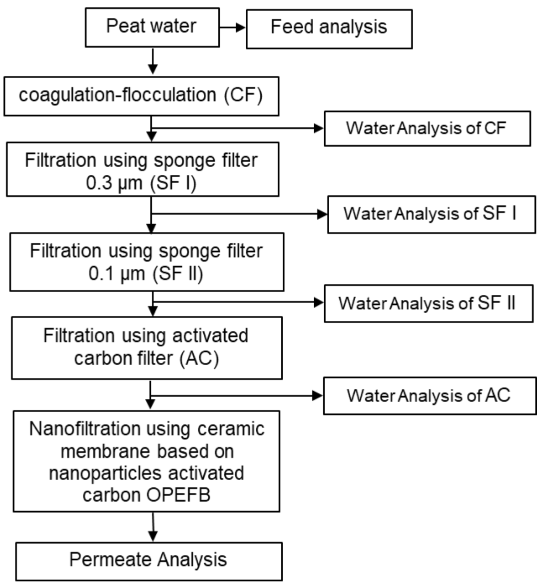

Figure 1. Research flowchart

RESULTS AND DISCUSSION

a. Membrane flux analysis

The membrane flux values at transmembrane pressures of 1 bar, 1.5 bars, and 2 bars based on changes in operating time are shown in Figure 2.

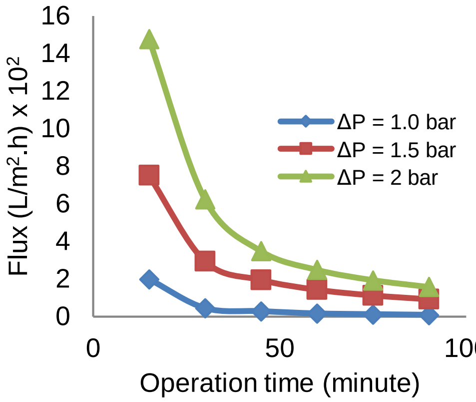

Figure 2. The effect of operation time and pressure on permeate flux of peat water

From the data shown in Figure 2, the highest flux value in peat water is achieved at a transmembrane operating pressure of 2 bars, and the lowest flux value is achieved at a pressure of 1 bar. The highest flux is 140.64 x 102 L/m^2.h. Meanwhile, the lowest flux value was obtained after the membrane was operated for 90 minutes at a pressure of 1 bar, namely 1.51 x 102 L/m^2.h. Based on this value, it is known that there is a decrease in the value of the membrane flux. The decrease in the membrane flux value was due to blockage by unwanted dissolved contaminant molecules from the feed flow.

The effect of pressure and operating time on the permeate flux shown in Figure 2 shows that the permeate flux increased with the increasing operating pressure. This corresponds to the driving force of the membrane operation. The presence of pressure applied to the feed stream passing through the membrane will result in a fluid flow with a particle size smaller than the membrane pores being able to pass through the membrane, while larger particles will be stuck on the membrane surface. In addition, the magnitude of the applied pressure causes an increase in the pore size of the membrane so that the rate of feed solution will be faster, and more feed passes through the membrane.

b. Analysis of the results of the pretreatment and nanofiltration of peat water

The results of the peat water pretreatment and nanofiltration analysis are shown in Table 1.

Table 1. Results of peat water analysis after pretreatment and nanofiltration.

Parameters	*Unit*	Initial	*CF*	SF I	SF II	AC	CM	%R	EQS*
pH	-	**4,1**	6,5	6,5	6,5	6,8	7,3	-	6 sd. 9
TDS	mg/L	389	380	374	363	353	202,5	42,63	1000
TSS	mg/L	**147,5**	**144,6**	**144,5**	**144,5**	**144,5**	11,72	91,89	50
Fe	mg/L	**0,33**	**0,3**	**0,3**	**0,3**	**0,3**	0,09	70,00	0,3
Mn	mg/L	**0,56**	**0,50**	**0,50**	**0,50**	**0,50**	0,034	93,20	0,1
Zn	mg/L	**0,02**	**0,02**	**0,02**	**0,02**	**0,02**	<0,003	95,00	0,005
SO_4	mg/L	191	177	25,3	25,3	22,9	15,522	32,22	400
NH_3-N	mg/L	**0,58**	**0,56**	**0,56**	**0,55**	**0,54**	0,157	68,60	0,5
NO_2^-	mg/L	**0,19**	**0,11**	**0,11**	**0,11**	**0,09**	0,027	70,00	0,06
PO_4^{-3}	mg/L	**0,264**	**0,225**	**0,224**	**0,224**	**0,215**	0,133	38,14	0,2
BOD_5	mg/L	**12,1**	**11,99**	**11,95**	**11,95**	**11,95**	0,957	91,99	2

Note:
CF : Coagulation Flocculation
SF I : Sponge Filter size of 0.3 μm
SF II : Sponge Filter size of 0.1 μm
AC : Activated Carbon Filter
CM : Ceramic Membrane
EQS : Environmental Quality Standard of South Sumatra Governor Regulation No. 16 Year 2005

From Table 1, it can be seen that the contaminant content that exceeds the environmental quality standard is pH and TSS. Fe, Mn, Zn, NH_3-N, NO_2^-, $PO_4^{-3,}$ and BOD_5. In the feed, there was an increase in pH from 4.1 at the outlet of the flocculated coagulation filter to 6.5 due to the addition of quicklime. This shows that quicklime has neutralizing power (Oktafiansyah et al., 2020). After passing through the activated carbon filter, the pH of the peat water becomes 6.8 and increases to 7.8 after passing through the filtration process with a membrane. This is because the source of acidity from peat water, namely humic acids (H^+ ions), has been blocked or has been filtered on the surface of the membrane so that the pH of the permeate produced has met environmental quality standards (Ahmad et al., 2022).

The concentration of Mn is decreased from 0.56 mg/L in the feed to 0.5 mg/L at the outlet of the activated carbon filter and after filtration to an average of 0.034 mg/L with an average rejection percentage of 93.20%. The concentration of Zn decreased from 0.02 mg/L to <0.003 mg/L with a rejection rate of 95.0%. The concentration of Zn decreased from 0.49 mg/L to 0.001 mg/L with an average rejection rate of 99.8%. The decrease in NH_3-N concentration from 0.5 mg/L to 0.157 mg/L with a rejection percentage of 68.6%. The decrease in the concentration of NO_2^- from 0.09 mg/L to 0.027 mg/L and the concentration of PO_4^{3-} could be reduced from 0.215 mg/L to 0.113 mg/L, with the rejection percent being 70.0% and 38, 14% respectively. Meanwhile, TSS can be reduced by filtration from 144.5 mg/L to 11.72 mg/L and is able to reject TSS by 91.89%.

From Table 1, it can be seen that the performance of the ceramic membrane used in this study is adequate because the permeate produced can meet environmental quality standards with a very high rejection percentage.

c. Effect of pressure and operating time on peat water quality

The effect of operation time on peat water quality values at transmembrane pressures of 1 bar, 1.5 bars and 2 bars based on changes in operating time are shown in Figure 3 to Figure 8.

- Effect of pressure and operating time on TSS concentration

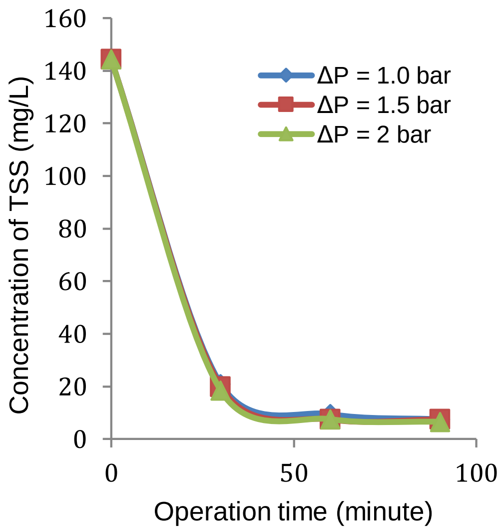

Figure 3. Effect of pressure and operating time on the TSS concentration

Figure 3 shows that the higher the driving force applied, the smaller the TSS concentration or, in other words, the higher the TSS rejection percentage will be. If the operating pressure applied is too low, there will be less suspended particles set aside. On the contrary, the higher the operating pressure applied, the higher the TSS rejection percentage will be. This is due to the faster fluid flow through the membrane, so suspended particles with high molecular weight or large particles cannot pass through the membrane. This causes particle deposition on the membrane surface to be more easily formed and makes it more difficult for suspended particles to penetrate the membrane wall, thereby reducing the TSS content in the permeate and ultimately increasing the rejection percentage (Meidinariasty et al., 2019).

- Effect of pressure and operating time on Fe concentration

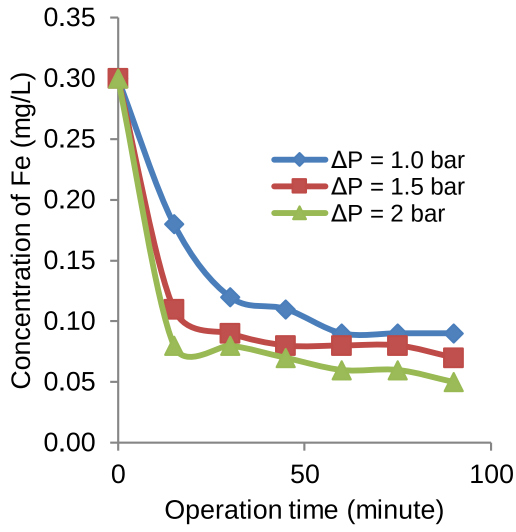

Figure 4. Effect of pressure and operating time on the Fe concentration

In Figure 4, the peat water feed that has flowed through the pretreatment process with activated carbon has a Fe content of 0.3 mg/L. This value is the maximum environmental quality standard for Fe. After 15 minutes of operation at a pressure of 1 bar, the decrease in Fe was 0.18 mg/L, while at a pressure of 1.5 bars and 2 bars, the Fe decreased to 0.05 mg/L and 0.11 mg/L. The largest decrease in Fe concentration occurred at an operating pressure of 2 bars at 90 minutes, which was 0.05 mg/L with a rejection percent of 83.33%, and the smallest rejection percentage was 40% which occurred at an operating pressure of 1 bar at 15 minutes.

The decreasing of Fe concentration after the filtration process with composite ceramic membrane, using activated carbon nanoparticles made from OPEFB and iron powder, is probably due to the precipitation of Fe contained in peat water which is not easily soluble. In addition, positive ions that are still dissolved can be inhibited by the membrane wall. The silica contained in clay and activated carbon as a constituent of membranes is able to bind Fe in water. In the presence of silica and activated carbon as an iron-exchanger that produces reactive oxygen (Kalsum et al., 2019).

- Effect of pressure and operating time on Mn concentration

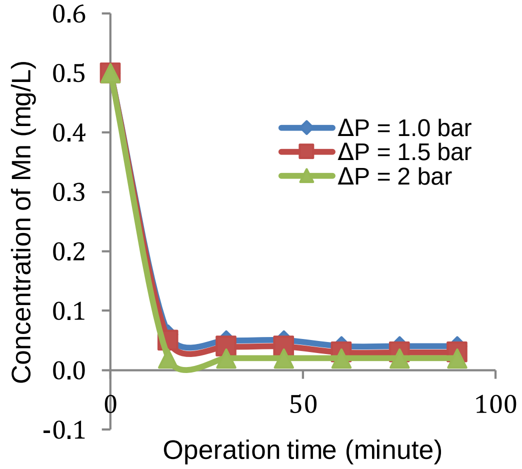

Figure 5. Effect of pressure and operating time on the Mn concentration

In Figure 5, the Mn content of the peat water feed passing through the activated carbon filter is 0.5 mg/L. This value is above the environmental quality standard for Mn, which is 0.1 mg/L. After the filtration process with the membrane, the concentration of Mn decreased to 0.02 - 0.06 mg/L. The largest decrease in Mn concentration occurred at a pressure of 2 bars from 15 to 90 minutes, which was 0.02 mg/L with Fe rejection of 96%. This proves that the filtration process is able to separate solids and colloids in liquids and membranes and effectively rejects multivalent ions (Kasim et al., 2017).

- Effect of pressure and operating time on Zn concentration

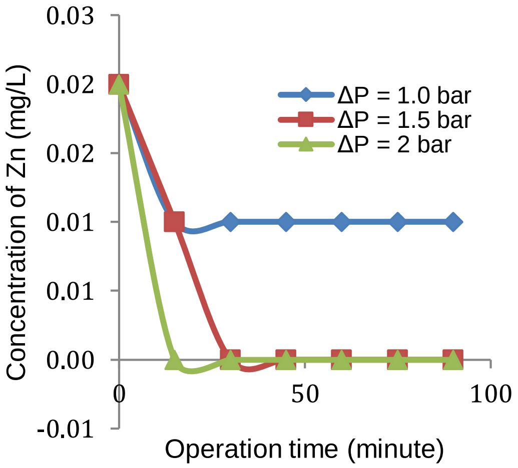

Figure 6. Effect of pressure and operating time on the Zn concentration

In Figure 6, it can be seen that the Zn content in peat water that has passed filtration with activated carbon is 0.02 mg/L. The value is still above the maximum allowable limit. After the filtration process with ceramic membrane, Zn concentration decreased to 0.01 - <0.003 mg/L. The concentration of Zn complied with environmental quality standards and was achieved at a pressure of 1.5 and 2 bars. The largest decrease in Zn concentration occurred at a pressure of 2 bars at operating time from 15 to 90 minutes, which was <0.003 mg/L with a rejection percentage of 95%. The decrease in the concentration of Zn in the permeate with increasing pressure could be due to the increase in the preference for adsorption of elements by the membrane, and the average pore size at the membrane surface has decreased, which is also due to an increase in flux with increasing applied pressure (Al-Alawy & Salih, 2016).

- Effect of pressure and operating time on the concentration of NH_3-N

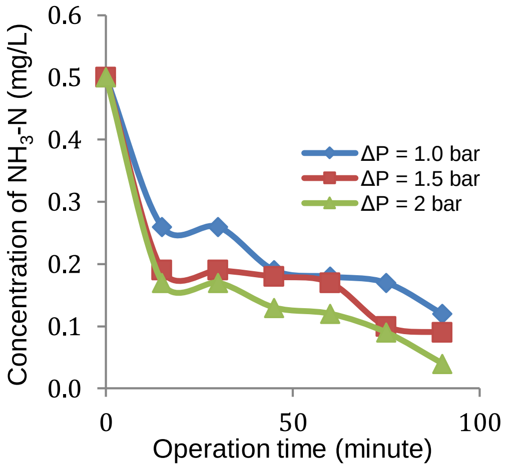

Figure 7. Effect of pressure and operating time on the concentration of NH_3-N

Figure 7 shows that there was a decrease in the concentration of NH_3-N from 0.54 mg/L to 0.04 – 0.26 mg/L. The greatest decrease in permeate concentration occurred at a pressure of 2 bars at 90 minutes of operation, which reached 0.04 mg/L with 92.0% NH_3-N rejection percent. This increase in the rejection percentage indicates that nitrating bacteria (*Nitrosomonas*) are able to oxidize ammonia to nitrite with the reaction equation (Hibban et al., 2016):

$$COHNS + O_2 + \text{Nutrient} \rightarrow CO_2 + NH_3 + C_5H_7O_2N + \text{other products}$$

In addition, the ammonium assimilation process also occurs, with the reaction shown below (Hibban et al., 2016):

$$4CO_2 + HCO_3^- + NH_4^+ + H_2O \rightarrow C_5H_7O_2N + 5O_2$$

The reactions above show that there is a very significant reduction in the presence of the nanofiltration process with the combination of the microfiltration process. The process using a combination of microfiltration and nanofiltration causes concentration polarization so that the NH_3-N content in peat water decreases (Sisnayati et al., 2018).

➢ The effect of pressure and operating time on the concentration of NO_2^-

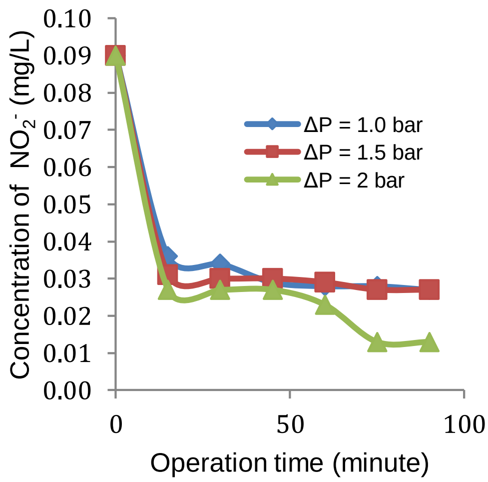

Figure 8. Effect of pressure and operating time on the concentration of NO_2^-

Figure 8 shows the NO_2^- content in the peat water feed of 0.09 mg/L. This value is still above the maximum allowable limit, which is 0.06 mg/L. After the filtration process with ceramic membranes, there was a decrease of NO_2^- from 0.013 to 0.036 mg/L. The highest decrease in NO_2^- concentration occurred at an operating time of 75 - 90 minutes at a pressure of 2 bars, with a rejection percentage of 85.56%. This decrease occurred because, during the filtration process, nitrite (NO_2^-) is converted to nitrate (NO_3^-) by Nitrobacter bacteria. This process takes place in an aerobic process, so it requires sufficient oxygen (Wang et al., 2022). The presence of this bacteria is most likely from the water that comes from the river and is suspected of having been contaminated by it.

In addition, the more concentrated the peat water causes, the more contaminants to be retained on the membrane surface which will form a filter cake, so this causes the membrane pores to become smaller, and the ability to remove NO_2^- will increase (Sisnayati et al., 2018).

- Effect of pressure and operating time on the concentration of PO_4^{-3}

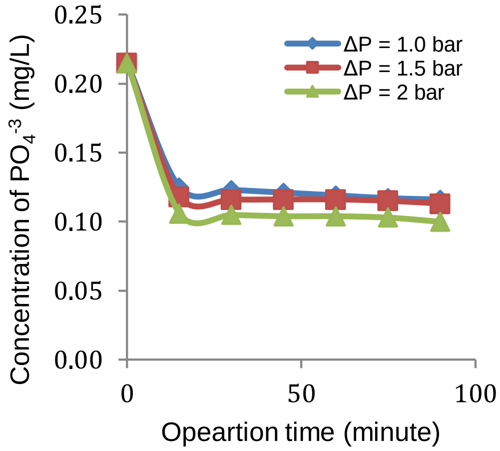

Figure 9. Effect of pressure and operating time on the concentration of PO_4^{-3}

The data shown in Figure 9 shows a decrease in the concentration of PO_4^{-3} after the filtration process with ceramic membranes, which was initially 0.215 mg/L to 0.1 – 0.125 mg/L. The decrease in PO_4^{-3} concentration occurred at an operating pressure of 2 bars which was taken within 90 minutes with a rejection percentage of 41.86%. The presence of PO_4^{-3} in peat water is obtained from the domestic waste of residents living around peat water. The decrease in PO_4^{-3} is caused by peat water containing PO_4^{-3} mixed with other materials bound by hydrophobic groups so that during filtration, not only PO_4^{-3} is filtered, but other materials are also filtered, causing fouling (Rasouli et al., 2022).

- Effect of pressure and operating time on BOD_5 concentration

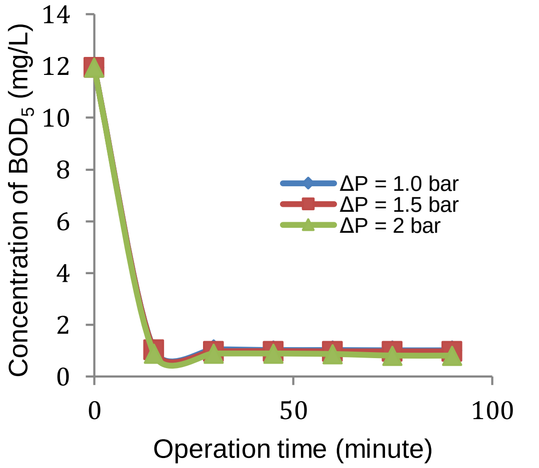

Figure 10.Effect of pressure and operating time on the concentration of BOD_5

Figure 10 shows that there was a decrease in the BOD_5 value from 11.95 mg/L to 0.81–1.05 mg/L during the filtration process. The decrease in the BOD_5 value is caused by the accumulation of organic matter, which triggers an increase in the value of BOD_5 and other contaminants. The highest BOD_5 rejection value occurred at an operating time of 75 to 90 minutes at a pressure of 2 bars, which was 93.22%, with a BOD_5 concentration of 0.81 mg/L. The rejection value of BOD_5 tends to increase with increasing operating time and pressure.

Based on Figure 3 to Figure 8, it is shown that the percentage of rejection of each contaminant (Fe, Mn, NH_3-N, NO_2^-, $PO_4^{-3,}$ and BOD_5) increased with increasing pressure and operating time. This is caused by the higher pressure applied to the feed stream. The more large-sized contaminants will be blocked on the membrane wall. In other words, concentration polarization occurs and will result in the flow of smaller-sized fluid passing through the membrane pores so that the concentration of contaminants in the permeate will be smaller and the percentage of contaminant rejection will be greater (Rasouli et al., 2022).

CONCLUSION

The filtration process of Telang River water gives the best results in reducing the levels of contaminants contained in peat water with an average reduction percentage of TSS of 91.89%, Fe of 70%, Mn of 93.2%, Zn of 95%, NH_3-N of 68, 6%, NO_2^- of 70%, PO_4^{-3} of 38.14%, and BOD_5 of 91.99% using transmembrane pressure difference of 2 bars with 100 minutes operating time.

The best results of this research were obtained using 2 bars pressure difference, which is the highest compared to two others, 1 bar, and 1.5 bars. Besides, the operating time of 100 minutes also gives better results compared to 50 minutes operating time. This means that the pressure difference and operating time have a high impact on the filtration process, where the greater the pressure difference and the longer operating time, the better the permeate produced.

ACKNOWLEDGEMENT

The author would like to thank the Internal Research Program at Universitas Tamansiswa Palembang which has assisted in financial matters and to the Chemical Engineering Study Program at Universitas Tamansiswa Palembang which has provided facilities and infrastructure for the implementation of this research.

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