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Effect of Filtration Time on the Performance of PVDF Membrane for Palm Oil Mill Effluent Treatment

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Abstract

Palm oil mill effluent (POME) is a high-viscosity wastewater generated during palm oil processing. Its high content of oil and grease, suspended solids, and colloidal organic matter contribute to elevated turbidity and pollutant loads. Therefore, effective treatment is necessary before POME can be discharged into the environment. Membrane filtration is a potential treatment method for reducing turbidity by retaining suspended and colloidal particles. This study investigated the effect of filtration time on the performance of a polyvinylidene fluoride (PVDF) hollow-fiber ultrafiltration membrane for POME treatment, with particular emphasis on pure water flux, permeate flux, and permeate turbidity. Before filtration, POME was pretreated with alum at a concentration of 1 g/L. The feed characteristics were assessed by measuring turbidity. Filtration was performed using a dead-end system at a constant pressure of 1 bar for 60 minutes, with measurements taken at 15-min intervals. Pure water flux was measured before POME filtration to establish a baseline for evaluating membrane performance. The results showed that pure water flux decreased from 345.5 to 247.4 L/m²·h, while permeate flux decreased from 56.6 to 10.7 L/m²·h over the filtration period. Meanwhile, pretreatment reduced feed turbidity from 5,060 to 405 NTU, corresponding to a 92% reduction. Subsequent membrane filtration produced permeate turbidity as low as 1.06 NTU at 30 minutes, representing a 99.74% reduction relative to the pretreated feed. The decline in flux indicated increased resistance to permeation, potentially due to the accumulation of retained materials on the membrane surface.

Keywords: filtration time; palm oil mill effluent; permeate flux; PVDF membrane; turbidity

1. Introduction

The palm oil industry is one of Indonesia's strategic economic sectors and contributes significantly to the national economy (Buluaro et al., 2025). Indonesia has approximately 14.98 million hectares of oil palm plantations, with crude palm oil (CPO) production reaching 45.58 million tons (Setiawan et al., 2025). As CPO production increases, the processing of fresh fruit bunches (FFB) also generates substantial amounts of waste. One of the major waste streams is palm oil mill effluent (POME), a liquid by-product generated during various stages of palm oil processing (Imam et al., 2025). POME contains high concentrations of organic matter and other pollutants, as reflected by its high chemical oxygen demand (COD), biochemical oxygen demand (BOD), total suspended solids (TSS), and oil and grease content (Setiawan et al., 2025). These characteristics make POME difficult to treat and pose environmental risks when the effluent is discharged without adequate treatment. Direct discharge can deteriorate water quality, deplete dissolved oxygen, and disrupt aquatic ecosystems (Dominic & Baidurah, 2022). Therefore, effective and sustainable treatment technologies are needed to reduce the pollutant load in POME before its discharge into the environment (Khan et al., 2025).

Biological treatment using anaerobic and aerobic ponds is commonly applied in the palm oil industry to treat POME (Sanjaya et al., 2023). Although this treatment method is relatively simple and economical, it has several limitations, including substantial land requirements, long hydraulic retention times, and variations in treatment performance under changing operating conditions (Razak et al., 2022). Membrane filtration has emerged as a potential alternative for wastewater treatment because it offers effective separation, requires relatively little space, and can produce high-quality permeate. These characteristics make membrane filtration a promising option for industrial wastewater treatment and potential integration into existing treatment processes (Ho et al., 2025).

Polyvinylidene fluoride (PVDF) is widely used as a membrane material for liquid separation in water and wastewater treatment (Kang & Cao, 2014). Its chemical resistance, thermal stability, and mechanical strength make PVDF suitable for various treatment applications (Sutrisna et al., 2023). PVDF membranes are commonly employed in microfiltration and ultrafiltration processes, which separate particles and other constituents from liquid streams based on membrane characteristics and operating conditions (Field & Wu, 2022). These applications have motivated further investigations into PVDF membrane performance under different operating conditions and with various wastewater types.

Several studies have evaluated the performance of PVDF membranes in wastewater filtration processes. Ahmad et al. (2020) reported that increasing the operating pressure from 50 to 200 kPa during POME filtration increased the permeate flux, reaching a maximum of 81.88 L/m²·h at 200 kPa. However, their study focused on variations in operating pressure and did not investigate the effect of filtration time on membrane performance at a constant operating pressure.

Meanwhile, Ding et al. (2020) reported that the flux of a PVDF membrane during papermaking wastewater filtration decreased from approximately 450 to 125 L/m²·h over 8 hours. This decline was associated with the development of membrane fouling as filtration progressed. However, their study used wastewater from the pulp and paper industry as the feed. Therefore, studies investigating the effect of filtration time on PVDF membrane performance during POME filtration at a constant operating pressure remain limited.

Based on this background, this study aims to evaluate the effect of filtration time on the performance of a PVDF membrane for POME filtration at a constant operating pressure of 1 bar. Membrane performance is evaluated based on pure water flux, permeate flux, and permeate turbidity. The findings are expected to provide insights into changes in membrane performance during POME filtration over time.

This article is organized as follows. Section 2 describes the materials and methods used in this study. Section 3 presents and discusses the filtration results. Section 4 presents the conclusions and recommendations.

2. Methods

2.1. Research Design

This study employed a quantitative experimental approach to investigate the effect of filtration time on the performance of the PVDF membrane during POME filtration. The filtration experiments were conducted using a dead-end filtration system at a constant operating pressure of 1 bar. Filtration time was set at 0, 15, 30, 45, and 60 minutes. Membrane performance was evaluated based on pure water flux (J_w), permeate flux (J_p), and permeate turbidity.

The POME filtration experiment consisted of a single filtration run, with measurements collected at different time points during the same run. Accordingly, the results were analyzed descriptively to identify temporal trends under the investigated operating conditions. The observations were not treated as independent experimental replicates.

Table 1. POME turbidity before and after pretreatment

Conditions	Turbidity (NTU)
Before pretreatment	5,060
After pretreatment	405

2.2. Materials

The materials used in this study were POME, the PVDF hollow-fiber membrane, alum (aluminum sulfate), distilled water, and filter paper. POME was used as the feed solution for the filtration process, while the PVDF membrane served as the filtration medium. Alum was used as a coagulant during POME pretreatment to reduce suspended particles before membrane filtration. Distilled water was used for membrane compaction and pure water flux characterization, while filter paper (New Star, Grade 102, 110 mm in diameter) was used to remove suspended solids from the pretreated POME.

The hollow-fiber PVDF membrane was supplied by Hydoki Indonesia and had a pore size of 0.01 μm. The membrane module consisted of seven fibers, each with a length of 0.27 m and an outer diameter of 0.002 m. The effective membrane surface area was 0.01187 m². Filtration was conducted in the outside-in direction, in which the feed passed from the outer surface of the hollow fibers toward their inner lumens.

2.3. POME Pretreatment

The POME sample was pretreated using alum at a concentration of 1 g/L. This concentration was selected based on preliminary jar test results, which identified 1 g/L as the appropriate dosage for turbidity reduction prior to membrane filtration. The POME was rapidly mixed at 150 rpm for 2 minutes, followed by slow mixing at 50 rpm for 30 minutes and settling for 1 hour. The supernatant was then separated and filtered using filter paper to obtain pretreated POME for subsequent membrane filtration. The turbidity values of POME before and after pretreatment are presented in Table 1.

2.4. Membrane Compaction and Pure Water Flux Characterization

Before POME filtration, the PVDF hollow-fiber membrane was conditioned using distilled water at an operating pressure of 1 bar for 30 minutes. After conditioning, distilled water filtration was continued at the same pressure for 60 min. J_w was evaluated at 0, 15, 30, 45, and 60 min.

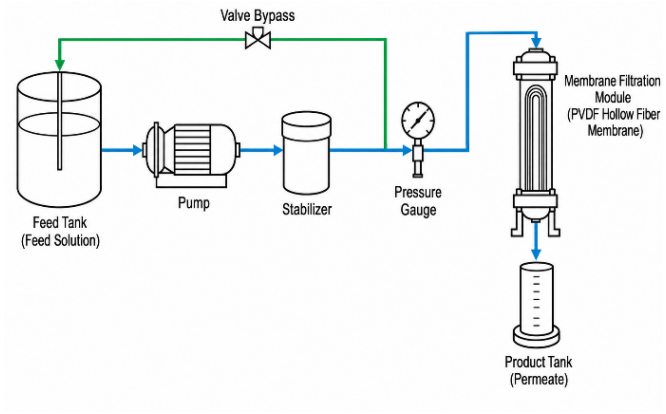


Figure 1. Filtration apparatus setup

At each observation point, the volume of collected permeate and the corresponding collection time were recorded. These measurements were used to calculate J_w. This test was conducted before POME filtration to characterize water permeation through the conditioned membrane.

2.5. POME Filtration and Turbidity Measurement

Following the pure water flux characterization, the pretreated POME was filtered using the PVDF hollow-fiber membrane at a constant operating pressure of 1 bar. Filtration was conducted for 60 min, with measurements taken at 0, 15, 30, 45, and 60 minutes. At each observation point, the permeate volume and corresponding collection time were recorded to calculate J_p. The collected permeate samples were also analyzed for turbidity using a turbidimeter. The filtration apparatus used for both distilled water and pretreated POME filtration is shown in Figure 1.

2.6. Flux calculation

The pure water flux (J_w) and permeate flux (J_p) were calculated based on the permeate volume and corresponding collection time using Equation (1) and (2):

$$J_w = \frac{V_w}{At}, \quad (1)$$

$$J_p = \frac{V_p}{At}, \quad (2)$$

where J_w is the pure water flux (L/m²·h), J_p is the permeate flux (L/m²·h), V_w is the volume of the pure water collected (L), V_p is the volume of the permeate collected (L), A is the effective membrane surface area (m²), and t is the corresponding collection time (h). The effective membrane surface area was determined based on the fiber diameter, fiber length, and number of fibers.

2.7. Data Analysis

The experimental data were analyzed quantitatively by evaluating changes in pure water flux (J_w), permeate flux (J_p), and permeate turbidity at different filtration times. J_w was used to characterize membrane permeability using distilled water, while J_p was used to evaluate membrane performance during POME filtration. Permeate turbidity was used to assess permeate quality and track changes in turbidity throughout the filtration process.

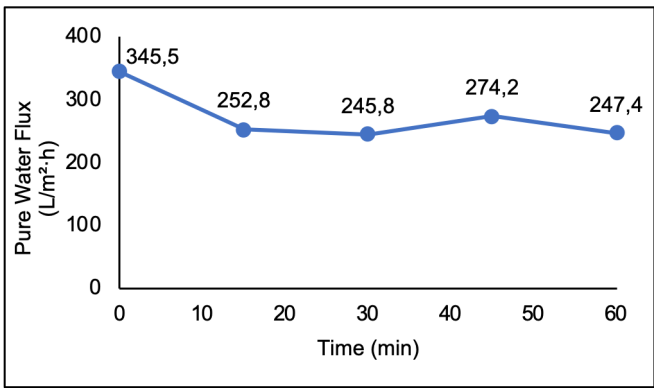


Figure 2. J_w at different measurement time

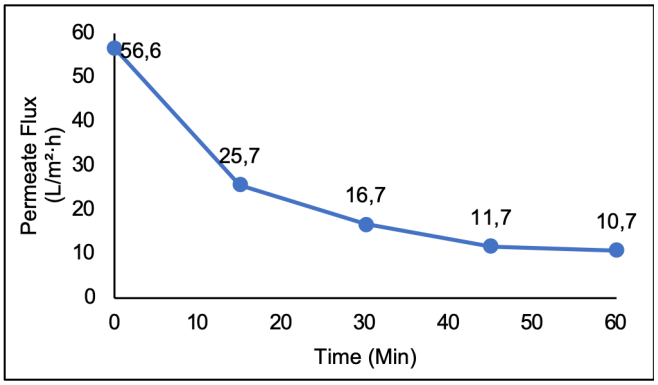


Figure 3. J_p at different filtration time

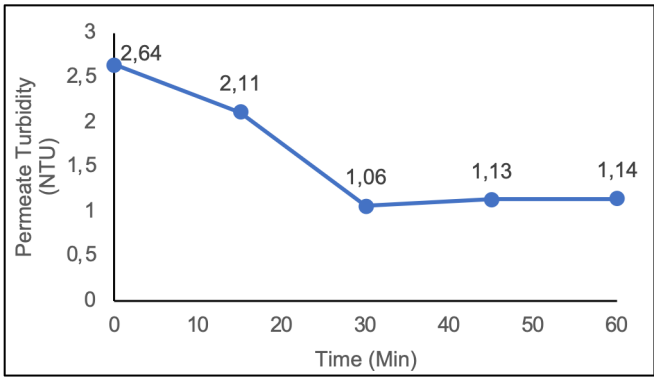


Figure 4. Permeate turbidity at different filtration time

3. Results and Discussion

3.1. Results

The pure water flux (J_w) at different measurement times, the permeate flux (J_p) at different filtration times, and the permeate turbidity at different filtration times are presented in Figure 2, 3, and 4, respectively.

3.2. Discussion

3.2.1. Pure Water Flux Characterization

The pure water flux decreased overall from 345.5 to 247.4 L/m²·h during the 60-minute measurement period. The flux showed a slight increase at 45 minutes before decreasing again at 60 minutes. Since this measurement was conducted before POME filtration, the observed changes represent the behavior of the membrane

during pure water flux characterization rather than the effect of POME filtration time.

The initial decrease in pure water flux may be associated with membrane compaction. Membrane compaction occurs when the polymeric membrane structure is compressed under applied pressure, resulting in pore constriction and increased resistance to water transport. This phenomenon can cause a gradual reduction in membrane permeability and flux during the initial stage of operation (Hung et al., 2022). The relationship between membrane resistance and flux has also been described in pressure-driven membrane filtration, where an increase in total membrane resistance results in a decrease in permeate flux under a constant pressure difference (Yuliwati et al., 2022). Therefore, the initial decrease in pure water flux may reflect the stabilization of the membrane structure under the applied pressure.

However, pure water flux did not decrease continuously, as a temporary increase was observed at 45 min. This fluctuation may be related to variations in membrane wetting or other changes in water transport during measurement. Wypsek et al. (2021) reported that wetting in polymeric hollow-fiber membranes can develop non-uniformly, potentially affecting fluid distribution within the membrane structure. Nevertheless, membrane wetting was not directly monitored in this study. Therefore, it cannot be confirmed as the cause of the observed fluctuation. Further measurements would be required to determine the mechanisms responsible for changes in pure water flux.

3.2.2. Effect of Filtration Time on Permeate Flux

The permeate flux (J_p) decreased continuously with increasing filtration time, from 56.6 L/m²·h at 0 min to 10.7 L/m²·h at 60 minutes. The decrease in permeate flux was more pronounced during the initial 15 minutes, followed by a more gradual decline until 60 minutes. This trend indicates a continuous reduction in permeate trans-port through the PVDF membrane during POME filtration.

Under constant operating pressure, the decrease in permeate flux suggests an increase in resistance to permeate transport through the membrane. This decrease may be associated with the accumulation of suspended solids, colloidal particles, and organic matter on the membrane surface or within its pores. Such accumulation may restrict permeate flow and contribute to increased filtration resistance (Mallah et al., 2024). Ding et al. (2020) reported that PVDF ultrafiltration can involve pore blockage and cake layer formation during filtration. These mechanisms may help explain the flux decline observed in the present study. However, since membrane fouling was not directly characterized, the specific mechanisms responsible for the observed decrease in permeate flux cannot be confirmed.

The permeate flux obtained in this study was lower than that reported by Ahmad et al. (2020), who recorded fluxes of 68.12 L/m²·h at the beginning of filtration and 56.33 L/m²·h after 60 minutes under the same operating pressure of 1 bar. However, differences in feed characteristics, membrane properties, and pretreatment conditions should be considered when comparing the results. Overall, the continuous decrease in permeate flux with increasing filtration time indicates that prolonged filtration reduced permeate transport through the PVDF membrane.

3.2.3. Effect of Filtration Time on Permeate Turbidity

The permeate turbidity decreased from 2.64 NTU at 0 min to its lowest value of 1.06 NTU at 30 minutes, representing a reduction of approximately 59.85% from the initial value. When compared with the pretreated POME turbidity of 405 NTU, the lowest permeate turbidity of 1.06 NTU corresponded to an overall turbidity reduction of approximately 99.74%. This indicates that the pretreatment and PVDF membrane filtration process effectively reduced the turbidity of POME (Arahman et al., 2022). The low permeate turbidity may be associated with the retention of suspended and colloidal particles by the membrane during filtration (Al-Muraisy et al., 2025).

After 30 minutes, permeate turbidity slightly increased to 1.13 NTU at 45 minutes and 1.14 NTU at 60 minutes. This slight increase may reflect changes in particle retention during filtration, although the underlying mechanism could not be determined from the available measurements. Similar variations in permeate turbidity have been reported for PVDF ultrafiltration membranes in association with changes in membrane deposits and fouling conditions (Tomczak et al., 2025). However, this mechanism could not be confirmed because membrane fouling was not directly characterized in the present study. Despite these fluctuations, permeate turbidity remained relatively low during the investigated filtration period.

Although the permeate turbidity remained low, the permeate flux declined from 56.63 to 10.68 L/m²·h, representing a decrease of approximately 81.1%. This decline indicates that maintaining low permeate turbidity did not necessarily correspond to maintaining filtration productivity. The substantial reduction in flux may limit productivity during prolonged filtration. Therefore, filtration performance should be evaluated by considering both permeate quality and flux.

The turbidity reduction achieved in this study can be compared with the 86.20% reduction reported by Ahmad et al. (2020) at an operating pressure of 1 bar, provided that the calculation basis and treatment stages are comparable. Further studies should evaluate suitable fouling-control and membrane-cleaning strategies to determine whether permeate flux can be maintained during prolonged operation.

4. Conclusion

The results showed changes in PVDF membrane performance during the investigated filtration period. Pure water flux decreased from 345.5 to 247.4 L/m²·h during the measurement period, corresponding to a 28.4% decrease. During POME filtration, permeate flux decreased from 56.6 to 10.7 L/m²·h over 60 minutes, representing an 81.1% decrease. The lowest permeate turbidity of 1.06 NTU was observed at 30 minutes, corresponding to a 99.74% reduction relative to the pretreated POME. This reduction reflects the combined effects of alum coagulation, filter paper filtration, and PVDF membrane filtration. Although permeate turbidity increased slightly after 30 minutes, the values remained low throughout the investigated period. The decline in permeate flux suggests

an increase in resistance to permeate transport during filtration.

This study was limited to a single operating pressure, a 60-minute filtration period, and one membrane type without further membrane characterization. Future research should investigate longer filtration periods and different operating pressures, as well as include membrane characterization and additional permeate quality parameters to provide a more comprehensive evaluation of PVDF membrane performance in palm oil mill effluent treatment.

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