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Evaluating the Separation Performance and Efficiency of MF Membranes in Industrial Textile Wastewater Treatment

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ABSTRACT

The rapid growth of the population and industrial development have led to a significant increase in wastewater generation across various sectors. The textile industry stands out as a major contributor to economic growth but also a substantial source of environmental pollution. The typical effluents discharged from textile industries are a complex mixture of dyes, metals, and other pollutants. The presence of high levels of pollutants may overwhelm traditional treatment methods. Therefore, it is necessary to use more advanced techniques such as membrane filtration to treat the wastewater. Membrane technology has recently become famous for wastewater treatment due to its flexibility, high efficiency in removing contaminants, and low energy usage. There are several membrane filtration methods which are extensively used in water treatment procedures, including microfiltration (MF), ultrafiltration (UF), nanofiltration (NF), and reverse osmosis (RO). In this study, the membrane process investigated the effect of feed pressure using a commercial MF flat sheet membrane on the performance of treatment. The pressure of the feed varies from 2 to 10 bar, with a stepwise increment of 2 bar. The water flux was measured using a cross-flow filtration system, and performance was assessed by calculating the water flux and removal efficiencies for total suspended solids (TSS) and turbidity. The results show that the MF membrane has a high removal efficiency of total suspended solids and turbidity. The removal efficiency of TSS ranged from 87.1% to 96.2%, while the removal efficiency of turbidity ranged from 91.2% to 93.7%.

Keywords: Textile wastewater, microfiltration, membrane, crossflow, permeability

1.0 INTRODUCTION

In recent decades, rapid industrialization and economic growth have led to increased industrial pollution and the depletion of natural resources globally. The textile industry stands out as a major contributor to global economic growth and industrialization [1]. It is also one of the most water-intensive industries [2]. Based on the World Bank report, around 17-20% of industrial wastewater is produced by the textile industry [3]. The annual water usage of a single textile plant is between 100,000 and 300,000 m^3 of water [2]. Consequently, the industry produces wastewater in the range of 200 to 350 m^3 per ton of finished product [4]. As water and energy consumption rise, as well as the pollutants released in wastewater, the environmental impact of the textile industry will become increasingly negative.

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Textile wastewater contains a wide range of pollutants. The finishing processes involve various operations that utilize large quantities of inorganic compounds like acids, alkalis as well as organic compounds, including dyes [2]. The substances which are highly water-soluble and toxic such as microbial pathogens and organic dyes can contaminate the natural ecosystem and reduce the availability of clean, fresh water for drinking [5]. Textile wastewater is known for its high pH, salinity, chemical oxygen demand (COD), biochemical oxygen demand (BOD_5), and color [1]. Textile wastewater typically has a pH range of 6 to 10, with high levels of chemical oxygen demand (COD) ranging from 150 to 12,000 mg/L and biological oxygen demand (BOD) levels between 80 and 6,000 mg/L. Due to the complex composition in the wastewater, it is essential to find an appropriate treatment method according to the desired quality of the effluent.

Other than biological treatment, coagulation-flocculation, and ozonation, the membrane process is one of the most effective methods of textile wastewater treatment. Membrane technology is particularly advantageous for treating textile dye wastewater. This is due to the fine pore size of the membrane can remove dye compounds and produce high-quality effluent [6]. The smaller pores can effectively block larger molecules, including many dye compounds. However, the effectiveness of dye removal depends on various factors beyond pore size. This includes the membrane material, which influences dye adsorption, the size of dye molecules relative to the pores and membrane fouling, which can reduce efficiency. Higher pressure may increase water flux but could also allow smaller dye molecules to pass through. Membrane filtration stands out for its efficiency, and purity in achieving desired water quality for reuse. Membrane processes are advanced treatment technologies that require minimal space and are easy to implement, allowing for both chemical recovery and water reuse. Membranes used in wastewater treatment are categorized into microfiltration, ultrafiltration, nanofiltration, and reverse osmosis. MF membranes have a pore size of approximately 0.1–1 μm [7]. They are typically used for dye removal in industrial dye wastewater applications. MF membranes are effective in removing colloidal dyes from dye and wash baths and can treat large volumes of liquid under low transmembrane pressure (≤ 2 bar) due to their high flux [8]. Additionally, MF is cost-effective and environmentally friendly, making it a suitable solution for many environmental challenges. This study assesses the performance of MF membrane filtration in treating textile wastewater, focusing on the effect of varying feed pressures on water flux and removal efficiency through crossflow membrane filtration.

2.0 METHODS

2.1 Materials

The membrane used in this study is a commercial microfiltration (MF) flat sheet membrane obtained from Rising Membrane Technology (Beijing) Co. Ltd. The membrane was used without any alteration. The wastewater in this work was derived from the textile production facility located at Batu Pahat, Johor, Malaysia without further purification and treatment.

2.2 Characterisation of Membrane

The morphology of the membrane was observed by scanning electron microscopy (SEM) model S-3400N by

Hitachi. The membrane was undergone pre-treatment before the scanning. The membrane was cryogenically cracked in liquid nitrogen. The membrane sample was then placed on the metal holder and sputter coated with a layer of gold using a sputter coating machine (Emitech, SC7620) to increase its surface conductivity. Afterward, the membrane sample will be placed into the vacuum chamber with an accelerated voltage of 15kV applied. The morphology of the membrane sample will be observed under different magnifications.

The porosity of the membrane was determined by the gravitational method. In general, the porosity was calculated by the ratio of the pore volume over the total membrane volume. The membrane sample was cut into a predetermined dimension and was weighted for its dry mass (W_2). Subsequently, it was soaked into the iso-butanol for two hours to ensure all the membrane pores were wetted. The weight of the wetted membrane was measured (W_1). The porosity was calculated by the following equation,

$$\mathcal{E} = \frac{\frac{(W_1 - W_2)}{\rho_b}}{\frac{W_1 - W_2}{\rho_b} + \frac{W_2}{\rho_{PES}}} \times 100\%$$

Where $\mathcal{E}$ is the membrane porosity (%), W_1 and W_2 represent the wetted and dry membrane weight (g), respectively, ρ_{PES} is the density of PES (1.37 g/cm^3) whereas ρ_b is the density of iso-butanol (0.802 g/cm^3). The procedure of the porosity determination was repeated three times to yield an average.

2.3 Crossflow MF Membrane Filtration

Cross-flow filtration (Figure 1) is employed in this study to evaluate the performance of the MF membrane in the treatment of industrial textile wastewater. The wastewater is first contained in the feed tank. The wastewater is pumped to the cross-flow membrane module with the assistance of an atomized pump (Walrus TH400P) with a constant flow rate of 6 LPM. The MF membrane with an effective surface area of 0.004275m2 was placed into the membrane module and tightly sealed with a gasket to prevent leakage. The cross-flow filtration is conducted under the constant flow rate with varying the pressure from 2 to 10 bar with a stepwise increment of 2 bar. The permeate will be collected in the permeate tank whereas the untreated wastewater will be recirculated to the feed tank.

The permeate water flux produced by the MF membrane can be determined by the following equation,

$$J = \frac{Q}{At}$$

where J is the water flux (L/m^2.hour), Q is the quantity of permeate (L), A is the filtration area (m^2), and t is the time (hour). The water flux sampling procedures were repeated three times to ensure its reproducibility.

Apart from the water flux, the performance of the membrane also be determined by its separation efficiency. The separation efficiency determines the proportion of material that is filtered out by the system compared to the amount of material that enters the system and is calculated by the following equation.

$$\eta = \frac{NTU_i - NTU_f}{NTU_i} \times 100\%$$

where η is the separation efficiency, NTU_i and NTU_f are their initial and final Nephelometric Turbidity Units (NTU), respectively.

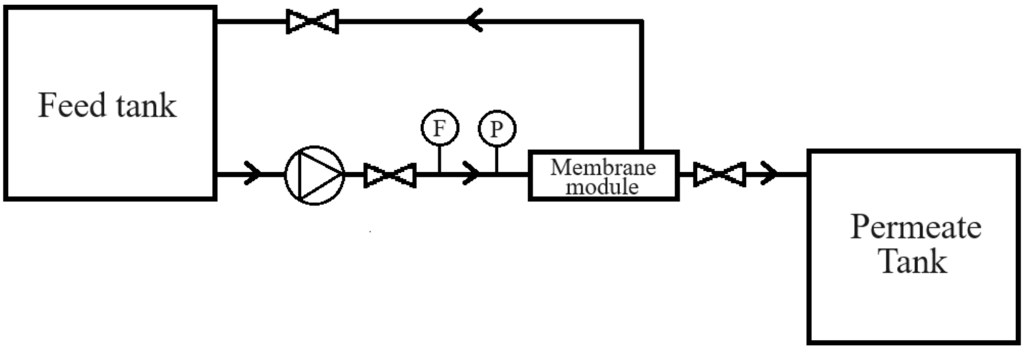


Figure 1 MF membrane crossflow filtration schematic diagram

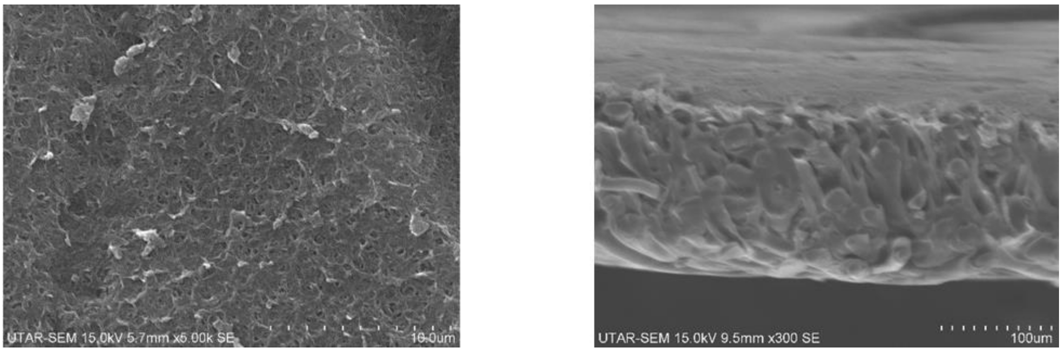
3.0 RESULTS AND DISCUSSION

3.1 Membrane Characteristics

The membrane surface morphology was carefully examined by SEM (Figure 2). The SEM images in Figure 2(a) show the top surface of the MF membrane, while Figure 2(b) displays the cross-sectional view. Figure 2(a) appears relatively smooth and homogeneous without visible defects like pinholes or cracks. However, minor surface irregularities may be present, which is typical in commercial membranes. This indicates the surface of the membrane was well-defined and good fabrication process which led to no signs of physical damage or degradation. The absences of impurities on the MF membrane surface ensure a good filtration performance and would not jeopardize the membrane performance.

In Figure 2(b), the cross-sectional morphological analysis reveals that the MF membrane exhibits a structure typical of MF membranes, with a dense top layer and a porous sublayer. The membrane structure shows characteristics of a symmetric MF membrane with some variations in pore distribution and density [9]. Specifically, all of the membranes had a dense top layer with a sponge-like structure and a porous sublayer with a finger-like structure. This sublayer provided mechanical support, while the dense top layer regulated the permeation and rejection of solutes [10]. Additionally, the sublayer exhibited macro voids and finger-like cavities.

On the other hand, the membrane porosity of MF membrane recorded in this study is 31.01 ± 0.38%, indicating the porosity appeared to be lower than the literature range but still acceptable [11].

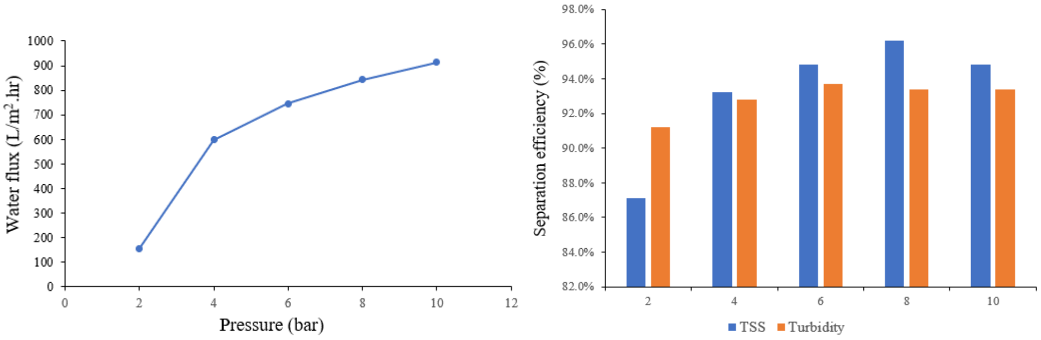


(a) (b)

Figure 2 Morphology of MF membrane by SEM image, a) Top surface at 5.00k magnification, and b) Cross sectional view at 300 magnification

3.2 Effect of Pressure on the Water Flux Performance of MF Membrane Filtration

The water flux results for varying feed pressure in MF membrane filtration are illustrated in Figure 3a. The result indicates a trend as the feed pressure if in directly proportional to the water flux. This phenomenon is attributed to the increased cross-flow velocity and shear force at the membrane surface, which minimize external concentration polarization near the membrane surface during filtration [12, 13, 14]. Higher shear forces associated with greater feed pressure effectively dislodge solids accumulating on the membrane surface, reducing membrane fouling [15]. The increase in feed pressure also enhances the mass transfer coefficient of the feed. As a result, higher average water flux and a stronger net driving force are achieved at higher feed pressure This is partly because the feed recovery rate is relatively lower at higher feed pressures, leading to a lower average bulk feed concentration [16, 17].



(a) (b)

Figure 3 Wastewater separation performance at feed pressure of 2, 4, 6, 8, and 10 bar (a) Water flux, and (b) Separation efficiency

Table 1 Properties of industrial textile wastewater before and after the MF membrane filtration

Properties	**Initial**	**2 bar**	**4 bar**	**6bar**	**8 bar**	**10 bar**
TSS (mg/L)	44.1 ± 9.8	5.7 ± 1.2	3.0 ± 0.8	2.3 ± 0.6	1.67 ± 0.8	2.3 ± 0.9
Turbidity (NTU)	45.7 ± 3.2	4.0 ± 1.8	3.3 ± 0.7	2.9 ± 1.1	3.0 ± 0.4	3.0 ± 1.1

The properties of the industrial textile wastewater before and after MF membrane filtration are presented in Table 1. The results indicate a significant reduction in suspended solids, demonstrating the membrane's effectiveness as a barrier in water separation, allowing only clear water to pass through as permeate [18]. The separation efficiency for total suspended solids (TSS) ranged from 87.1% to 96.2%, while turbidity reduction exceeded 91.2% (Figure 2). These findings suggest that the MF membrane has good separation efficiency for these parameters, highlighting its potential for application in wastewater treatment.

4.0 CONCLUSION

This study has determined the performance of MF membranes in industrial textile wastewater treatment. SEM analysis suggested that the MF membrane surfaces are free from defects. The membranes exhibited an asymmetric structure with a dense top layer and a porous sublayer, typical of

MF membranes, providing both mechanical support and efficient filtration. The water flux performance under varying feed pressures showed that increased pressure leads to higher water flux due to enhanced cross-flow velocity and shear force, which mitigate external concentration polarization and membrane fouling. Additionally, higher feed pressures improved the mass transfer coefficient, resulting in a stronger net driving force and more efficient filtration. Furthermore, the MF membrane demonstrated significant separation efficiency, with TSS removal ranging from 87.1% to 96.2% and turbidity reduction exceeding 91.2%. These results underscore the membrane's potential for effective wastewater treatment, ensuring high-quality permeate and operational reliability. In summary, MF membranes offer a promising solution for industrial textile wastewater treatment, combining high separation efficiency with durability and reliability.

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CONFLICTS OF INTEREST

The authors declare that there is no conflict of interest regarding the publication of this paper.

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