J. Applied Membrane Science & Technology, Vol. 27, No. 3, December 2023, 111-117

Industrial Textile Wastewater Treatment by Crossflow NF Membrane Filtration

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Submitted: 17/10/2023. Revised edition: 9/11/2023. Accepted: 9/11/2023. Available online: 20/11/2023

ABSTRACT

Ineffective dyeing procedures frequently lead to the release of approximately 10–50% of the dye applied, which does not adhere to the fabric and is consequently discharged into the environment along with the effluent. This situation is undesirable both for potential recycling within the textile manufacturing process and because of its adverse environmental pollution effects. This study thoroughly examines nanofiltration (NF) membrane characteristics and their performance in textile wastewater treatment. Pristine NF membrane surfaces were revealing a web-like structure with well-defined pores predominantly in the membrane active region. This assessment confirms the membrane initial cleanliness, free from any external contaminants, which is vital for effective membrane-based filtration. Additionally, the study investigates how different feed flow rates affect water flux during NF membrane filtration. The results demonstrate a clear relationship, where the increasing flow rates boost water flux. This can be attributed to heightened cross-flow velocity and shear force on the membrane surface due to the increased water flux, minimizing external concentration polarization and reducing membrane fouling. The impact of feed flow rate on membrane separation efficiency is also examined, showing consistent efficiency at feed flow rates between 2 LPM and 5 LPM (approximately 80.8% to 82.22%). However, efficiency drops as the feed flow rate increases from 5 LPM to 6 LPM, likely due to increased pressure drop across the membrane, affecting separation efficiency.

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

1.0 INTRODUCTION

The textile industry encompasses the design, development, production, and distribution of textiles, fabrics, and apparel, playing a significant role in Malaysia economy. In 2021, the textile and clothing sector's contribution to the Malaysian GDP experienced a remarkable surge, reaching an impressive growth rate of 93.6% [1]. The industry contributed 1.70% to the manufacturing sector with over 662 factories involved in textile production [2]. The variation in textile application techniques among industries makes it challenging to standardize the properties of textile wastewater [3]. Typically, wastewater from the textile industry contains numerous chemical compounds, auxiliaries, elevated levels of suspended solids, extreme COD, varying pH values, and heavy metals. Inefficient dyeing processes often

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DOI: https://doi.org/10.11113/amst.v27n3.281

result in approximately 10–50% of the applied dye not binding to the fabric, leading to the discharge of unused dye into the environment with the effluent [4]. This is undesirable both for recycling in the textile manufacturing process and due to its environmental pollution impact [5].

Nanofiltration (NF) was first introduced in 1984, employs nanometer-sized pores to separate particles from water. NF is increasingly used in water treatment, outpacing reverse osmosis (RO) in various sectors. It's also vital for recovering fine chemicals in pharmaceutical and feed additive industries [6]. In the NF membrane process, the incoming feed stream is divided into two components: the permeate, which is the filtered portion, and the retentate, which consists of the unfiltered content. NF employs two mechanisms, referred to as ionic separation and sieving, to separate solutes from the solution. NF is experiencing rapid adoption in water treatment, wastewater treatment, and various industries, gradually becoming the prevailing separation technology [7]. Consequently, NF is replacing RO in multiple sectors to enhance profit margins, such as in chemical industry applications involving chemical or solute separation and biomaterial production. Additionally, NF is commonly used to recover fine chemicals from outlet streams in drug and feed additive industries [8]. To support the textile industry manufacturing processes, a reliable water supply is essential. Utilizing treated textile wastewater for dyeing and washing can meet the high water demand, but this wastewater often contains organic and inorganic pollutants, including heavy metals, posing risks to the environment [9].

This study assesses NF membrane filtration performance in wastewater treatment through laboratory experiment under the effect feed flow rate.

2.0 METHODS

2.1 Materials

Commercial NF flat sheet membrane (NF1) was purchase from Rising Membrane Technology (Beijing) Co. Ltd. and use without modification. The wastewater used in this study is derived from a textile production factory located in Batu Pahat, Johor, Malaysia.

2.2 Characterisation of Membrane

The membrane morphology was examined using a scanning electron microscope (SEM) (Hitachi S-3400N). To prepare the sample, the membrane was initially cryogenically fractured into smaller pieces using liquid nitrogen. These samples were then placed on a sample holder and coated with gold using a sputter coating machine (Emitech, SC7620) to improve conductivity. Subsequently, the pristine NF membrane surface were observed and imaged at magnifications of 5,000x, 10,000x, and 15,000x under an accelerated voltage of 15 kV.

2.3 Crossflow NF Membrane Filtration

In the treatment of textile wastewater, a cross-flow filtration unit was employed. The raw textile wastewater was stored in a large tank adjacent to the unit and its properties were tabulated in Table 1. To transfer the raw wastewater, an atomize pump (Walrus TH400P) was employed, pumping it into the cross-flow filtration unit. The NF membrane was situated within a membrane holder, with an effective membrane surface area of 0.004275m^2 (Figure 1). This project focus was on investigating the impact of feed flow rate and pressure on NF membrane filtration. The NF membrane filtration was conducted under five different feed flow rates: 2, 3, 4, 5, and 6 LPM, all at a constant pressure of 7 bar. Water flux, representing the rate of water passing through the membrane's surface area, was determined using the following equation,

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

Where J is the water flux (L/m^{2}hr), Q is the amount of permeate collected (L), A is the membrane area (m^2) and t is the sampling time (hr). The experimental procedures were repeated three times to yield the average in ensuring the reproducibility of the results.

Table 1 Properties of industrial textile wastewater

Properties	Value
pH	6.87 ± 0.2
TSS	33 ± 16
TDS	520 ± 20
Turbidity (NTU)	27 ± 12

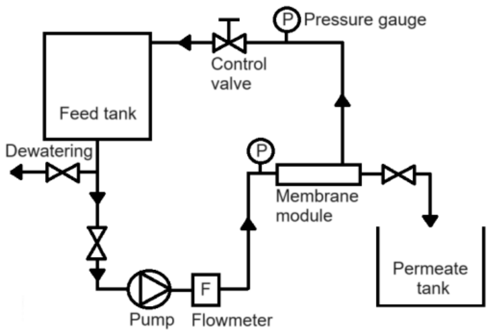

Figure 1 NF membrane crossflow filtration schematic diagram

3.0 RESULTS AND DISCUSSION

3.1 Membrane Characteristics

The SEM images of the pristine membrane surface, magnified at 5.0 K, 10.0 K, and 15.0 K (Figure 2), provide valuable insights into the membrane's original condition. The detailed examination showed a web-like structure with discernible pores, primarily located in the active area of the NF membrane. These observations are significant as they illustrate the initial state of the membrane before any filtration processes were applied. The web-like structure and well-defined pores on the membrane surface indicates that it was free from any foreign contaminants such as dust or dirt particles. This cleanliness is critical in membrane-based filtration processes where the presence of impurities can hinder the effectiveness and lifespan of the membrane [10, 11]. The absence of contaminants in the pristine NF membrane enhances its filtration performance and ensures that the processes it is involved in are not compromised by external particles [12].

3.2 Effect of Feed Flow Rate on the Water Flux Performance of NF Membrane Filtration

The results of water flux of the feed flow rate in the cross-flow filtration are depicted in Figure 3. It is observed from the graph overall trend that as the flow rate increased, water flux also increased.

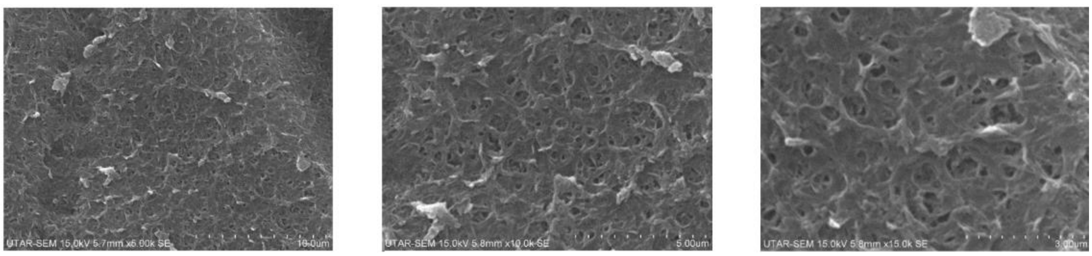

Figure 2. SEM images pristine NF membrane surface under different magnification, a) 5k, b) 10k, and c) 15k

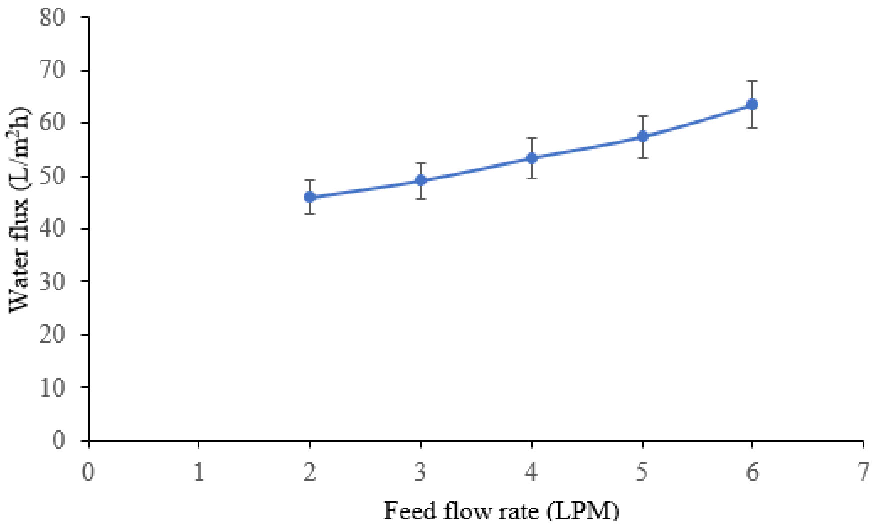

Figure 3. Water flux of NF membrane filtration at feed flow rate of 2, 3, 4, 5, and 6 LPM

This observation can be attributed to the rising cross-flow and shear force at the membrane surface due to increased water flux [13]. This effect serves to minimize external concentration polarization, which refers to the localized fluctuation in solution concentration near the membrane surface during filtration [14]. Moreover, the higher shear forces associated with a greater feed flow rate effectively dislodge dirt particles that accumulate on the membrane surface during filtration, mitigating the issue of membrane fouling. Additionally, the increase in cross-flow velocity due to the rising feed flow rate enhances the mass transfer coefficient of the feed [15, 16]. Consequently, higher average water flux and a stronger net driving force can be achieved at higher feed flow rates [17]. This is partly because the feed recovery rate is relatively lower at higher feed flow rates, resulting in a lower average bulk feed concentration [18].

However, it's worth noting that the increase in water flux is directly proportional to feed flow rate from 3 to 6 LPM. The increase in water flux suggesting that the shear force exerted by the higher feed flow rate was adequate to overcome the particle accumulation limit on the membrane surface, leading to the increment of water flux as feed flow rate increases [19]. In Figure 4, the membrane separation efficiency graph against the filtration feed flow rate is displayed. This efficiency was calculated based on the initial and final turbidity values of the samples. The graph indicates that membrane separation efficiency remained relatively stable as the feed flow rate increased from 2 LPM to 5 LPM, fluctuating between 80.8% and 82.2%. However, a noticeable drop in separation efficiency occurred as the feed flow rate increased from 5 LPM to 6 LPM, falling from 82.2% to 76.9%. One plausible explanation is that the higher feed flow rate led to increased pressure drop across the membrane, resulting in reduced separation efficiency at the higher flow rate [20].

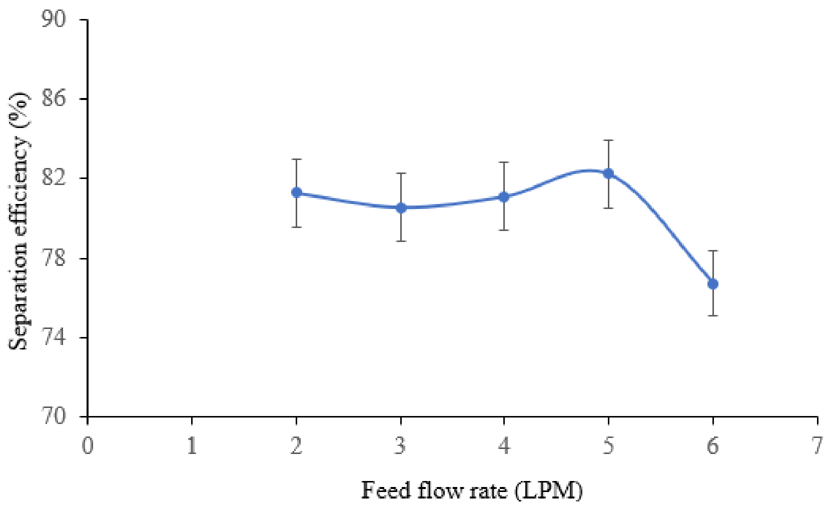

Figure 4. Separation efficiency of NF membrane filtration at feed flow rate of 2, 3, 4, 5, and 6 LPM

4.0 CONCLUSION

The pristine membrane showcased a well-defined web-like structure with discernible pores primarily concentrated in the active area of the membrane. These findings underscore the absence of foreign contaminants such as dust or dirt particles on the membrane's surface, which holds significant importance in membrane-based filtration processes. The investigation into the impact of feed flow rate on water flux performance, disclosed valuable insights. It was evident that an increase in flow rate led to higher water flux, attributed to elevated cross-flow velocity and increased shear forces at the membrane surface. This effect played a crucial role in minimizing external concentration polarization and efficiently dislodging dirt particles that accumulated on the membrane during filtration, thereby mitigating membrane fouling. Furthermore, the rise in cross-flow velocity due to increased feed flow rates enhanced the mass transfer coefficient of the feed, resulting in higher water flux and a stronger net driving force. Although an increase in water flux became less significant at certain feed flow rates (3, 4, and 5 LPM), potentially due to membrane fouling, it was ultimately restored at 6 LPM. This restoration suggested that the shear forces exerted by a feed flow rate of 6 LPM were sufficient to overcome the particle accumulation limit on the membrane surface. In summary, the study findings contribute to enhancing the efficiency of water treatment processes and, ultimately, the sustainability of the textile industry.

ACKNOWLEDGEMENT

The authors would like to thank Sincerely Dyeing & Finishing Sdn. Bhd., Johor for providing facilities and guides to finish this project.

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