

ORIGINAL ARTICLE

The Effect of Fiber Thickness of Styrofoam Made Using Rotary Forcespinning for Water Filter Applications

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ABSTRACT – The increasing demand for clean water and the growing accumulation of plastic waste have driven the development of sustainable and efficient water filtration technologies. This study investigates the effect of fiber membrane thickness on the water filtration performance of styrofoam-based nanofiber membranes fabricated using the rotary forcespinning method. Waste styrofoam was dissolved in d-limonene to produce a 28% w/w polymer solution, which was subsequently spun into fibers without the application of high voltage. The resulting fibers were pressed into membranes with thickness variations of 0.35 mm, 0.75 mm, and 1.20 mm. Membrane morphology was analyzed using scanning electron microscopy (SEM), while filtration performance was evaluated through flux and filtration efficiency tests under air pressures up to 30 kPa. The results show that increasing membrane thickness leads to a decrease in water flux but an improvement in filtration efficiency. The membrane with a thickness of 0.35 mm exhibited the highest flux, comparable to the glass fiber membrane used as a control, whereas thicker membranes demonstrated average filtration efficiencies of approximately 90%. SEM observations confirmed that the pressing process increased fiber density without damaging the fiber structure. These findings indicate that styrofoam waste-derived nanofiber membranes produced via rotary forcespinning have strong potential as effective and sustainable water filtration materials, with membrane thickness playing a critical role in balancing flux and filtration efficiency.

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INTRODUCTION

The availability of clean water is a global strategic issue that remains a serious challenge, particularly in developing countries with rapid population growth and industrial activity. The increasing pollutant load in water sources demands water treatment technologies that are not only effective in removing contaminants but also economical, sustainable, and applicable at various scales. In this context, membrane technology is rapidly developing as a filtration solution due to its ability to efficiently separate particles, microorganisms, and dissolved substances without the need for excessive chemicals [1,2].

Nanofiber-based membranes have attracted widespread attention over the past decade due to their superior structural characteristics, such as high specific surface area, high porosity, and the ability to control pore size and distribution. This combination of characteristics enables high water flux and good particle removal efficiency, making them highly promising for water filtration and wastewater treatment applications [1,6]. Several recent studies have reported that nanofiber membranes can improve filtration performance compared to conventional membranes, particularly in microfiltration and ultrafiltration applications [3,8].

Electrospinning is the most commonly used technique for nanofiber production due to its ability to produce fibers with very small diameters and relatively uniform morphology. However, this method has significant limitations, including low production rates, high voltage requirements, and limitations in the types of materials that can be stably processed [6]. These limitations have driven the development of more productive and economical alternative methods, such as centrifugal-based techniques, including rotary force-spinning or centrifugal spinning. This method enables nanofiber production at higher rates, lower energy consumption, and greater material flexibility [7,8].

Along with the development of membrane technology, environmental issues related to plastic waste are also becoming increasingly pressing. Expanded polystyrene (EPS), or styrofoam, is a type of plastic waste that is difficult to degrade and still has a low recycling rate. Efforts to utilize EPS as a raw material for nanofiber membranes not only contribute to reducing plastic waste but also create value-added functional materials for environmental applications. Recent research has shown that EPS can be processed into nanofibers with competitive filtration performance for both air and water applications [5].

The performance of nanofiber membranes is significantly influenced by structural parameters, one of which is membrane thickness. Thickness plays a crucial role in determining the relationship between flux and particle removal efficiency. Thinner membranes generally produce higher flux but potentially decrease filtration efficiency, while thicker membranes tend to increase removal efficiency at the expense of reduced flux and increased fouling risk [1,7]. Therefore, optimizing membrane thickness is crucial in developing nanofiber membranes for practical and sustainable water filtration applications.

Several previous studies have discussed the influence of rotary forcespinning process parameters on fiber morphology, such as rotation speed, solution viscosity, and solvent evaporation conditions [7]. However, studies specifically linking variations in the thickness of styrofoam waste-based nanofiber membranes to water filtration performance, particularly flux and particle removal efficiency, are still limited, especially in the context of utilizing high-capacity production methods such as rotary forcespinning.

Based on this background, this study aims to analyze the effect of the thickness of styrofoam nanofiber membranes produced using the rotary forcespinning method on water filtration performance. The main focus of this study includes the quantitative relationship between thickness, fiber morphology, filtration flux, and particle removal efficiency. The novelty of this study lies in the integration of the concept of upcycling styrofoam waste with the optimization of the structural parameters of nanofiber membranes based on high-throughput production methods, so that it is expected to provide both scientific and practical contributions in the development of sustainable water filtration technology [4,5,9,10].

EXPERIMENTAL METHOD

Materials and Instruments

The main materials used in this study were waste styrofoam obtained from unused styrofoam waste collected from the surrounding environment, and d-limonene as a solvent, which was used without further treatment. Styrofoam serves as the raw material for forming polymer fibers, while d-limonene is used to dissolve the styrofoam in the precursor solution preparation process.

The equipment used in the precursor solution preparation process included a spatula, beakers, an analytical balance (As One Corporation, Japan) for weighing materials with high accuracy, and a magnetic stirrer for homogenizing the solution during the styrofoam dissolution process. The fiber spinning process was carried out using a rotary force-spinning tool, which consists of a syringe with an inner diameter of 1.5 cm, a syringe pump (Harvard Apparatus, USA) to regulate the solution flow rate, a motor controller, a reservoir, and aluminum foil as a fiber collector.

For the membrane formation process, a hydraulic press was used, which functions to press the spun fibers to make them denser and form a membrane structure. In the filtration testing stage, a set of filtration test equipment was used, consisting of an air compressor as a pressure supplier, a HEPA filter to filter air from the compressor, a flow control valve, a digital pressure readout, a 1 L capacity reservoir as a container for the test solution, a filter holder as a membrane holder, and a 500 mL measuring cup to hold the filtered solution. In addition, a BC-500 balance was used to determine the mass of the permeate solution, as well as a UV-Vis spectrophotometer to analyze the concentration of dissolved substances in the feed and permeate solutions.

Method and Procedure

The research began with the preparation of a styrofoam d-limonene precursor solution. Styrofoam waste was first cut into small pieces, then weighed and dissolved in d-limonene at a concentration of 28% w/w, using a 5:2 ratio of styrofoam to d-limonene. The solution was then stirred using a magnetic stirrer at 85°C for 4 hours until a homogeneous solution was obtained.

The homogeneous solution was then transferred to a 5 mL syringe with a needle diameter of 0.6 mm, which was then placed in the syringe holder of a rotary forcespinning machine.

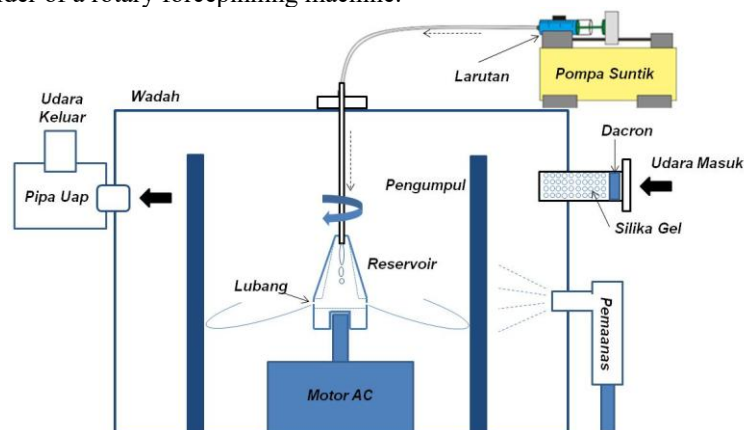


Figure 1. Rotary Forcespinning.

The spinning process was carried out without the use of high voltage, making this technique more environmentally friendly and capable of spinning both conductive and non-conductive materials into fibers. The resulting fibers were collected on aluminum foil until a sufficient quantity was obtained.

The forspinning fibers were then processed using a hydraulic press into membranes with varying thicknesses of 0.3 mm, 0.75 mm, and 1.20 mm. The pressing process was carried out at varying pressures, resulting in membranes with varying density characteristics.

Water filter testing was conducted through flux and efficiency tests using fiber membranes mounted on a filter holder. The test solution was flowed at varying pressures up to 30 kPa, and the resulting filtrate volume was recorded to determine the flux value. Efficiency testing was conducted using an antacid suspension whose particle size had been characterized. The filtrate concentration before and after filtration was analyzed using a UV-Vis spectrophotometer at a wavelength of 322 nm to determine the membrane's filtration capacity.

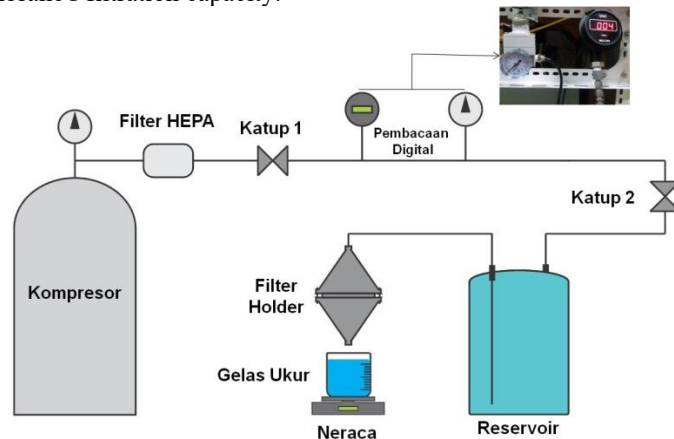


Figure 2. Filtration test equipment for flux test

RESULT AND DISCUSSION

In this study, the fibers made into membranes were produced through a rotary forspinning process. The solution used to produce the fibers was styrofoam with a concentration of 28% w/w. The results of the fibers used to form the membranes before and after pressing can be seen in Figure 2. The images were taken using SEM. The SEM images in Figure 2 show that (a) of the fiber before processing and (b) of the fiber after being pressed did not damage the fibers, but after pressing, the initially loose fibers became more compact. From the images it can also be seen that the styrofoam fibers were not damaged after being pressed. This is advantageous, as styrofoam is a widely available waste material that is easy to find.

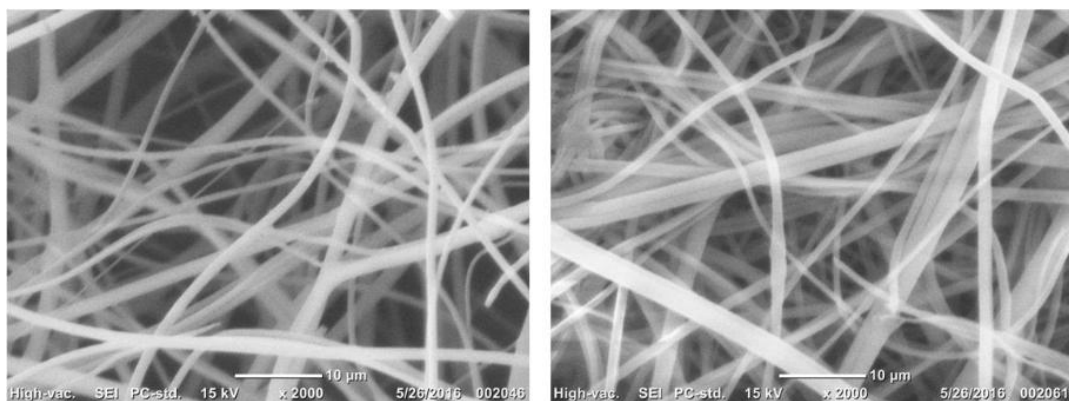


Figure 3. SEM Images (a) Fiber before pressing (b) Fiber after pressing.

In this test, the styrofoam fibers that had been made for filtration tests with varying thicknesses were inserted into the filter holder. Air from the compressor was first flowed without filling it with water for five minutes, in order to minimize contamination from impurities in the air. During the testing process, ensure that there is no air leakage whatsoever.

Data collection for thickness variations was carried out every minute for each applied air pressure, and the volume of water released was recorded, as shown in the following table.

Table 1. Effect of pressure on flux for different thicknesses

Tekanan (kPa)	Fluks ($\times 10^{-3}$ L/Jam.m ²)			
	0,35 mm	0,75 mm	1,20 mm	GF/b, 0,67mm
2	1,08	0,64	0	0
4	6,88	1,13	0	0,10
6	10,31	1,70	0,27	2,44
8	12,05	2,16	0,87	6,69
10	15,49	2,62	1,26	9,73
12	18,49	3,36	1,51	11,66
14	21,61	4,09	2,23	15,72
16	25,07	4,70	3,11	19,27
18	29,94	5,40	3,89	20,98
20	35,18	6,04	4,97	23,61
22	40,37	7,11	6,43	27,00
24	41,82	8,28	8,18	30,59
26	47,78	10,53	9,48	32,87
28	53,01	12,26	10,44	35,64
30	55,27	14,33	12,60	37,42

Table 1 shows the relationship between operating pressure (2–30 kPa) and flux values for styrofoam membranes with thicknesses of 0.35 mm, 0.75 mm, and 1.20 mm, as well as the control glass fiber membrane (GF/b) with a thickness of 0.67 mm. In general, all membrane variations exhibit an increase in flux with increasing pressure. This behavior is consistent with the basic principle of pressure-driven filtration, where a higher driving force enhances the rate of water permeation through membrane pores.

However, significant differences are observed among the membrane thicknesses. The 0.35 mm membrane exhibits the highest flux values across the entire pressure range. At 30 kPa, the flux reaches 55.27×10^{-3} L/h·m². The thinner membrane results in lower flow resistance, allowing water to pass more easily through the membrane structure. This indicates that the diffusion distance and flow path length are shorter compared to thicker membranes. For the 0.75 mm membrane, the flux increases linearly with pressure but remains consistently lower than that of the 0.35 mm membrane. At 30 kPa, the flux reaches 14.33×10^{-3} L/h·m². This decrease is attributed to the increased membrane thickness, which leads to greater hydraulic resistance. The 1.20 mm membrane, being the thickest, shows the lowest flux at low pressures, even approaching zero at 2–4 kPa. This indicates that at low pressures, the driving force is insufficient to overcome the structural resistance of the membrane. At 30 kPa, the flux increases to 12.60×10^{-3} L/h·m², but it remains significantly lower than that of the thinner membrane. The control GF/b membrane (0.67 mm) shows a significant increase in flux with increasing pressure, reaching 37.42×10^{-3} L/h·m² at 30 kPa. Although this value is still lower than that of the 0.35 mm styrofoam membrane, it is higher than those of the 0.75 mm and 1.20 mm membranes. This indicates that pore structure and material characteristics strongly influence permeability, not merely membrane thickness.

The reduced rate of flux increase within the pressure range of 22–24 kPa is associated with the initial membrane compaction phenomenon under moderate pressure, which temporarily increases hydraulic resistance. Once the pressure exceeds 24 kPa, the higher driving force overcomes this resistance, causing the flux to increase significantly again. This phenomenon indicates that the membrane response to pressure is not entirely linear and is influenced by pore structure dynamics during the filtration process. Such behavior is normal in fiber-based filtration systems and does not indicate system failure, but rather a structural response to applied pressure. The efficiency value of the membrane can be seen in the following table.

Table 2. Membrane Thickness Efficiency

Time (Second)	Test Sample GF/B	Efficiency(%)		
		Thick 0,35 mm	Thick 0,75 mm	Thick 1,20 mm
2	0	70,17	79,35	83,38
4	0	83,03	79,69	89,08
5	94,53	93,57	95,25	95,25
10	94,00	94,32	95,18	95,29
15	96,50	93,54	93,61	94,5
20	75,30	93,61	94,34	95,52

The membrane efficiency under pressure variation was recorded during the first two minutes and the following two minutes, and subsequently every five minutes for four measurements. The efficiency measurement results using UV–Vis on the test solution were determined using Equation (1) below.

$$R = \left(1 - \frac{C_p}{C_f} \right) \times 100\% \quad (1)$$

C_f = Concentration of the feed solution before filtration

C_p = The concentration of the permeate solution after filtration.

R = Efficiency (%)

For example, in the test at the 5th minute for the membrane with a thickness of 0.35 mm, the following results were obtained: $C_f = 1$, $C_p = 0,0547$, so that :

$$R = \left(1 - \frac{C_p}{C_f} \right) \times 100\% \quad (2)$$

$$R = \left(1 - \frac{0,05}{1} \right) \times 100\%$$

$$R = 0,9453 \times 100\%$$

$$R = 94,53\%$$

This value is consistent with the data presented in Table 2. (efficiency $\approx 94,53\%$).

From the data, a graph is made as in Figure 3(b). The membrane efficiency value in the first four minutes is below 90%, only after five minutes the efficiency value is above 90%. In the first minute the magnetic rod rotates the solution on the surface so that it becomes flat (cake fouling). This causes small particles to pass into the inside of the membrane (fouling depth), the particles that pass cause a high flux but the efficiency value decreases. The next five minutes the particles that pass accumulate on the inside of the membrane so that the flux becomes low and the efficiency becomes high.

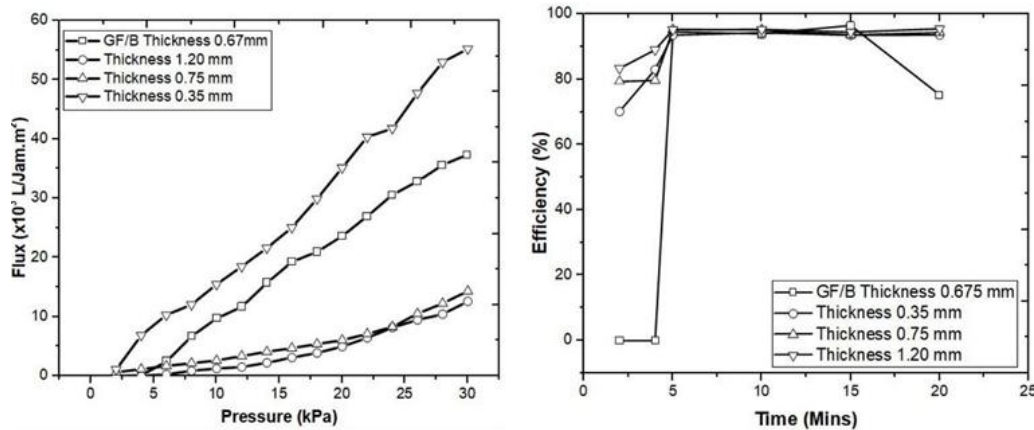


Figure 4. (a) Graph of pressure against flux

(b) Graph of Time against Efficiency

CONCLUSION

Styrofoam fibers with thickness variations, namely styrofoam membranes with thicknesses of 0.35 mm, 0.75 mm, and 1.20 mm used as water filtration membranes were successfully synthesized. Optimal fiber characteristics were obtained in membranes with a concentration of 28% w/w. This membrane demonstrated the ability to purify water.

The results of characterization and filtration testing indicate that fiber membranes with a concentration of 28% w/w have strong potential to be applied as effective water filtration membranes. The 28% w/w concentration was selected because, at this concentration, the styrofoam solution possessed sufficient viscosity to form continuous fibers without the formation of beads or fiber breakage during the spinning process. SEM observations presented in the manuscript show that at 28% w/w, the fibers exhibited relatively uniform and continuous morphology and did not experience structural damage after the pressing process.

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REFERENCES

- [1] S. Shi, W. Bai, X. Chen, Y. Si, C. Zhi, H. Wu, Y. Su, B. Fei, C.-W. Kan, and J. Hu, “Advances in nanofiber filtration membranes: From principles to intelligent applications,” *Advanced Functional Materials*, vol. 35, no. 27, 2025.
- [2] “A review Bahramian, M., Abdouss, M., Aghababaei, N., & Shakiba, M. (2025). *A review of advanced water treatment with polyurethane nanofiber membranes: Current advances and future directions*. Journal of Environmental Chemical Engineering, 13(6), 119442.
- [3] A. Rianjanu, “Recent advances in electrospun nanofiber membranes for dye filtration: A focused mini-review,” *Environmental Chemistry and Safety*, vol. 1, no. 2, 2025.
- [4] M. Jiang, C. Jing, C. Lei, *et al.*, “A bio-based nanofibre hydrogel filter for sustainable water purification,” *Nature Sustainability*, vol. 7, pp. 168–178, 2024.
- [5] B. H. Arrosyid, A. Zulfi, S. Nur’aini, *et al.*, “High-efficiency water filtration by electrospun expanded polystyrene waste nanofibers,” *ACS Omega*, vol. 8, no. 26, pp. 23664–23672, 2023.
- [6] M. H. Mobarak, “Progress and prospects of electrospun nanofibrous membranes as solutions to global water issues,” *Desalination*, 2024.
- [7] A. Pakolpakçıl, “Optimization of the centrifugal spinning parameters to achieve high-performance nanofibers for filtration,” *Nanomaterials*, vol. 13, no. 24, 2023.
- [8] R. Sarbatly, “An overview of recent progress in nanofiber membranes for liquid separation,” *Nanomaterials*, vol. 12, no. 17, Art. no. 2919, 2022.
- [9] H. Sosiati, F. Ramadhan, and M. B. N. Rahman, “Fabrication and characterization of PVC-based nanofiber membranes for water filtration application,” *Semesta Teknika*, vol. 26, no. 1, pp. 78–85, 2023.
- [10] “A El-Aswar, E. I., Ramadan, H., Elkik, H., & Taha, A. G. (2022). *A comprehensive review on preparation, functionalization and recent applications of nanofiber membranes in wastewater treatment*. Journal of Environmental Management, 301, 113908.