New generation of patterned membranes for water treatment

Asad A.[1], Sameoto D.[2], Sadrzadeh M.[3,*]

1 University of Alberta, 6-64 National Institute for Nanotechnology (NINT), T6G 2M9, Canada

2 University of Alberta, 10-390 Donadeo Innovation Center for Engineering (DICE), T6G 2M9, Canada

3 University of Alberta, 10-367 Donadeo Innovation Center for Engineering (DICE), T6G 2M9, Canada

*corresponding author: e-mail: sadrzade@ualberta.ca

Abstract

Membrane technology is an energy-efficient separation process that is expected to dominate the water treatment industry. However, the high vulnerability of membranes to fouling has limited the expansion of sustainable and energy-efficient membrane processes. Surface patterning has been proven to be an effective method to improve the performance of membranes by increasing the permeate flux and lowering the attachment of fouling materials on membrane surfaces. In this study, a new generation of patterned membranes was prepared using a novel hydrogel facilitated phase separation (HFPS) method. Hydrogel contains a high water content which initiates phase separation as a nonsolvent upon contact with the polymer solution. Structuring a hydrogel mold provides the ability to control the location of the skin layer on the patterned side of the membrane. The performance of the patterned and the unpatterned membranes made with HFPS was examined in a cross-flow filtration system; a significant increase in the pure water flux (~100%) was observed for the patterned membrane. Moreover, a fouling experiment with bovine serum albumin (BSA) solution showed that the patterned membranes maintained 76% higher flux after 90 minutes of operation.

Keywords: patterned membranes, phase separation, hydrogel, antifouling, micro-molding.

1. Introduction

Phase inversion is the most common method to develop porous polymeric membranes for different applications including liquid-liquid extraction (de Castro & Alvarez-Sanchez, 2008) solid-liquid filtration (Mulder, 2012) and gas separation (Sadrzadeh, Rezakazemi, & Mohammadi, 2018). However, membrane separation processes have high susceptibility to fouling which is the accumulation of undesired materials on the membrane surface or inside the membrane pores (Heinz, Aghajani, Greenberg, & Ding, 2018a). The latter results in the flux decline of membranes and reducing the membrane performance over time. Recently, more attention has been directed towards surface patterning as an approach to increase and maintain high performance of membranes without the need to alter the membrane surface chemistry (Heinz, Aghajani, Greenberg, & Ding, 2018b). Surface patterning increases the water permeate due to the increase in the surface area, also creates local streamlines at the vicinity of the membrane which reduces the attachment of fouling materials and thus results in less flux decline (Maruf, Wang, Greenberg, Pellegrino, & Ding, 2013; Won et al., 2012). In this work, we introduce a novel method to surface pattern membranes using hydrogel facilitated phase separation (HFPS) method. Hydrogel consists of three-dimensional polymeric network that is capable of holding and retaining large amounts of water molecules. This allows phase separation to be initiated from the patterned side of the mold results in having patterned membranes with a skin layer at the patterned side. Hydrogel can be easily replicated from almost any structure which makes it a water-based structured mold.

2. Methodology

The preparation steps of the HFPS membranes is started by fabricating a patterned mold that acquires the desired features and dimensions. Next, hydrogel solution is cast on the patterned side with a uniform thickness. The hydrogel mold is then demolded and placed on a flat substrate and polymer solution is cast on the patterned side. Thereafter, the solvent, from the polymer solution, exchange with the water, from the hydrogel mold, and the membrane forms. Finally, the membrane is demolded and stored and water bath for later use.

3. Results and Conclusion

Figure 2. shows SEM images of some HFPS membranes. The internal structure is finger-like asymmetric that is typical for non-solvent induced phase separation (NIPS).

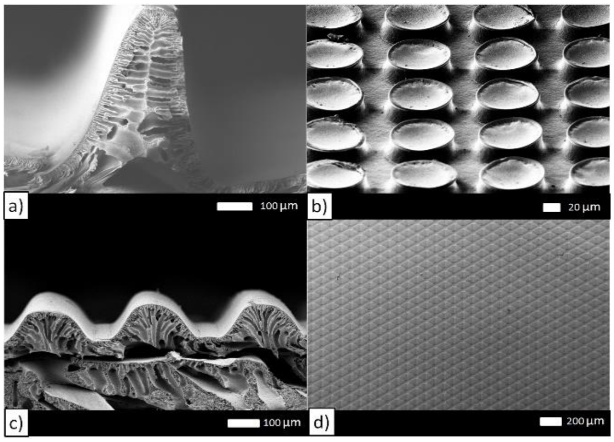

Figure 1. Scanning electron microscope images of different HFPS membranes. (a) a high aspect ratio ridge with a height of 530 µm. (b), (c) and (d) show other uniform patterned membranes.

The performance of ridge patterned membranes was examined using a cross-flow filtration system and results are shown in figure 2. Figure 2.a shows a comparison between pure water flux of HFPS patterned and HFPS unpatterned membranes. The HFPS patterned membrane doubled the pure water flux compared with the unpatterned one. Moreover, after 90 minutes of filtration with BSA solution the HFPS patterned membrane showed a 76% increase in the flux compared to the unpatterned membrane, demonstrating the influence of surface patterning on the membrane performance.

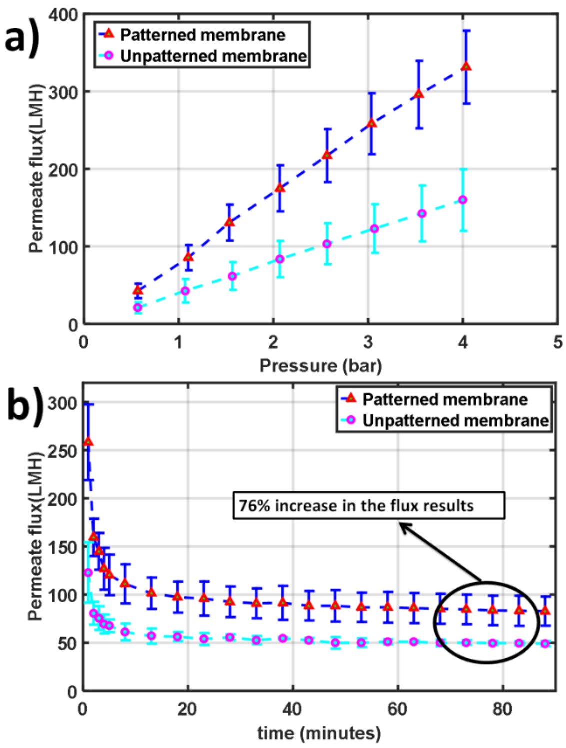

Figure 2. (a) pure water flux vs transmembrane pressure and (b) flux decline over time using BSA solution.

In summary, HFPS is a novel method to directly produce patterned membranes while maintaining the location of the dense layer to be at the patterned side. This technology introduces different patterns and geometries to the membrane separation processes. The simplicity of this method increases the design space of developing high-flux and antifouling membranes.

References

de Castro, M. L., & Alvarez-Sanchez, B. (2008). Membrane-based separation techniques: Liquid–liquid extraction and filtration. *Comprehensive analytical chemistry* (pp. 235-264) Elsevier.

Heinz, O., Aghajani, M., Greenberg, A. R., & Ding, Y. (2018a). Surface-patterning of polymeric membranes: Fabrication and performance. *Current Opinion in Chemical Engineering, 20*, 1-12.

Heinz, O., Aghajani, M., Greenberg, A. R., & Ding, Y. (2018b). Surface-patterning of polymeric membranes: Fabrication and performance. *Current Opinion in Chemical Engineering, 20*, 1-12.

Maruf, S. H., Wang, L., Greenberg, A. R., Pellegrino, J., & Ding, Y. (2013). Use of nanoimprinted surface patterns to mitigate colloidal deposition on ultrafiltration membranes. *Journal of Membrane Science, 428*, 598-607.

Mulder, J. (2012). *Basic principles of membrane technology* Springer Science & Business Media.

Sadrzadeh, M., Rezakazemi, M., & Mohammadi, T. (2018). Fundamentals and measurement techniques for gas transport in polymers. *Wilson, R., S, aK, George, SC (Eds.), Transport Properties of Polymeric Membranes.Elsevier*, , 391-423.

Won, Y., Lee, J., Choi, D., Chae, H. R., Kim, I., Lee, C., & Kim, I. (2012). Preparation and application of patterned membranes for wastewater treatment. *Environmental Science & Technology, 46*(20), 11021-11027.