3D Printed Fouling-resistant Composite Membranes

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MEMBRANE FOULING

Fouling (Fig. 1) remains a long-standing unsolved problem that hinders the widespread use of membranes in industry.

Fouling leads to:

- Permeance decline
- Increased energy consumption
- Impaired quality of product
- Increased capital and operational costs

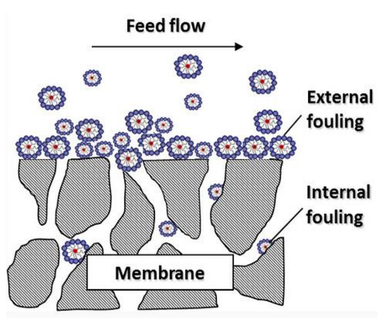


Fig. 1. Membrane fouling [1]

3D PRINTING TECHNOLOGY

Patterning of membrane surface is a promising chemical-free approach to promote fluid shear stress and create localised turbulence near the membrane surface, leading to reduced or delayed fouling build-up.

Current patterning methods (Fig. 2) suffer from insufficient fidelity and flexibility, while negatively affecting the performance and durability of the membranes.

3D printing can overcome these challenges by enabling the fabrication of complex/irregular patterns which would otherwise be impossible to manufacture using current techniques.

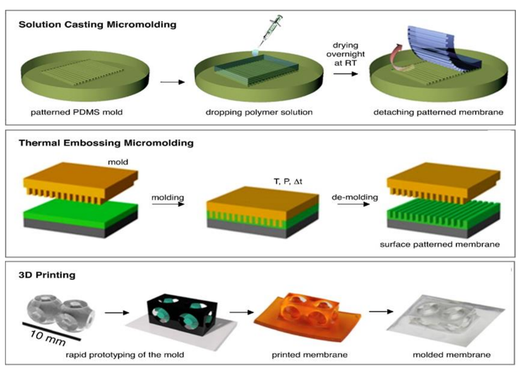
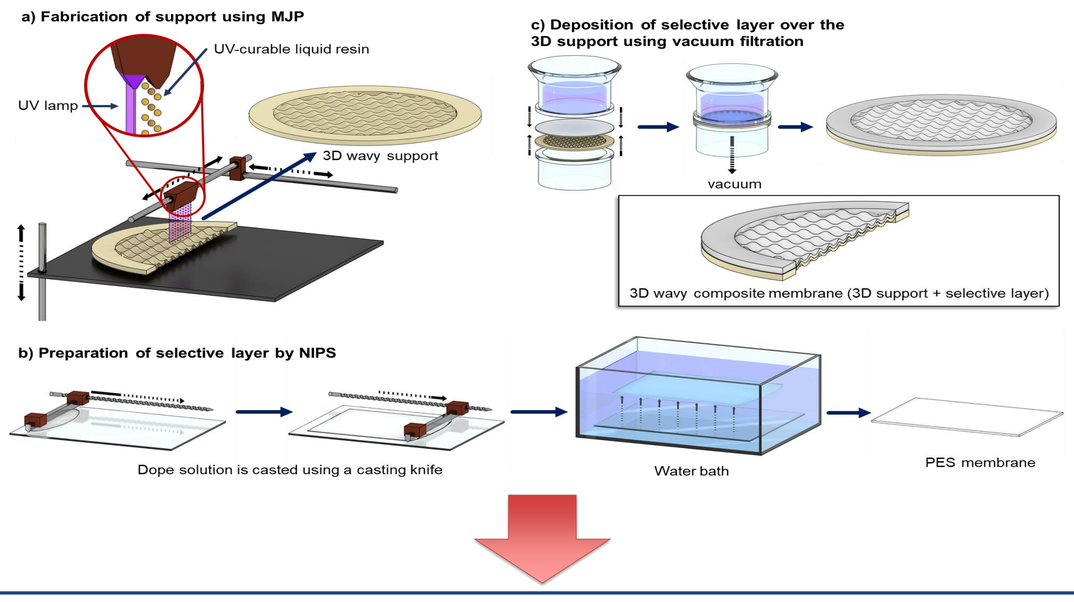


Fig. 2. Patterning of membrane surface [2]

FABRICATION OF 3D COMPOSITE MEMBRANES



CHARACTERISATION

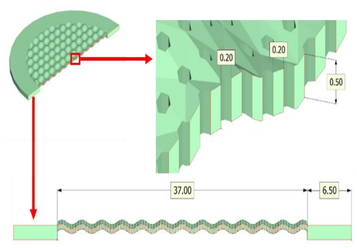


Fig. 3. CAD of 3D wavy support

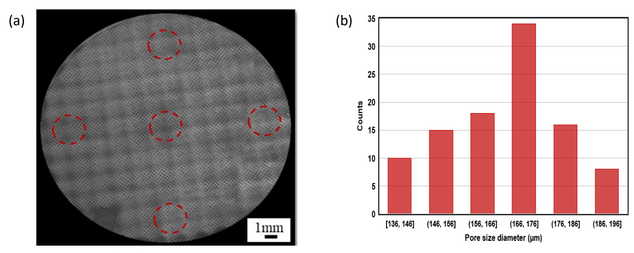


Fig. 4. (a) Mosaic micrograph of the wavy support, (b) pore size distribution of the wavy support

3D wavy support
- ABS-like material
- Total diameter (50 mm)
- Active area (37 mm)
- Thickness (0.5 mm)

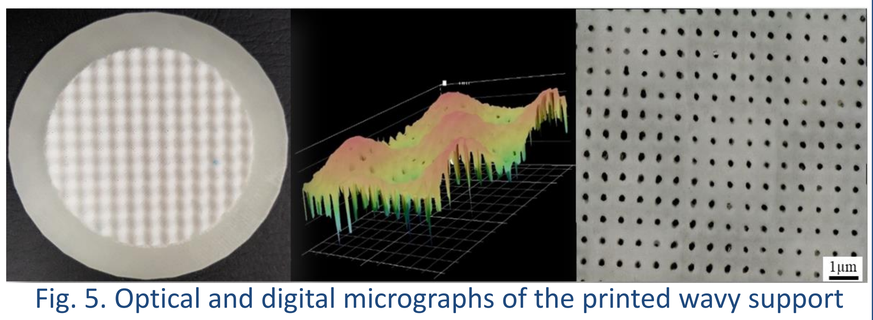


Fig. 5. Optical and digital micrographs of the printed wavy support

Selective layer
- Polyether sulfone (PES)
- Dense layer (0.5)
- Ave. pore size (30 nm)
- Total thickness (50)

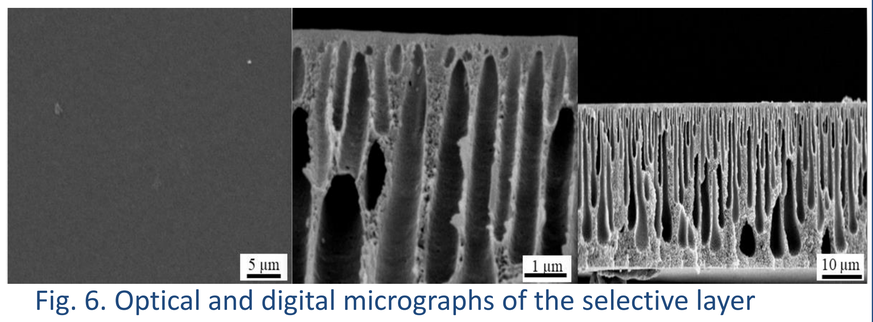


Fig. 6. Optical and digital micrographs of the selective layer

3D composite membrane

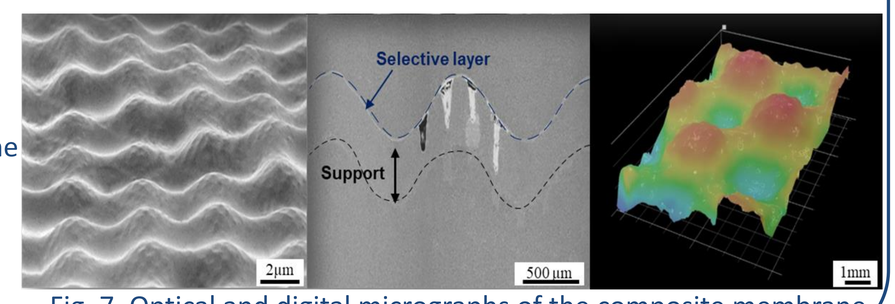


Fig. 7. Optical and digital micrographs of the composite membrane

OPTIMISATION

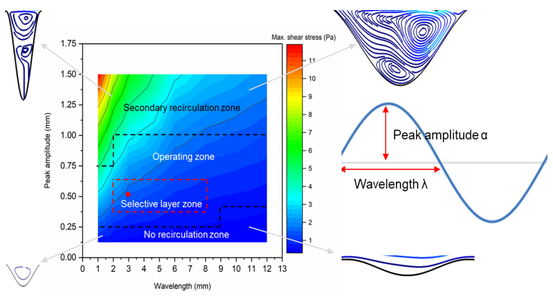


Fig. 8. Contour plot of maximum surface shear stress for printable values of α and λ at cross-flow Re = 1000.

- **No Recirculation zone**

No sustained localised recirculation could form for all values of wavelength tested.

- **Secondary recirculation zone**

Large shear stress could be generated on the membrane surface for all values of wavelength tested and this is desirable for fouling mitigation.

- **Operating zone**

Preferred high surface shear stress condition with primary flow recirculation.

- **Optimal zone**

For large α values within the operating zone, the selective layer would be pierced and the support would not be fully covered, whereas for long λ values, there was poor adhesion between the selective layer and the wavy support.

FOULING

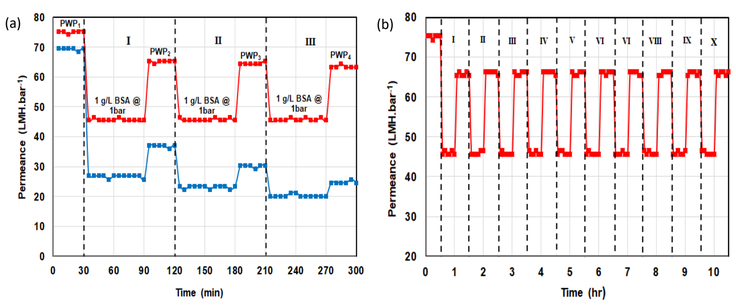


Fig 8. Permeance profiles of BSA solution for flat (blue) and wavy (red) membranes (a) 3 cycles (b) 10 cycles

- Higher initial pure water permeance (PWP) for the wavy membrane.
- A marked permeance decline (~61%) for the flat membrane compared to the wavy membrane (~37%)
- The wavy membrane could retain 87% of its initial PWP after 10 complete filtration cycles.
- High rejection (96 %) was observed for both membranes.

CLEANING

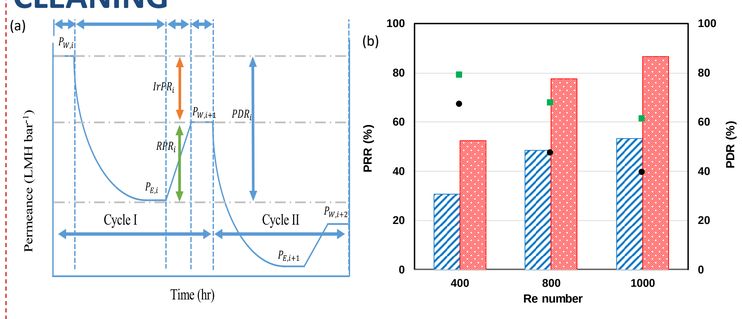


Fig. 9. (a) PRR and PDR of flat and wavy membranes after the first filtration cycle, (b) schematic of the filtration cycle

- The proportion of irreversible fouling for the wavy membrane is consistently lower than the flat membrane.
- The larger portion of reversible fouling of the wavy membrane could be removed by simply front washing with water.
- Apart from the first cycle, the value of PRR for the wavy membrane could maintained at approximately 98 %.

NUMERICAL SIMULATIONS

The conservation of mass and momentum equations, and particle tracing model were solved by using a commercial CFD software COMSOL Multiphysics™ v5.4.

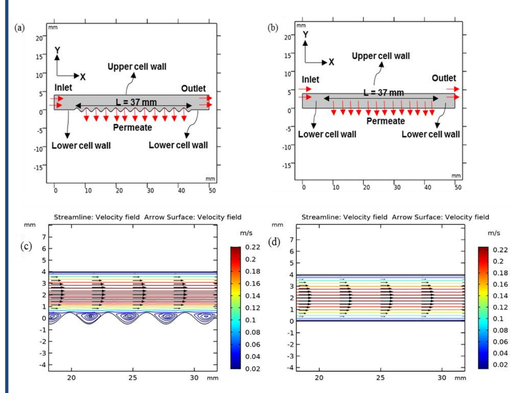


Fig. 10. The geometry for (a) wavy and (b) flat membranes along with velocity profiles for (c) wavy and (d) flat membranes.

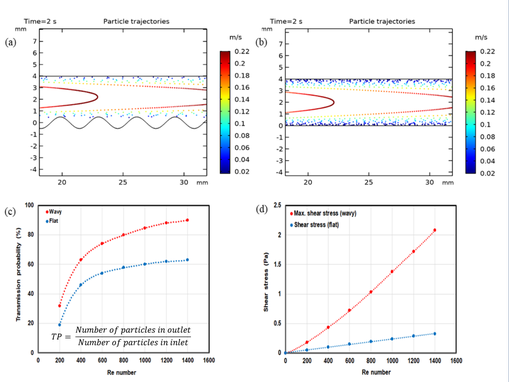


Fig. 11. Particle trajectories for (a) wavy and (b) flat 3D composite membranes at Re = 1000; (c) TP at different Re; and (d) Maximum surface shear stress values as a function of Re.

- The BSA particles enter the valley regions of the wavy structure due to the permeation drag but can escape this region and return to the bulk cross-flow stream only when primary recirculation (Figure 10c) is present.
- The amount of BSA particles exiting the outlet for the wavy membrane is higher than for the flat membrane, indicating less fouling (Figure 11b).
- With increasing Re numbers, the difference in the maximum surface shear stress between the wavy and flat membranes increases.

CONCLUSIONS

- This work demonstrates the success of fabrication of 3D printed fouling-resistant composite membranes.
- The wavy 3D composite membrane exhibited superior fouling-resistant performance compared to flat membrane for multiple (1, 3 and 10 cycles) filtration cycles under all the operating conditions.
- The wavy composite membrane retained 88% of its initial permeance after 10 complete cycles, using only water.

REFERENCES

[1] W. Gao, H. Liang, J. Ma, M. Han, Z. Chen, Z. Han, G. Li, Membrane fouling control in ultrafiltration technology for drinking water production: a review. Desalination 2011, 272 (1-3), 1-8.
[2] O. Heinz, M. Aghajani, A. R. Greenberg, Y. Ding, Surface-patterning of polymeric membranes: fabrication and performance. Current Opinion in Chemical Engineering 2018, 20, 1-12.
[3] A. Al-Shimmery, S. Mazinani, J. Chew, D. Mattia, 3D printed composite membranes with enhanced anti-fouling behaviour. Journal of Membrane Science, 574, 76-85, 2019.
[4] S. Mazinani, A. Al-Shimmery, J. Chew, D. Mattia, 3D Printed Fouling-resistant Composite Membranes, ACS Applied Material Interfaces, Accepted, 2019.