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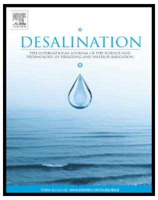


Thin-film composite membrane on a compacted woven backing fabric for pressure assisted osmosis

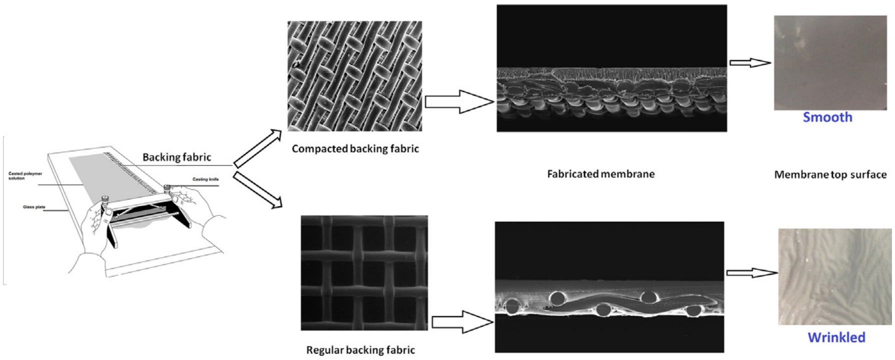
Soleyman Sahebi [a], Sherub Phuntsho [a], Leonard Tijing [a], Gang Han [b], Dong Suk Han [c], Ahmed Abdel-Wahab [c], Ho Kyong Shon [a,*]

[a] Centre for Technology in Water and Wastewater, School of Civil and Environmental Engineering, University of Technology Sydney (UTS), PO Box 123, 15 Broadway, NSW 2007, Australia
[b] Department of Chemical and Biomolecular Engineering, National University of Singapore, Singapore 117585, Singapore
[c] Chemical Engineering Program, Texas A&M University at Qatar, PO, Box 23874, Doha, Qatar

HIGHLIGHTS

- TFC membrane supported on backing fabric was fabricated for PAO process.
- RO and FO membrane casting methods were investigated.
- PAO membrane had a higher S value compared to FO membranes.
- PAO membrane had a higher water permeability compared to FO membranes.
- Developed PAO membrane can sustain applied hydraulic pressure.

GRAPHICAL ABSTRACT



Casting thin-film composite membrane on a regular and compacted woven backing fabric for pressure assisted osmosis

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ABSTRACT

The water flux in forward osmosis (FO) process declines substantially when the draw solution (DS) concentration reaches closer to the point of osmotic equilibrium with the feed solution (FS). Using external hydraulic pressure alongside the osmotic driving force in the pressure assisted osmosis (PAO) has been found effective in terms of enhancing water flux and even potentially diluting the DS beyond osmotic equilibrium. The net gain in water flux due to the applied pressure in the PAO process closely depends on the permeability of the FO membrane. The commercial flat sheet cellulose triacetate (CTA) FO membrane has low water permeability and hence the effective gain in water flux in the PAO process is low. In this study, a high performance thin film composite membrane was developed especially for the PAO process through casting polyethersulfone (PES) polymer solution on a compacted woven fabric mesh support followed by interfacial polymerisation for polyamide active layer. This PAO membrane possesses a water flux of 37 L m^2 h^{-1} using 0.5 M NaCl as DS and deionised water as the feed at an applied hydraulic pressure of 10 bar. Besides, the membrane was able to endure the external hydraulic pressure required for the PAO process owing to the embedded backing fabric support. While the membranes with low structural parameters are essential for higher water flux, this study shows that for PAO process, polymeric

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[*] Corresponding author.
E-mail address: Hokyong.Shon-1@uts.edu.au (H.K. Shon).

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membranes with larger structural parameters may not be suitable for PAO. They generally resulted in compaction and poor mechanical strength to withstand hydraulic pressure.

1. Introduction

Forward osmosis (FO) has drawn significant research attention as an alternative membrane process for desalination, osmotic energy generation and treating impaired water sources [1–4]. Unlike pressure-based membrane processes such as reverse osmosis (RO) and nanofiltration (NF), FO utilises the osmotic pressure generated by draw solution (DS) as a driving force to transfer water across a semipermeable membrane without the need of hydraulic pressure [5]. However, since the osmotic pressure is based on concentration difference, the water flux decrease in the FO process is due to cumulative decline in the DS concentration [1,6,7]. Water flux occurs until the osmotic pressure of the DS attains equilibrium with the feed solution (FS) [4,8].

Recently, combined processes of applied hydraulic pressure and osmosis have been reported with an attempt to exploit the synergies of the two processes in a single stage to overcome low flux in the FO process even generating water flux beyond osmotic equilibrium point [9–11]. The concept of pressure assisted osmosis (PAO) is in fact a hybridisation of the FO process and the RO process where the intrinsic loss of osmotic driving force in the FO process is supplemented by the external hydraulic pressure applied to the FO system. Therefore in the PAO process, external hydraulic pressure is applied to the feed side to enhance the water flux [11]. Several earlier works have demonstrated that the applied hydraulic pressure can increase the FO process performance [11,12]; however, the performance also closely depends on the characteristics of FO membranes including its water permeability, structural properties, mechanical strength, etc. [10].

To date, most of the published articles dealing with osmotic processes such as FO, pressure retarded osmosis (PRO) and particularly PAO are based on use of commercialised CTA-FO membrane with embedded woven polyester support mesh from HTI [11,12]. Most other studies are reported using lab-scale fabricated membranes but for FO and PRO studies only [13–15]. Although CTA was the most commercially available FO membranes however, the low water flux associated with the CTA membrane is the most common issue in many studies [10,11]. Although it has been reported that Hydration Technology Inc. (HTI) has commercialised thin film composite (TFC) FO membrane, it is still largely unavailable to the researchers yet. One exception is a study by Coday et al. in which TFC from HTI has been used in addition to the CTA membrane for assessing the PAO process [10].

The TFC-FO membranes can be made with or without any backing fabric support and membranes prepared without a backing support are generally more efficient than those with backing fabric as its presence contributes towards enhanced internal concentration polarisation (ICP) effect that lowers the water flux during the FO process. Nevertheless, the membrane needs adequate mechanical strength to perform sustainably under certain hydraulic pressure and the function of the backing fabric is mainly to provide mechanical strength of a TFC membranes. This could be true even in the normal FO process where pressure drop could automatically occur in large-scale modules. Most recent efforts for fabricating high performance TFC-FO membrane have been widely devoted to modifying the structural morphology and chemical properties of the polymeric support layer in order to enhance the membrane performance by reducing ICP effects. These lab-made TFC-FO membranes without any fabric support have shown enhanced water flux and salt rejection compared to the commercial CTA-FO membrane or the TFC membranes [16,17]. However, most of these membranes are generally not effective in the PAO process due to the likely membrane compaction and low mechanical strength when subjected to hydraulic pressure [16,17].

Based on casting procedures of the FO membrane on a large commercial-scale, the TFC membrane for the FO seems to have been fabricated in a similar way to that of the CTA-FO membrane [18]. The polymer solution is casted on a roll, which is followed by pulling the fabric from the top to embed it in the casted polymer solution. This unique fabrication method for the FO membrane confines the polymer penetration to the back of the porous fabric support and prevents the formation of air bubbles [18]. The polymer solution is first casted onto a rotating drum and then the woven fabric mesh is pulled onto the polymer solution from the top so that the backing fabric is fully embedded without formation of air bubbles and defect points [18]. This approach is adopted to prevent the penetration of polymer solution during casting thereby preventing wrinkle formation and substrate defects.

Tiraferri et al. have presented the successful reinforcement of FO membrane with highly porous non-woven PET fabric support using a RO style (conventional method) in the lab environment [19,20]. In this approach of synthesis, the backing fabric support was placed on the roll and then the polymer solution was poured on the top of the fabric support and casted by a casting blade on top of the roll. Another study by Qiu et al. also applied the commercial scale FO membrane casting method for fabricating embedded FO membrane on a woven fabric using polyamide-imide (PAI) material through phase inversion [21]. In order to limit polymer penetration and wrinkle formation for producing large pieces of defect and wrinkle-free membrane substrate, Mc Ginnis, and Mcguregan [18,22] have used bilayer backing fabric to make the support layer sturdier and thicker. The use of bilayer backing fabric can block the polymer solution from penetrating the backing layer and limit the wrinkle and defect problems. Furthermore, Sairam et al. presented a method to prevent polymer penetration and formation of air pocket while fabricating cellulose acetate based FO membrane supported by woven mesh fabric at a lab scale level. The backing fabric is pasted with polyvinyl pyrrolidone (PVP-K60) on the glass plate where it can prevent polymer bleeding to the backing fabric and limit the formation of air bubbles during phase inversion [23].

The present work is therefore aimed to develop an effective TFC membrane tailored for PAO process by incorporating a woven mesh backing fabric into the polyethersulphone (PES) substrate formed by phase inversion. This study adopted unique approaches for embedding woven mesh fabric to the PES membrane support layer by applying both the conventional and commercial scale FO membrane fabrication methods to produce a wrinkle and defect-free TFC-FO membrane for PAO application. The properties of the TFC-FO membranes including their substrate morphologies and physical characteristics were investigated, and compared to two commercial FO membranes: commercialised CTA-FO membrane from HTI and the recently commercialised polyamide-based TFC-FO membrane (WJ-FO) from Woongjin Chemicals (now Toray Chemicals Korea). Commercial TFC-RO membrane from Woongjing Chemicals (WJ-RO) was also used for comparison.

2. Materials and methods

2.1. Chemicals and materials

Polyethersulfone (PES) granules (Mn: 55,000 — Good fellow, UK) and polyester mesh woven fabric (PETEX 07-11/5, 07-40/25, SEFAR

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