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Thin-film composite forward osmosis membrane with high water flux and high pressure resistance using a thicker void-free polyketone porous support

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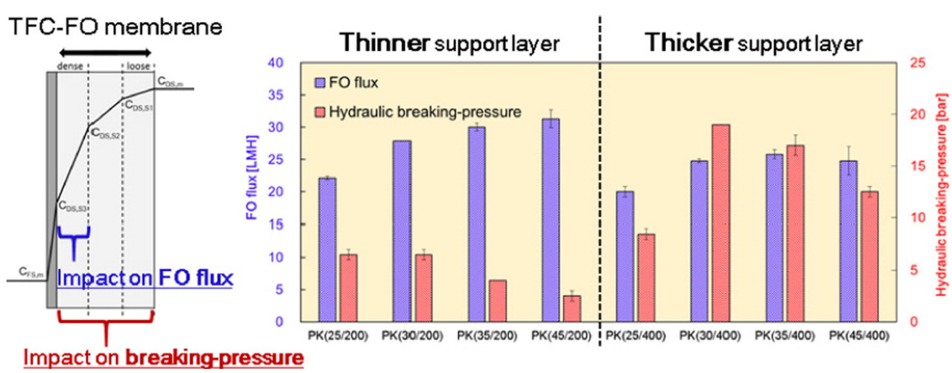
HIGHLIGHTS

- TFC membranes were prepared on 8-types of polyketone porous supports with varying morphology.
- FO flux depended on partial dense part of the whole support layer.
- Maximum hydraulic breaking pressure depended on whole support layer including the loose part.
- Void-free morphology was preferable to maximum hydraulic breaking pressure.
- Thicker and highly porous support was preferable to achieve the compatible feature.

GRAPHICAL ABSTRACT



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ABSTRACT

In this study, we investigated the effect of the morphology of the support membrane on the forward osmosis (FO) flux and maximum hydraulic breaking pressure of thin-film composite (TFC) FO membranes for engineered osmosis applications. Eight types of porous support membranes were prepared using polyketone as a polymer material by changing the coagulation bath composition and initial casting height *via* the non-solvent induced phase separation method. The intrinsic membrane parameters of the prepared TFC FO membranes were determined from both reverse osmosis and FO experiments. The results revealed that there was a good correlation between the FO flux and the partial dense part morphology of the support layer, whereas the hydraulic breaking pressure strongly depended on the thickness of the entire support layer and the presence of large voids. This significant difference enabled the design of an optimal TFC FO membrane that exhibited both high FO flux as well as high pressure resistance. The prepared TFC FO membrane showed an FO flux of 24.8 L m^{-2} h^{-1} when tested in the active layer facing to feed solution mode using 0.6 M sodium chloride and deionized water as draw solution and feed solution, respectively, with a pressure resistance of 19 bar.

1. Introduction

The rapid increase in the global population and increasing urbanization will lead to serious shortages in the available water and energy resources [1]. Owing to the increase in the water and energy demands,

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Table 1
Conditions used for the preparation of porous support membranes in this study.

Sample membranes	Polymer conc. [wt%]	MeOH conc. [wt%]	Initial casting height [mm]
PK(25/200)	10	25	200
PK(30/200)	10	30	200
PK(35/200)	10	35	200
PK(45/200)	10	45	200
PK(25/400)	10	25	400
PK(30/400)	10	30	400
PK(35/400)	10	35	400
PK(45/400)	10	45	400

there is a strong need for identifying alternative water and energy resources [2]. Engineered osmosis (EO) processes including forward osmosis (FO) and pressure-retarded osmosis (PRO), which are driven by concentration gradients, have been recognized as emerging technologies that can contribute not only to clean water production from alternative resources such as seawater [3,4] and wastewater [5,6], but also energy production from renewable natural resources such as seawater reverse osmosis (RO) brine and municipal waste water [7].

However, commercial success of EO applications has been limited and further trials and developments are needed to successfully apply these technologies worldwide. Recently, various applications such as desalination (including direct desalination using recyclable draw solutions (DSs) by low-grade energy [8,9], indirect desalination using wastewater as feed for pre-dilution [10,11], and direct fertigation using fertilizer as DS [12,13]), membrane concentrators targeted towards zero liquid discharge (ZLD) [14,15], osmotic membrane bioreactor systems [16,17], and energy recovery systems using RO brine [7] have been proposed as potential applications of the FO technology. In the case of FO, owing to internal concentration polarization (ICP), a low water flux results in high installations costs for the FO membrane module [10]. Therefore, further improvement in the FO membrane performance is required.

In addition, recent studies on FO have also highlighted the need for developing FO membranes that can provide both high flux performance as well as high pressure resistance, because the FO membrane is sometimes used under hydraulic pressurized conditions such as during the PRO and pressure-assisted osmosis (PAO) operations. In the case of the RO/PRO system [7,18], the preferred hydraulic operating pressure is about 30 bar because the maximum net power can be obtained at a hydraulic pressure that is half of the osmotic pressure difference between the RO brine and other wastewater. On the other hand, in the cases of PAO/RO [10] and fertilizer-driven FO (FDFO) [19], a relatively low hydraulic pressure of less than about 10 bar is applied to enhance the FO flux, in order to achieve initial membrane cost reduction.

To achieve high FO flux, the morphology of the support membrane is one of the most important factors and needs to be designed such that the ICP in the support membrane is reduced. For achieving high FO flux, the ideal support membrane must be very thin, highly porous, and have low tortuosity [20]. However, a highly porous structure may also lead to low mechanical strength of the support membrane. In our previous study [21], we prepared thin-film composite (TFC) FO membranes using the polyketone (PK) porous membrane as the support layer. The prepared TFC FO membrane exhibited a water flux of 40.4 LMH in the active layer facing to feed solution (AL-FS) mode with 1.2 M sodium chloride and DI water used as DS and feed solution (FS), respectively. This water flux value is among the highest values published so far in the literature. However, we also observed a trade-off between the FO flux and hydraulic breaking pressure of the TFC FO membrane. The TFC FO membrane that exhibited the highest FO flux also showed a breaking pressure of only 6 bar. Such a low mechanical strength of the TFC FO membrane would be a significant disadvantage when this membrane would be installed into a large-scale module such as a spiral-wound module because the module would need to be operated under hydraulic-pressurized conditions to overcome the pressure drop generated in the module. Therefore, to overcome this problem, further developments are still required. However, there are few reports in the literature that have examined the maximum breaking pressure of the TFC FO membrane in detail, even in the case of flat sheet TFC FO membranes, which have been widely studied.

In this study, in order to gain knowledge for designing TFC FO membranes with compatible features for achieving both high FO performance and high hydraulic breaking pressure, we investigated the effect of the morphology of the support membrane on the FO flux and maximum hydraulic breaking pressure of the prepared TFC FO membranes. Eight types of porous support membranes were prepared using PK as the polymer material *via* the non-solvent induced phase separation (NIPS) method. The morphologies of the PK porous membranes were controlled by changing preparation conditions such as coagulation bath composition and initial casting height, and the performance of the resultant TFC FO membranes was examined.

2. Experimental

2.1. Materials and chemicals

Polyketone (PK) (M_w: 200,000; Asahi Kasei Fibers Co., Japan) was used as the polymer material for the support layer. Resorcinol, *N*-

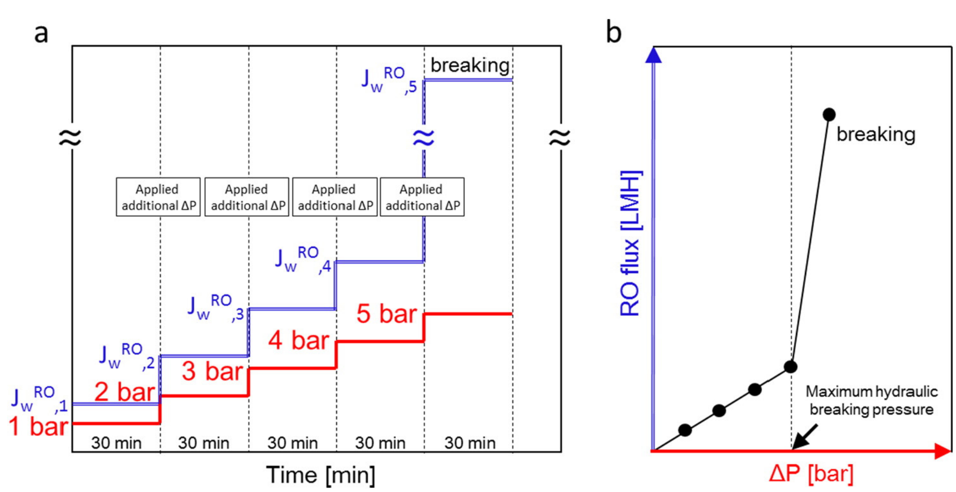

Fig. 1. Experimental protocol for the measurement of the maximum hydraulic breaking pressure for the prepared TFC FO membranes. (a) Experimental procedure and (b) Schematic RO flux change with increasing Δ*P*.