

Modification of bi-composite membrane support layer by macro puncture for membrane distillation application



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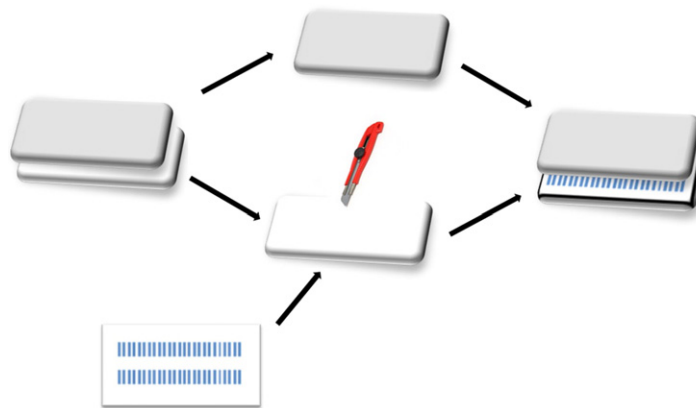
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HIGHLIGHTS

- Modifications of support layer were conducted using a commercial PTFE/PP bi-composite membrane.
- Macro punctures of support layer were designed based on the porosity of the support layer.
- Porosity of support layer and sizes of macro punctures affected the fluxes of the modified membranes.
- The orientation, type and porosity of support layer should be considered to guarantee its tensile strength.
- The flux of the modified membrane was affected by the enhanced turbulence produced by the support layer.

GRAPHICAL ABSTRACT



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ABSTRACT

Membrane distillation (MD) is a thermally driven membrane process. For MD application, a hydrophobic and porous membrane is required. A bi-composite membrane has been introduced for many MD applications because of its superior membrane performance, especially flux. In this research, in order to increase the flux of a commercial bi-composite membrane, various macro punctures were formed in the support layer. The modified MD membranes were tested in a direct contact membrane distillation (DCMD) configuration. The flux of a modified membrane was affected by the size and location of macro punctures and overall porosity in the support layer. The flux of a modified membrane was enhanced up to 27% compared with that of pristine membrane when the size of the macro puncture and overall porosity of the support layer were larger than 20 mm² and 60%, respectively. The overall porosity and size and location of macro punctures in the support layer affected the flux due to the turbulent production in the permeate side. The membrane integrity was checked not only by the tensile strength of the modified membrane samples but also by the long term operation by using the secondary effluent of the wastewater treatment plant as a feed.

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1. Introduction

Recently, humans have been confronted by the growing problems of water shortages and rising energy costs globally. Conventional desalination, wastewater reuse and various water treatment technologies which use thermal (MSF, MED and etc.) and electrical power (reverse osmosis)

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Nomenclature

A	cross-sectional area of the channel
A_m	area of the membrane sample for the porosity measurement (m^2)
h	heat transfer coefficient ($W/m^2 K$)
J	flux (L/m^2h)
k	thermal conductivity ($W/m K$)
L	characteristic length (m)
Nu	Nusselt number
p	wetted perimeter of the channel (m)
Pr	Prandtl number
Q	heat flux (W/m^2)
Re	Reynolds number
T	temperature (K)
V	Volume (m^3)
W	weight (kg)
ΔH_V	latent heat (kJ/kg)
δ	thickness (m)
ε	porosity
ρ	density (kg/m^3)

Subscripts

a	active layer
b	bulk
f	feed (side) or feed solution boundary layer
g	gas
m	membrane
p	permeate (side) or permeate solution boundary layer
ref.	reference
s	support layer
w	water

are still feasible, however, many researchers are now trying to find novel low energy alternatives, such as forward osmosis (FO) and membrane distillation (MD) processes [1–5]. The membrane distillation process is thermally driven and has been tested as a next generation desalination process because of its relatively low temperature feed side requirement (60–80 °C) compared with other thermally driven desalination processes such as MSF (Multi-stage Flash) and MED (Multi-effect Distillation) [3–5]. Membrane distillation can be operated by abandoned waste heat or abundant solar energy [6–8]. Recent advances in membrane technology have also boosted the development of various membrane processes including the MD process. Therefore, the membrane distillation process is considered to be one of the possible alternatives in desalination and water treatment work. If the flux of a membrane could be enhanced significantly, commercialization of the MD process can be achieved in the near future.

The membrane distillation process requires a hydrophobic and porous membrane. A range of membrane properties suited for the MD process, including materials (PP, PE, PTFE, and PVDF, etc.) and structures (pore size, thickness, porosity, and tortuosity) have been suggested by many researchers [3–5]. In detail, the membrane material for the MD process is required to have low thermal conductivity in order to decrease a direct heat loss through the membrane material and to have high hydrophobicity to provide high LEP (liquid entry pressure). The ranges of the pertinent pore size and membrane thickness have been suggested to harmonize the flux increase and LEP decrease by the large pore size and the flux increase and thermal efficiency decrease due to the heat loss by the thinner membrane, respectively. Large porous membrane having enough tensile strength is required and the straight pore structure will guarantee high flux by decreasing the transport path of the water vapor. The operating conditions including temperature difference between the feed and permeate and

hydrodynamic characteristics (cross-flow velocity and Reynold's number (Re)) of the flows in the feed and permeate also affect significantly the performance of the MD process. Among the feasible options for promising membranes, the PTFE/PP type bi-composite membrane has been tested by various researchers [9–13].

In order to develop a high flux membrane for the MD application, the active layer of the membrane has been variously altered into a more porous and hydrophobic structure, as represented by the CNT-spiked membrane, electro-spun membrane, and new polymer MD membrane [14–17]. The PTFE material is considered to be the best option for fabricating a MD membrane due to its high performance, especially flux, and resistance against strong chemicals which are potential membrane washing agents, including HCl and H_2SO_4 . However, the main limitation of the PTFE material is its workability. Due to its high resistance to chemicals, fabrication of PTFE fibers in the lab is not easy. Recently, several researchers have also focused on the effect which the support layer structure contributes to the membrane performance when bi-composite membranes were used [13,18–19]. Compared with modification of the active layer in MD membrane fabrication, support layer modification has not been well studied. The support layer faces the cold side (permeate or air) in the MD and its primary role is to strengthen the whole membrane. In previous research, the support layer employed for water treatment has been designed to be highly permeable compared with the active layer, having a large pore size, a high porosity, a cylindrical pore structure and a hydrophilic characteristic [20–24]. Hence, in this paper, we focused on modifying the support layer of a commercial flat-sheet membrane.

One option for the modification would be to change the support layer mesh. For example, the physical (thickness, pore size, porosity and tortuosity) and chemical (hydrophobicity) characteristics of the support layer mesh can be modified. In this study, as a novel method of enhancing the prefabricated mesh structure, it was modified by creating additional macro punctures in the support layer.

In this study, the support layer of a commercial bi-composite membrane was modified by making macro punctures of various porosities, sizes and locations. This study presents the first attempt to modify the porosity of the prefabricated support layer without chemicals, and also elucidates the benefits of a macro-void structure in the support layer.

2. Theory

In order to understand the reasons for flux variations resulting from the various support layer modifications, the heat transfer model was adopted from the previous research [9]. The major governing equations for the PTFE/PP bi-composite membrane was suggested by Qtaishat et al. in 2009 [25]. In order to solve the heat transfer due to the water vapor transport across the membrane, it is assumed that the total heat transfer from the feed (Q_f) and permeate (Q_p) is identical under steady state condition. Consequently, we assumed that all the flux tests were conducted under a steady state condition and the water flow channels of the feed and permeate were well stabilized. It was also assumed that heat loss during the experiment was negligible. The following equation is commonly used for the heat transfer across the membrane from the feed to the permeate:

$$Q = Q_f = Q_a = Q_s = Q_p \quad (1)$$

where Q is the total heat flux from the feed to the permeate. Q_f , Q_a , Q_s and Q_p are the heat fluxes through the feed solution boundary layer, active layer, support layer and permeate solution boundary layer. Each heat flux and heat convection coefficient are written as:

$$Q_f = h_f(T_{b,f} - T_{m,f}) \quad (2)$$

$$Q_a = h_a(T_{m,f} - T_{m,p}) + J_W \Delta H_V \quad (3)$$

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