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Effect of heat-press conditions on electrospun membranes for desalination by direct contact membrane distillation

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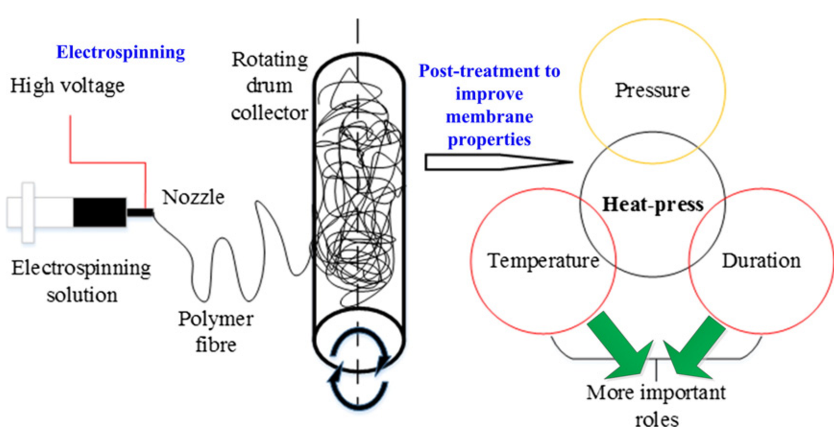
HIGHLIGHTS

- Electrospun membranes show good potential for membrane distillation.
- Heat-press treatment can improve the properties of electrospun membrane.
- Heat-press conditions are comprehensively studied here.
- Heat-press temperature and duration play more important roles in heat-press.

GRAPHICAL ABSTRACT



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ABSTRACT

Membrane distillation (MD) is considered as a promising next-generation technology for desalination. However, there is no specific membrane designed and engineered for this application yet. Recently, electrospun polymeric membranes have been widely investigated due to their relatively high porosity, high hydrophobicity and controllable pore size. However, the robustness of such membranes is not guaranteed as they are susceptible to wetting in long-term operation. Heat-press treatment is a simple and effective procedure to improve both morphological and mechanical characteristics of the electrospun membrane. Nevertheless, the heat-press technique is not fully investigated although some conditions are applied to the electrospun membrane in previous researches. In this paper, a comprehensive investigation of the effect of heat-press temperature, pressure and duration on the morphological and mechanical characteristics of electrospun membrane is accomplished. Impressive improvement of mechanical strength and liquid entry pressure (LEP) can be achieved after heat-press treatment on the electrospun membranes. It is also found that temperature and duration play more important roles than pressure in heat-press treatment. In addition, it is ascertained that optimal treatment conditions for heat-press includes temperature at 150 °C, pressure at 6.5 kPa, and duration for 8 h for the present electrospun polyvinylidene

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fluoride-co-hexafluoropropylene membrane. A decent DCMD permeation flux of 29 LMH and salt rejection of 99.99% can be achieved with the optimally heat-pressed electrospun membranes for desalination at feed and permeate temperatures of 60 and 20 °C, respectively.

1. Introduction

Water and energy have been recognized as the top two major challenges in the world today and in the coming future. Nowadays, lots of freshwater resources are becoming unrenewable due to climate change and massive human activities. Moreover, the water shortage issues are much more serious in some countries with bad climate and poor economic conditions, so lack of clean water is a great threat to the hygiene of local residents [1].

Desalination is a viable option to obtain freshwater supply stably for coastal countries that are short of fresh water, and currently reverse osmosis (RO) is widely applied in desalination due to its relatively high efficiency. However, the capital and maintenance costs of RO plants are high and large amounts of electrical energy are required for generating high pressure in the process. In addition, RO has a negative impact on global environment by carbon dioxide as the generation of electrical energy is very likely fossil-fuel based. RO brine disposal is another major issue that is widely concerned by the society due to their impact on the local ecological system. Therefore, development of new generations of technology is strongly needed for replacement of RO technology [2].

Membrane distillation (MD) has been considered as a promising next-generation technology for desalination because of its higher efficiency and permeation performance independent on the salt concentration [3,4]. The potential usage of low grade heat such as industrial waste heat or solar heat makes it a more attractive option. The MD mechanism is based on a separation process where water vapour molecules at feed side pass through pores of a hydrophobic membrane and condenses at permeate side [5–8]. The driving force of the vapour molecules is generated by the temperature difference of vapours between both sides of the membrane [9]. Evaporation of liquid water occurs at the membrane interface with the contact of hot solution [10]. The vapour molecular then diffuses through the pores to the other side of interface where it condenses by cool permeate side [11].

However, as an emerging technology, MD has not yet been widely applied in the global water industry due to lack of suitable membranes for long-term operation. Qualities such as strong resistance against wetting and fouling is lacking in current available membranes on the market [12]. At the moment, membranes designed for microfiltration are utilized in MD and they are mainly made of polyvinylidene fluoride (PVDF) due to its high hydrophobicity, good solubility in common solvent, and high resistance against chemicals and heat [10,13]. Non-solvent-induced phase separation (NIPS) and thermally induced phase separation (TIPS) are the two most common approaches exercised to fabricate membranes. However, these membranes are not good enough for MD processes due to their low flux performance and susceptibility to wetting [14–17]. Thus, recently there is an increasing trend on membrane fabrication with new approaches for MD. Zhang et al. noted that the main challenges for membranes used in MD are to design features including porous structure and superhydrophobic surface for good filtration performance, as well as high mechanical properties for long-term operation [18].

Electrospun membranes possess some appropriate advantages involving high hydrophobicity, high porosity, adjustable pore size, and membrane thickness, which make them attractive candidates as MD membrane [2,19]. Compared to NIPS and TIPS, electrospinning is a relatively simple technique to fabricate membrane. By applying high electric fields on a polymer solution, millions of fibres are formed joining together to become nonwoven membrane sheet and collected on the collector [19,20]. Though electrospun membranes have many attractive properties for MD, however, they had some drawbacks limiting its performance, including relatively big pore sizes, low mechanical properties, and LEP compared to the membranes fabricated by casting methods. Thus, there is a requirement to improve these characteristics without sacrificing high porosity and hydrophobicity by some membrane modification approaches [20]. For this reason, post-treatment process, one type of membrane modification procedures, has been widely applied on the electrospun membrane to enhance its morphology and characteristics including robustness and capability against wetting [21,22]. Previous studies indicated that “heat-press” could enhance the desalination performance by changing mechanical and morphological structure of the membranes in a favourable way [20,23]. It is expected that higher LEP, higher mechanical strength, lesser thickness, smaller average pore size and more uniform distribution of the pore size can be obtained through this technique.

Though a few studies have utilized heat-press to modify their MD membranes, the post-treatment approach is still not fully investigated (i.e., only few heat-press conditions were used) especially for electrospun membranes. Hence, in this study, the effect of different heat-press conditions such as temperature, pressure, and duration are comprehensively investigated to determine their effects on the electrospun membrane properties and MD performance. The optimal heat-press condition set is then identified and applied on electrospun membranes with various initial thicknesses to check the improvement. MD tests with as-spun, heat-pressed and commercial membranes are conducted and compared regarding permeation flux and salt rejection.

2. Experimental

2.1. Materials

The polymer used for the fabrication of membranes was polyvinylidene fluoride-co-hexafluoropropylene (referred herein as PH, MW = 455,000), and it was purchased from Sigma-Aldrich, USA. Acetone (ChemSupply, Australia) and N,N dimethylacetamide (DMAc, Sigma, USA) were used as solvent. All the chemicals were used as received without further purification. A polypropylene (PP) filter layer purchased from Ahlstrom was applied in each MD experiment as support layer. Commercial microfiltration membrane (pore size = 0.22 μm, porosity = 70%, GVHP) bought from Millipore was used for MD test as a reference.

2.2. Membrane fabrication by electrospinning

PH at 20 wt% was dissolved in a mixed solvent consisting of acetone and DMAc (1:4 acetone/DMAc ratio). To obtain homogenous polymer solution, the mixture was magnetically stirred for 24 h. The prepared PH solution was then stored in a 12 ml plastic syringe fitted with a 21G nozzle (internal diameter = 0.51 μm). Fig. 1 illustrates the configuration of the electrospinning device used in this study. The polymer solution was pulled out of the syringe by the syringe pump and formed whipping fibres within a high voltage electrical field (applied voltage = 21 kV). Then fibres were collected onto the rolling drum after most contained solvent evaporated during the whipping process. During electrospinning process, the nozzle was continuously moving inwards and outwards parallel to the axis of the rotation of the drum. The setting operation conditions for electrospinning were constant throughout the study in all the experimental stage: The distance between the nozzle tip and collector was set at 20 cm. The syringe pump had a pushing rate of