Journal of Membrane Science 526 (2017) 395–408

Contents lists available at ScienceDirect

Journal of Membrane Science

journal homepage: www.elsevier.com/locate/memsci

Theoretical modeling and experimental validation of transport and separation properties of carbon nanotube electrospun membrane distillation

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ARTICLE INFO

Keywords:
Carbon nanotubes
Desalination
Direct contact membrane distillation
Electrospun membrane
Heat and mass transfers

ABSTRACT

Developing a high flux and selective membrane is required to make membrane distillation (MD) a more attractive desalination process. Amongst other characteristics membrane hydrophobicity is significantly important to get high vapor transport and low wettability. In this study, a laboratory fabricated carbon nanotubes (CNTs) composite electrospun (E-CNT) membrane was tested and has showed a higher permeate flux compared to poly(vinylidene fluoride-*co*-hexafluoropropylene) (PH) electrospun membrane (E-PH membrane) in a direct contact MD (DCMD) configuration. Only 1% and 2% of CNTs incorporation resulted in an enhanced permeate flux with lower sensitivity to feed salinity while treating a 35 and 70 g/L NaCl solutions. Experimental results and the mechanisms of E-CNT membrane were validated by a proposed new step-modeling approach. The increased vapor transport in E-CNT membranes could not be elucidated by an enhancement of mass transfer only at a given physico-chemical properties. However, the theoretical modeling approach considering the heat and mass transfers simultaneously enabled to explain successfully the enhanced flux in the DCMD process using E-CNT membranes. This indicates that both mass and heat transfers improved by CNTs are attributed to the enhanced vapor transport in the E-CNT membrane.

1. Introduction

Compared to conventional thermal distillation desalination processes, membrane distillation (MD) is a membrane based thermal driven separation process with the principle of vapor–liquid equilibrium. The temperature gradient as driving force generates the water vapor pressure difference between the liquid–vapor interfaces. The evaporated water vapor transport through the hydrophobic membrane pores from feed side to permeate side due to the water vapor pressure difference. Typically, MD is operated at moderate feed temperature (60–90 °C), which is significantly lower than thermal-based processes, such as multi-stage flash (MSF). Thus, recently, the MD process has been focused for desalination and many applications due to the attractive features and especially the relatively low operating feed temperature, which is suitable to apply the solar energy or utilizing low-grade heat source [1–4].

The advantages of MD compared to the conventional desalination processes are as follows: (i) lower operating conditions, such as temperature and pressure compared to MSF and multi effect distillation (MED), and reverse osmosis (RO), respectively, (ii) theoretically high rejection efficiency (100%) of non-volatile solute, and (iii) low effect of high osmotic pressure or concentration to vapor flux [5–7]. However, there is a need to develop membranes offering high flux and better selectivity (solute passage) in order to make the MD process competitive in seawater desalination applications [8]. High flux and selective membrane in MD process depends on membrane hydrophobicity, which enhances vapor transport and reduces possibility of wetting. Wetting is the main problem to increase solute passage through the membrane pores [9].

The developing of novel MD membrane architecture is of great value to enhance the MD performance. Several hydrophobic polymeric membrane materials including polypropylene (PP), polyvinylidene

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http://dx.doi.org/10.1016/j.memsci.2016.12.045
Received 8 September 2016; Received in revised form 3 December 2016; Accepted 22 December 2016
Available online 27 December 2016
0376-7388/