



Spacer optimization strategy for direct contact membrane distillation: Shapes, configurations, diameters, and numbers of spacer filaments



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ABSTRACT

The decrease of vapor flux in a direct contact membrane distillation (DCMD) system is usually triggered by temperature polarization (TP) and concentration polarization (CP). Optimal spacer design is therefore essential to minimize vapor flux decrease. In this study, a numerical DCMD model was developed using computational fluid dynamics. Using a simultaneous evaluation of the effects of TP, CP, and spacer shape and configuration on vapor flux, shear stress and hydraulic pressure drop, the model seeks an optimal manufacturable spacer design. Fifty-one different spacer designs were comprehensively compared after model validation. Based on the simulation results, a symmetric circular-zigzag configuration of spacers gives the best performance for vapor flux, 26% higher than an empty channel. Spacer design optimization was conducted with reference to various sizes and number of spacer filaments. In conclusion, with relatively expensive heat sources, a symmetric circular-zigzag spacer design with a larger diameter and more filaments can be theoretically recommended to maximize vapor flux; in contrast, with cost-free heat sources, a smaller diameter size and fewer filaments can be theoretically recommended to minimize hydraulic pressure drop. In addition, the model outlined in this study could be used to evaluate the performance of other membrane processes associated with spacers.

1. Introduction

With increasing industrialization and urbanization, there has been a significant growth in the global demand for water over the past few decades [1,2]. Desalination technologies have been used as a solution to water stress in many countries to ensure an adequate water supply [3–6]. Large-scale thermal desalination plants were introduced in the 1950s. Middle Eastern countries contributed to the initial development and implementation of thermal seawater desalination processes, such as multi-effect distillation (MED) and multi-stage flash (MSF). Recently, in conjunction with significant technological advances, the reverse osmosis (RO) process has gained popularity in the seawater desalination market due to its low energy consumption [3,7]. Despite significant progress in the RO process, a number of other ways to increase the recovery rate of desalination and to reduce energy consumption have also been explored. One such potential solution is membrane distillation (MD). The MD process combines the advantages of thermal process and membrane processes: it can be driven with a lower temperature difference than traditional distillation processes, and with a lower

operating hydraulic pressure than pressure-driven membrane desalination processes. It also provides high quality water, a low impact from feed water concentrations, and so on [8]. Therefore, MD can be considered as a promising new desalination process for producing high quality water from saline water. Where the major permeate component is water, as in desalination, direct contact membrane distillation (DCMD) has been highlighted from a range of other MD processes [8].

The driving force behind the DCMD process is the vapor pressure difference between feed and permeate solutions. The vapor pressure difference is caused by temperature differences. Therefore, temperature polarization (TP) should be given serious consideration. TP is a phenomenon where the temperature difference between membrane surfaces is lower than the bulk temperature difference due to heat conduction and evaporation [9]. TP reduces DCMD performance because it leads to lower vapor pressure difference. At the same time, concentration polarization (CP) occurs in the vicinity of the membrane. CP is induced by vapor transfer across the membrane, which concentrates the feed concentration in the membrane vicinity. As a result, CP decreases water vapor flux because of lower vapor pressure caused by

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