Desalination 249 (2009) 380–387

Contents lists available at ScienceDirect

Desalination

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

Simulation of membrane distillation modules for desalination by developing user's model on Aspen Plus platform

Hsuan Chang [a,b,*], Jung-Shing Liau [a], Chii-Dong Ho [a,b], Wei-Hong Wang [c]

[a] Department of Chemical and Materials Engineering, Tamkang University, 151 Ying-Chuan Rd., Tamsui, Taipei, 25137, Taiwan
[b] Energy and Opto-Electronic Materials Research Center, Tamkang University, 151 Ying-Chuan Rd., Tamsui, Taipei, 25137, Taiwan
[c] Chemical Engineering Section, Chemical Systems, Research Division, Chung-Shan Institute of Science & Technology, Taoyuan 32544, Taiwan

A R T I C L E I N F O

Article history:
Accepted 23 November 2008
Available online 1 October 2009

Keywords:
Membrane distillation
Simulation
Optimization
Response surface method
Direct contact membrane distillation
Air gap membrane distillation

A B S T R A C T

This paper presents a simulation study of direct contact membrane distillation (DCMD) and air gap membrane distillation (AGMD) for desalination. Simulation models are built on Aspen Plus® platform as user defined unit operations for these two types of modules, respectively. Large scale modules for practical industrial applications are simulated and studied for the effects of design and operation variables, as well as the importance of heat and mass transfers of each phase. For each type of modules with heat recovery design, the response surface method (RSM) is applied to develop the performance-variables quadratic model, followed by the multivariable optimization. Optimal designs can realize separation efficiencies, defined as the ratio of water produced to the feed, of 8.2% and 5.8% for DCMD and AGMD, respectively.

1. Introduction

Membrane distillation (MD) is a thermally-driven process and has received significant interest recently due to the development of novel membranes. The development of MD technology is referred to several significant review papers [1–3]. The ability to utilize low grade heat has made solar-powered MD for desalination an emphasized developing technology in many countries [4–7]. The configurations focused on for desalination are DCMD and AGMD. Solar-powered AGMD compact systems with production rate of pure water around 100 to 200l per day have been demonstrated [5].

As extensively reviewed in El-Bourawi et al. [3], numerous modeling studies, with experiments or not, on MD have been reported. New papers are still evolving, including [8–10]. Almost all of the models apply the fundamental relationships on MD modeling given in Lawson and Lloyd [1], where mass flux is determined by considering the heat transfer resistances in all parts and the mass transfer resistance inside the membrane. The mass transfer resistances of hot liquid and cold liquid are neglected. These models perform well with laboratory scale experimental devices where fluid velocities are relatively high. In practical applications, however, in order to be competitive with other commercial desalination technologies in separation efficiency, such as 10–25% for multi-effect distillation (MED), 30–50% for multi-stage flash (MSF) and 8% for reverse osmosis (RO) [11], MD modules should be operated under much lower fluid flowrates than those used in the laboratory studies. With this consideration, the mass transfer resistances of liquid phases should be included in the mathematical model to avoid improper ignorance.

For design purposes, process simulation packages such as Aspen Plus® [12] has become more and more convenient and powerful. Although many complex process units might not be available in these packages, researchers have successfully built various models on the platform [13–15]. Building of MD units on Aspen Plus® platform has not been reported and will be helpful for the design and development of MD for industrial applications.

This study intends to build on Aspen Plus® platform the models for DCMD and AGMD desalination modules considering all the heat and mass transfer resistances. The models are then utilized to analyze and optimize larger scale systems, such as those reported in Song et al. [16], which can be adopted as compact systems in practical applications. For the multivariable optimization, based on the simulated results from Aspen Plus® for data points selected via the experimental design concept, RSM [17,18] is applied to set up a quadratic model for describing the performance-variables relation. Optimal designs are found by the numerical search on the quadratic models.

2. Mathematical models

In this paper, the models for DCMD and AGMD are set up to include all heat and mass transfer resistances, including hot liquid, membrane and cold liquid in DCMD, as well as hot liquid, membrane, air gap, condensing water, metal and cooling liquid in AGMD. The mass and

* Corresponding author. Department of Chemical and Materials Engineering, Tamkang University, 151 Ying-Chuan Rd., Tamsui, Taipei, 25137, Taiwan. Tel.: +886 2 26232094; fax: +886 2 26209887.
E-mail address: nhchang@mail.tku.edu.tw (H. Chang).

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doi:10.1016/j.desal.2008.11.026

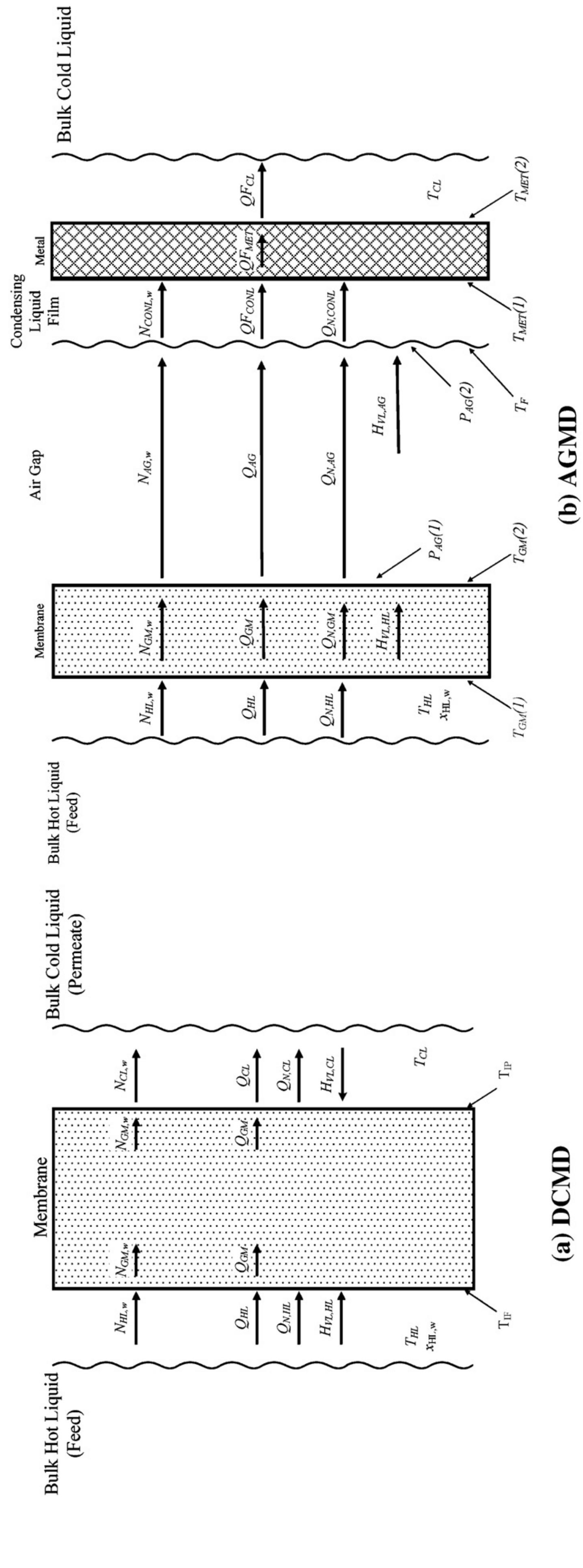

Fig. 1. Mass and energy fluxes.