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Modeling and Simulation for Direct Contact Membrane Distillation in Hollow Fiber Modules

Salah S. Ibrahim and Qusay F. Alsalhy
Dept. of Chemical Engineering, University of Technology, Alsinaa street 52, Baghdad, Iraq

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Direct contact membrane distillation (DCMD) offers an attractive operation for the separation of mixtures at atmospheric pressure with reasonable energy requirement. A new simultaneous heat and mass transfer model in DCMD in a hollow fiber configuration is presented. Flow regime in feed and permeate side, the variations of mean temperature and concentration along the membrane module, the length of the membrane, and various properties of membrane characteristics are taken into account in the present model. A system of nonlinear equations describing the DCMD process is solved numerically for each cell using the FSOLVE coding, which is a built-in function in MATLAB® to find the influence of the temperature and velocity of the feed and permeate streams, and the salt concentration of the feed along the module on the permeate flux. The predicted results by the new model show a good accord with a wide range of various experimental results available in the literature. © 2012 American Institute of Chemical Engineers *AIChE J*, 00: 000–000, 2012
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Introduction

The desalination of sea water is commercially performed by reverse osmosis (RO) and thermal processes like multi-stage flash distillation (MSF). Although such traditional processes are widely used, there is a need for new desalination techniques which are cheaper than both RO and MSF processes or have other significant advantages. Membrane distillation (MD) is considered as a potential alternative to such traditional separation processes.[1]

MD is a novel membrane separation process in which two aqueous solutions at different temperatures are separated by a microporous hydrophobic membrane.[2]

MD is suited for both distilled water production or for the concentration of aqueous solutions. It may offer various advantages in comparison to the traditional distillation and membrane processes if low-grade waste heat energy sources, such as industrial heat streams, geothermic water or even solar energy are provided.[3–6]

MD has been applied for the separation of nonvolatile and trace volatile components from water such as ions, colloids, macromolecules, benzene, chloroform, trichloroethylene, and so forth.[7–12] Moreover, the extraction of alcohols from dilute aqueous solutions has been studied by Garcia-Payo et al.[13] In addition, Tang, et al.[14] also applied MD for the concentration of acids.

However, MD is still being developed at desalination testing stages, and however, it is not fully implemented in industries. The process still under evaluation and different contradicted opinions exist concerning its features.[15]

Correspondence concerning this article should be addressed to Q. F. Alsalhy at qusayalsalhy@yahoo.com or qusayalsalhy@uotechnology.edu.iq.

There are different configurations developed to perform MD process, one of them considered the most used configuration is the direct contact MD (DCMD). In DCMD, a hot nonvolatile solute containing aqueous solution, such as hot brine, is brought into contact with one side of a porous hydrophobic membrane and a colder aqueous distillate stream flows on the other side of the membrane. Transfer of water vapor from the hot brine at the membrane interface takes place through the hydrophobic membrane pores; the water vapor is condensed in the cold distillate on the other side of the membrane. DCMD is quite attractive, because it operates at atmospheric pressure and it is not subject to the osmotic pressure driven limitations of RO process. For this reason, it can be used to treat brines of various salt concentrations.[1,2,16]

Many attempts appeared in the literature for the modeling of MD process. Almost all of the models apply the fundamental relationships on MD modeling given by Lawson and Lloyd,[17] where permeate flux is determined by considering the heat transfer resistances in all parts and the mass transfer resistance inside the membrane. El-Bourawi et al.[18] presented an extensively revision of numerous modeling studies, with or without experiments, on MD. New papers are still evolving.[19–21] Phattaranawik et al.[22] suggested a model based on the assumption of linear temperature profile through the membrane. This proposed model which was able to study the effect of mass transfer on heat transfer rates and heat transfer coefficients, it covered both flow regimes (laminar and turbulent). Qtaishat et al.[19] used the experimental values of permeate flux to determine the boundary layer's heat transfer coefficients, the membrane heat transfer coefficient, membrane/liquid interface temperatures, and membrane mass transfer coefficient. The deviations of the theoretical and experimental results of