"The Influence of Microstructure on Membrane Distillation: Accurate 3-D Reconstructions for Analysis of Pore-scale Phenomena"

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Water filtration technologies play a central role in addressing the water-energy climate nexus through applications such as desalination, contaminant removal, and demineralization. While reverse osmosis is the most common method for such applications, it requires significant power input, and is unable to handle highly-concentrated brines, making waste brine management/chemical discharge a challenge. Membrane distillation (MD) has emerged as a promising approach to desalinate high-concentration brines, brackish waters, produced waters, and seawater to near-saturated conditions, which allows for a smaller physical footprint than other current techniques. MD is a thermal process that can operate at comparatively low temperatures, which enables running on waste heat from industrial or renewable sources. Though attracting considerable attention, several technological barriers must be solved before MD sees significant industrial application. Membrane pore-structures play a dominant role in determining conductive heat losses and membrane permeability to vapor, but are poorly understood to date. Most studies focus on MD hydrodynamics and few attempts have been made to understand pore-scale phenomena within membrane pores. Without sufficient understanding of MD processes at the pore scale, appropriately designed MD systems (membranes and feed spacers) cannot be developed to optimize MD for industrial applications.

This presentation will describe attempts to determine design criteria for the development of new membranes via predictive pore-scale modeling of heat and vapor transport. Current transport models struggle to predict microstructure influence due to inadequate membrane pore-structure representation. Typically, effective membrane parameters are determined by fitting to bench-scale vapor flux measurements, which immediately removes any predictive capability, neglects the link between specific membrane microstructural properties and the resulting mass and heat flows, and prevents a true understanding of the coupling between local hydrodynamic characteristics and the pore fluxes that act as a boundary condition for these flows.

We address this issue by directly measuring the 3-D pore-structures of commercial membranes using *focused ion beam scanning electron microscopy* (FIB-SEM). Via FIB-SEM, structures can be numerically reconstructed for accurate 3-D pore-scale simulations of heat and vapor transport. These 3-D pore scale simulations are then used as a "numerical experiment," for validation of reduced-order, low-cost simulations. These reduced-order models can then be incorporated into system-level, hydrodynamic models to directly link membrane microstructural properties with MD module performance and identify optimal membrane properties. This presentation will demonstrate FIB-SEM as an appropriate technique for developing accurate 3-D transport models at a pore-scale level. The reconstructed 3-D structures are analyzed to determine microstructure parameters such as porosity, tortuosity and mean pore diameter that are important in understanding transport phenomena. We will also discuss efforts to couple the 3-D reconstructed microstructures with 1-D reduced-order heat- and mass-transfer simulations.