OPTIMIZING HOLLOW FIBER MEMBRANES AND MODULES FOR OSMOTIC PROCESSES: MEMBRANES, MODULES, AND MODELS

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Hollow fiber membranes have long been considered a valuable platform for membrane separations because of their high packing density relative to flat sheet membranes. Recently, the osmotic process community has developed hollow fiber membranes intended for forward osmosis (FO) and pressure retarded osmosis (PRO) applications in order to capitalize on these same advantages. Many of these hollow fiber membranes were made using a thin film composite (TFC) approach with the focus on the design of support layer toward a thin, highly porous, minimally tortuous supporting structure to minimize the mass transfer resistance during osmotic processes. These hollow fiber FO membranes demonstrated excellent FO performance, but also suggested a need for intensively and delicately tailored membrane support layers which can lead to compromised membrane properties. This study evaluates an approach to make thin film composite hollow fiber membranes for forward osmosis by simply employing commercial hollow fiber ultrafiltration (UF) membranes as support material. A thin polyamide film with excellent selective properties was synthesized on the inner surface of hollow fibers via interfacial polymerization. Besides demonstrating the feasibility to be used as good TFC FO membrane supports, the commercial hollow fiber UF membranes also provide a systematic platform with consistent properties to study structure-performance relationship of FO hollow fiber membranes. A series of commercial hollow fiber membranes were used to evaluate how molecular weight cutoff (MWCO) impacted the properties of the polyamide layer and overall performance of the TFC membrane. Aside from using commercial hollow fiber UF membranes as FO membrane supports at bench scale, we also demonstrate that the TFC hollow fiber FO membranes can be made on existing hollow fiber modules at pilot scale. A series of commercial hollow fiber modules with different fiber size were used to make TFC hollow fiber FO membrane modules. The resultant TFC hollow fiber membranes were evaluated under various operating conditions (membrane orientation, cross flow arrangement, cross flow velocity, and draw solution concentration). While we evaluate how basic performance metrics (water and solute flux) are impacted by module operating conditions, overall the modules demonstrate impressive FO performances. The facile approach for modification may promote exploration of other hollow platforms for even better performance. With the availability of reproducible membranes and modules, we have developed a computational fluid dynamics (CFD) model with COMSOL Multiphysics to study the impacts of hollow fiber and module properties in order to optimize hollow fiber module design for FO application. Properties like module dimensions (length, width) as well as fiber dimensions (inner diameter and outer diameter) were modeled to better elucidate how such features impact performance. The FO process in a hollow fiber membrane was simulated in a 2D axis-symmetry geometry and described by fluid dynamics coupled with mass transfer across the membrane. We verified the models accuracy by constructing modules with the same dimensions and fibers and testing under pertinent conditions. The agreement between the model and experimental results provided insight into both how more accurate models can be developed and how these models can be used to design better modules without costly experimental testing.