Process Modeling of Hybrid Forward Osmosis-Distillation Desalination Systems

Xingshi Zhou, Daniel B. Gingerich, Jeffrey J. Siirola, Meagan S. Mauter
Chemical Engineering Department, Carnegie Mellon University, Pittsburgh, PA 15213, USA

Forward osmosis (FO), also known as engineered osmosis, is two step process for desalinating seawater and other complex aqueous feed streams. The first step, the passive diffusion of water across a polyamide thin-film composite membrane (similar to that used in reverse osmosis) is driven by an osmotic gradient between the feed stream and a high osmotic pressure draw solution. When using a thermolytic salt, the second step of draw solute recovery uses low-temperature heat to recycle the draw solution and produce a permeate stream of fresh water. Compared to alternative techniques for water desalination this process does not require electricity to power high-pressure pumps (as in reverse osmosis) or high grade thermal energy to evaporate the water (as in multi-stage flash distillation). One promising draw solute/recovery pair are the thermolytic salts created by ammonia and carbon dioxide (NH_4HCO_3, $(NH_4)_2CO_3$, and $NH_2CO_2NH_4$) which can be driven out of water at relatively low temperatures (<70°C) in distillation columns.

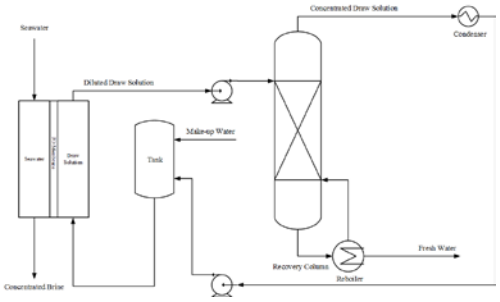


Figure 1. Process Flow Diagram of a Hybrid Forward Osmosis-Distillation Desalination System.

Despite five decades of research on the membrane separation step in FO processes, there are only a handful of papers that have been published on the draw solute recovery step (McGinnis and Elimelech 2007, Kim et al. 2012, Kim et al. 2013). These papers have potential flaws in their modeling and costing approach: neglecting to include the energy consumption of the vacuum in vacuum-assisted distillation, ignoring intermediate equipment, or simply using RO processes for reconcentration. Establishing rigorous models for the temperature and heat duty of the draw solute recovery system is the primary barrier to FO deployment and integration with infrastructure, like power plants, with abundant low-temperature heat.

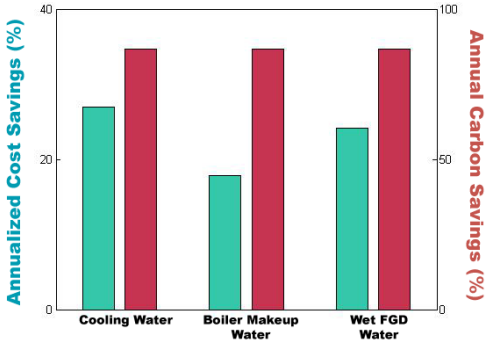


Figure 2. Annual Costs and Carbon Dioxide Emissions Savings for Water Treatment for a 550MW PCC Power Plant (NETL, 2009) using Forward and Reverse Osmosis Processes.

In this study, we design a model to assess the techno-economic feasibility of FO integration with a 550MWH coal fired power plant to treat both on-site boiler make-up water and wastewater effluent from a wet flue gas desulfurization system. The draw solute recovery module for recycling thermolytic ammonia-carbon dioxide salts was modeled using fundamental process models and was compared to a simulation built in commercial software (i.e. ASPEN® Plus). Rigorous calculations considering the existence of dissociations and reactions has made the model more plausible. We then optimized the system to consider heat availability at the power plant, methods for heat capture and utilization, and different column configurations. Finally, we perform an optimization case study for total annual cost and environmental metrics (CO_2 emissions, wastewater effluent composition) by varying membrane area, heat load of distillation column, and necessity of vacuum operation. According to the optimization results, with all possible forms of energy consumption taken into consideration, the hybrid forward osmosis-distillation desalination systems still saved much energy from the ordinary RO or thermal desalination technologies and the integration with waste heat from power plant makes it stand out as a green separation scheme for the future.