Membrane desalination: Where are we and what can we learn from fundamentals

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Reverse osmosis (RO) has matured from a laboratory curiosity at the University of Florida and the University of California at Los Angeles in the early 1960s to an accepted industrial desalination process widely considered as the least energy intensive and most economically attractive technology for separating salt from water. With this wonderful success story, why should we consider alternate methods of desalination? To address this question, we need to understand the limitations of RO, consider fundamental principles of the molecular behavior of water and salt at solid interfaces (i.e. synthetic membranes), and critically assess the potential of other desalination processes.

In this provocative talk, we will first summarize the major technological break-throughs associated with the success of large-scale RO including the development of optimal membrane casting, composition and structure, and module and system design. While fouling and concentration polarization offer inherent limitations, they are dealt with through pretreatment (removal of foulants), chemistry and hydrodynamics. Electro dialysis, an alternative desalination technique, removes the minor component (salt) from brackish water, but has been limited by economics to salt concentrations below ~10,000 ppm. On the other hand, RO requires that 80-90% of the water be removed and most of the salt be retained, contrary to the basic principles taught in an undergraduate separation class. As a result, the thermodynamic efficiency of RO is only about 30-40% today, offering opportunities for significant improvement. Despite its successes, the molecular basis of salt separation by RO is still controversial: Gluekauff, Matsuura and Sourirajan, and Belfort have suggested molecular mechanisms that depend on dielectric, bound water and ion hydration arguments, respectively. Given the importance of water-polymer interactions (hydrogen bonding), polar membrane materials such cellulose acetate and aromatic polyamides are widely used. However, the lack of a molecular-level understanding means that a rational design strategy for improving RO efficiency is missing.

Recent experiments with oxidized graphene and single walled carbon nanotubes, together with simulations of water near polar and non-polar interfaces suggests exciting possibilities for desalination. These results indicate that water moves through non-polar nano-pores with little or no friction, with very high water fluxes using small amounts of energy. Recent attempts to take advantage of these and other ideas, such as electrical forces in the context of desalination will be discussed. They include nature-inspired transport through the well-known aquaporin channels in biological membranes, use of osmotic forces to pull water across a membrane, electrical potential fields in a fluidics channel to divert ions or fractionate water from ions. In summary, we plan to discuss how integrating recent molecular insights with decades of industrial advances will provide exciting opportunities for scalable desalination.