

Ion Solubility, Diffusivity, and Transport in Charged Polymer Membranes

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Charged polymer membranes are widely used for water purification applications involving control of water and ion transport, such as reverse osmosis and electrodialysis. Efforts are also underway worldwide to harness separation properties of such materials for energy generation in related applications such as reverse electrodialysis and pressure retarded osmosis. Additional applications, such as energy recovery ventilation and capacitive deionization, rely on polymer membranes to control transport rates of water, ions, or both. Improving membranes for such processes would benefit from more complete fundamental understanding of the relation between membrane structure and ion sorption, diffusion and transport properties in both cation and anion exchange membrane materials. Ion-exchange membranes often contain strongly acidic or basic functional groups that render the materials hydrophilic, but the presence of such charged groups also has a substantial impact on ion (and water) transport properties through the polymer.

We are exploring the influence of polymer backbone structure, charge density, and water content on ion transport properties. Results from some of these studies will be presented, focusing on transport of salt, primarily NaCl, through various neutral, positively charged and negatively charged membranes via concentration gradient driven transport (i.e., ion permeability) and electric field driven transport (i.e., ionic conductivity). One long-term goal is to develop and validate a common framework to interpret data from both electrically driven and concentration gradient driven mass transport in such polymers and to use it to establish structure/property relations leading to rational design of membranes with improved performance.

Ion sorption and permeability data were used to extract salt diffusion coefficients in charged membranes. Concentrations of both counter-ions and co-ions in the polymers were measured via desorption followed by ion chromatography or flame atomic absorption spectroscopy. Salt permeability, sorption and electrical conductivity data were combined to determine individual ion diffusion coefficients in neutral, cation exchange and anion exchange materials. Manning's counter-ion condensation models and the Mackie/Meares model were used to correlate and, in some cases, predict the experimental data.

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Benny Freeman is the William J. (Bill) Murray, Jr. Endowed Chair in Engineering at The University of Texas at Austin and is Professorial Fellow at Monash University. He is a professor of Chemical Engineering and has been a faculty member for 35 years. Dr. Freeman's research is in polymer science and engineering and, more specifically, in mass transport of small molecules in solid polymers. He currently directs 17 Ph.D. students and postdoctoral fellows performing fundamental research in gas and liquid separations using polymer and polymer-based membranes. His research group focuses on discovery of structure/property relations for desalination and gas separation membrane materials, new materials for hydrogen separation, natural gas purification, carbon capture, and new materials for improving fouling resistance, permeation, and separation performance in liquid separation membranes. He is Director of the Center for Materials for Water and Energy Systems (M-WET), a Department of Energy EFRC (Energy Frontier Research Center).

His research is described in more than 500 publications and 24 US and international patents. He has co-edited 5 books on these topics. His research has served as the basis for several startup companies, including EnergyX and NALA Systems. He has won numerous awards, including the AIChE Materials Engineering & Sciences Division Braskem Award for Excellence in Materials Science and Engineering, the ACS Award in Applied Polymer Science, and the American Institute of Chemical Engineers (AIChE) Institute Award for Excellence in Industrial Gases Technology. He is a Fellow of the AIChE, ACS, North American Membrane Society, AAAS, PMSE, POLY, and IECR divisions of ACS. He is a member of the U.S. National Academy of Engineering and the Texas Academy of Medicine, Engineering, Science & Technology.

