Ultra-fast Propylene-Propane Separation with Hierarchical Molecular Sieves

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Propylene is the monomer for polypropylene and a basic ingredient for many other chemicals including acrylic acid, acrylonitrile, propylene oxide, propanol, allyl chloride. Separation of propylene/propane mixtures using cryogenic distillation is one of the most energy intensive industrial processes due to the similar physical-chemical properties\(^1\). A pressure swing adsorption (PSA) process can be an attractive alternative for propylene propane separation, where microporous zeolites like CHA and LTA are used to provide desired selectivity. But along with this advantage, zeolites impose slow diffusion kinetics/mass transport rates which limit their large-scale implementation. This transport limitation can be tackled by developing Hierarchical Molecular Sieves (HMSs).

In this study, we are focusing on the development of HMSs with small micropore structures and precisely controlled mesopore structures. Two different synthesis routes will be used, top-down and bottom-up. 3D ordered carbon will be used as a hard template in the bottom-up approach where ordered mesopores will be created\(^3\). The top-down route will involve surfactant templating of microporous zeolites. This would result in disordered mesoporous structure\(^3\). Mesopore size and connectivity of the resulting HMSs can be altered using various parameters in both the routes. This series of molecular sieves of small micropore zeolites, CHA and LTA, with different mesopore structures will be used as model materials to carry out a systematic study of mass transport properties. Diffusion pathway in hierarchical molecular sieves involves steps like intracrystalline diffusion in micropores, diffusion on the external surface, and diffusion in mesopores. Previous studies were carried out in a low-pressure range along with the assumption that the diffusivity remains constant under different pressures\(^4,5\). This has led to conflicting results where a decrease in diffusivity was observed after incorporating mesoporosity into the zeolites. In this study, we will investigate this loading dependence of diffusivity because the practical applications of the HMSs are required to run in a wide range of pressure to achieve desired separation capacity.

Sustainable, safe energy storage will be key to fully utilizing renewable power sources and enabling new classes of technology. One significant limitation of electrochemical energy storage is performance loss or failure at low (<-20°C) temperatures. This shortcoming impacts the efficiency of mature technologies such as electric vehicles in cold climates. In more extreme environments, such as polar regions, aerospace, and other potentially habitable planets, the development of certain novel technologies which demand power delivery at -70°C and colder are even more severely limited. Clearly, a means of low temperature energy storage is needed.

Here, we show that aqueous electrolytes represent an unexpectedly promising solution to this low temperature issue. The high solubility of lithium chloride in water greatly lowers the freezing point at the eutectic concentration, allowing for a liquid aqueous electrolyte to exist at -74°C. This electrolyte is used to support low temperature energy storage in supercapacitors containing an industry standard activated carbon, retaining 72% of room temperature capacity (28 F/g) at -70°C and 42% at -80°C. Since the electrolyte is non-flammable, high temperature operation is also possible up to 80°C, amounting to a broad 160°C temperature range which covers the most extreme conditions on Earth. At -70°C, the electrolyte has a remarkably high conductivity (1.83 mS/cm) and a three-volt stability window, on par with conventional organic electrolytes at room temperature. By blending in poly(vinyl alcohol), a polymer electrolyte is made which retains much of the low temperature performance and is used to make a device capable of lighting an LED at -70°C for more than a minute. The devices made here excel at low temperature energy storage and use only safe, low-cost, commodity materials.