Design and Evaluation of CO2-Responsive Forward Osmosis Draw Solutes

Clean water is necessary for every aspect of human life. Unfortunately, the energetic and financial cost of filtering water increases with the feed concentration, to the point of being prohibitively expensive. Forward osmosis (FO) is a promising purification method, with much lower energy demands than conventional methods and the capability to process concentrated wastewater (see figure 1).

The efficiency of FO hinges on the draw solute, which requires two contradictory properties: high osmotic pressure (\(\pi\)) for efficient filtration and low \(\pi\) for low energy removal. CO2-responsive materials are attractive draw solutes as they possess different \(\pi\) in the presence and absence of CO2. CO2-responsive materials contain tertiary amines that react with carbonated water to form one bicarbonate anion per protonated nitrogen, thereby increasing the \(\pi\) of the solution. This can be easily reversed by mild heating (~60 °C), returning the solution to a low \(\pi\) state:

\[
NR_3 + CO_2 + H_2O \rightleftharpoons [HNR_3^+][HCO_3^-]
\]

The most successful draw solute reported to date, trimethylamine (TMA), is a highly efficient draw solute but is also flammable, toxic, degrades membranes and exhibits significant reverse solute flux. This work focused on the design, synthesis, and evaluation of CO2-responsive draw solutes for FO as alternatives to TMA. A range of materials have been synthesized and tested, including polymers, hydrogels and particles. The basicity, structure, molecular weight, and hydrophilicity of the amines are key to producing a favorable balance of \(\pi_{\text{air}}\) to \(\pi_{\text{CO2}}\). The specific case of polymeric draw solutes will be presented, illustrating how a successful candidate, poly(N,N-dimethylallylamine, PDMAAm) was identified. PDMAAm posses an unsurpassed \(\pi_{\text{air}}: \pi_{\text{CO2}}\) and is in the process of being explored on a large scale.

Figure 1. The FO process using a generic draw solute.