

TRIMETHYLAMINE DRAW SOLUTE IN OSMOTIC HEAT ENGINE FOR POWER GENERATION

Lingling Xia, Department of Chemical and Biomolecular Engineering, University of Connecticut, CT, US
lingling.xia@uconn.edu

Jeffrey R. McCutcheon, Department of Chemical and Biomolecular Engineering, University of Connecticut, CT, US
jeff@enr.uconn.edu

Key Words: pressure retarded osmosis; osmotic heat engine; draw solute; trimethylamine; power generation

Naturally occurring salinity gradients, such as where river water meets seawater, were considered untapped sources energy that could be harnessed with technologies like pressure retarded osmosis (PRO). Unfortunately, relatively low osmotic pressure of seawater limits power generation potential. Pretreatment to remove contaminants in natural streams would be cost prohibitive and could result a substantial loss in energy production [1]. The concept of the osmotic heat engine (OHE), addresses these two problems of PRO. The OHE is a “closed loop” PRO process with a thermally regenerable draw solute. By choosing a thermolytic solute with a high solubility, osmotic pressures far in excess of seawater are possible. In addition, no pretreatment is needed because the solutions are pristine and contain no foulants. OHEs therefore can produce far more power and with fewer losses than conventional PRO. The development of the OHE was made possible by the recently developed $\text{NH}_3\text{-CO}_2$ thermolytic draw solute. This solute, which in water consists of ammonium salts, can be easily regenerated by conventional steam stripping and was the focus of numerous studies on forward osmosis (FO) [2, 3]. However, one of the major challenges with the $\text{NH}_3\text{-CO}_2$ solute is its high reverse salt flux, impairing the water flux and power density due to lost osmotic pressure and internal concentration polarization.

A newly investigated thermolytic draw solute is trimethylamine–carbon dioxide (TMA-CO_2). Like $\text{NH}_3\text{-CO}_2$, TMA-CO_2 has a high solubility in water and can generate high osmotic pressure. It also features comparable volatility to ammonia and low enthalpy of vaporization, indicating comparable or less energy would be consumed for draw solute regeneration. The benefit of TMA-CO_2 lies in its larger molecular size. This makes it less likely to pass through the membrane. In this work, we explore the use of TMA-CO_2 in PRO and compare its performance to other model draw solutes (NaCl) and $\text{NH}_3\text{-CO}_2$. Tests were conducted with up to 5 M solutions of TMA-CO_2 using a lab-scale PRO test system with a proprietary Porifera membrane. Estimated power densities of up to 18.6 W m^{-2} were achievable at relatively low pressures (10 bar). For comparison, NaCl and ammonia-carbon dioxide ($\text{NH}_3\text{-CO}_2$) have been evaluated for PRO performance using Porifera membrane. The water flux of TMA-CO_2 was about 20 % lower than that of NaCl and comparable with that of $\text{NH}_3\text{-CO}_2$. Reverse solute flux of TMA-CO_2 ranged from 0.5 to $3.5 \text{ mol m}^{-2} \text{ h}^{-1}$ in all experiments. This value was much lower than $\text{NH}_3\text{-CO}_2$ (4.0 to $51 \text{ mol m}^{-2} \text{ h}^{-1}$) and approximately half that of NaCl. Low solute flux was attributed to molecular size differences between solutes. In addition, the overall PRO performance of TMA-CO_2 (higher water flux, lower salt flux and higher power density) can be further improved by conditioning the existing membrane prior to PRO testing. It has been proved by our result that by conditioning porifera membrane under 150 psi pressure (essentially in RO) for 2 hours prior to testing under relevant PRO conditions with 3 M NaCl, water flux increases by 17% and salt flux drops by an astonishing 85%. In all, TMA-CO_2 represents an OHE draw solute option with low draw solute flux without substantial sacrifice of power density. This solute, as well as its many derivatives, may therefore represent the “sweet spot” for thermolytic OHE systems.

[1] N.Y. Yip, M. Elimelech. *Environ.Sci.Technol.*, 46 (2012) 5230.

[2] J.R. McCutcheon, R.L. McGinnis, and M. Elimelech. *J.Membr.Sci.*, 278 (2006) 114.

[3] R.L. McGinnis, N.T. Hancock, M.S. Nowosielski-Slepowron, and G.D. McGurgan. *Desalination*, 312 (2013) 67.