

Mini Review on the Effects of Concentration Polarization in Forward Osmosis and Pressure-retarded Osmosis Processes

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Extended Abstract

Discharge of water from the boundary layer of the thin film composite membrane can unbalance the concentration of solution at the membrane–feed interface and the bulk solution. This phenomenon is known as concentration polarization, and is common in pressure-driven membrane processes, particularly in reverse osmosis (RO) and nanofiltration (NF), but also in emerging forward osmosis (FO) and pressure retarded osmosis (PRO) processes. There are two types of concentration polarization, external (ECP) and internal (ICP). The effect of concentration polarization is always to decrease the membrane productivity (water flux) and selectivity (salt rejection); in other words, it undermines membrane performance regardless of the process. The ECP can occur at both interfaces of a membrane and can be dilutive or concentrative. However, it can be mitigated by promoting turbulence at a fluid-membrane interface. On the other hand, the ICP, which also can be dilutive or concentrative, occurs within a porous sublayer of the membrane. Therefore, the ICP is unavoidable because it is not possible to induce turbulence within the porous sublayer. The ICP is unique to the FO and PRO processes because of the opposite direction of solute and water fluxes. Although it is not possible to eliminate the effects of ICP in FO and PRO processes, it is possible to partly reduce its negative effects by optimizing the membrane structure. In turn, this requires an understanding of the mass transfer processes taking place in FO and PRO membranes. In this mini-review, we will examine basic transport equations pertinent to FO and PRO processes and link them to the phenomena of ECP and ICP, and the membrane performance.

Keywords: Mass transfer, FO, PRO, membrane, ICP and ECP

References

- [1] S. Sablani, M. Goosen, R. Al-Belushi, M. Wilf, Concentration polarization in ultrafiltration and reverse osmosis: a critical review, *Desalination* vol. 141 (2001) pp. 269-289.
- [2] S. Sablani, M. Goosen, R. Al-Belushi, M. Wilf, Concentration polarization in ultrafiltration and reverse osmosis: a critical review, *Desalination* vol. 141 (2001) pp. 269-289.
- [3] J.R. McCutcheon, M. Elimelech, Modeling water flux in forward osmosis: Implications for improved membrane design, *AIChE Journal* vol. 53 (2007) pp. 1736-1744.
- [4] M. Reali, G. Dassie, G. Jonsson, Computation of salt concentration profiles in the porous substrate of anisotropic membranes under steady pressure-retarded-osmosis conditions, *Journal of membrane science* vol. 48 (1990) pp. 181-201
- [5] J.R. McCutcheon, M. Elimelech, Influence of concentrative and dilutive internal concentration polarization on flux behavior in forward osmosis, *Journal of Membrane Science* vol. 284 (2006) pp. 237-247.
- [6] C.H. Tan, H.Y. Ng, Modified models to predict flux behavior in forward osmosis in consideration of external and internal concentration polarizations, *Journal of Membrane science* vol. 324 (2008) pp. 209-219.
- [7] M. Park, J.J. Lee, S. Lee, J.H. Kim, Determination of a constant membrane structure parameter in forward osmosis processes, *Journal of Membrane Science* vol. 375 (2011) pp. 241-248.
- [8] C.Y. Tang, Q. She, W.C. Lay, R. Wang, R. Field, A.G. Fane, Modeling double-skinned FO membranes, *Desalination* vol. 283 (2011) pp. 178-186.

- [9] N.T. Hancock, P. Xu, D.M. Heil, C. Bellona, T.Y. Cath, Comprehensive bench-and pilot-scale investigation of trace organic compounds rejection by forward osmosis, *Environmental science & technology* vol. 45 (2011) pp. 8483-8490.
- [10] C.Y. Tang, Q. She, W.C. Lay, R. Wang, A.G. Fane, Coupled effects of internal concentration polarization and fouling on flux behavior of forward osmosis membranes during humic acid filtration, *Journal of Membrane Science* vol. 354 (2010) pp. 123-133.
- [11] J.R. McCutcheon, R.L. McGinnis, M. Elimelech, Desalination by ammonia-carbon dioxide forward osmosis: Influence of draw and feed solution concentrations on process performance, *Journal of Membrane Science* vol. 278 (2006) pp. 114-123.
- [12] A. Achilli, T.Y. Cath, A.E. Childress, Power generation with pressure retarded osmosis: An experimental and theoretical investigation, *Journal of Membrane Science* vol. 343 (2009) pp. 42-52.
- [13] B. Gu, D. Kim, J. Kim, D. Yang, Mathematical model of flat sheet membrane modules for FO process: Plate-and-frame module and spiral-wound module, *Journal of Membrane Science* vol. 379 (2011) pp. 403-415.
- [14] G. Schock, A. Miquel, Mass transfer and pressure loss in spiral wound modules, *Desalination* vol. 64 (1987) pp. 339-352.
- [15] V. Gekas, B. Hallström, Mass transfer in the membrane concentration polarization layer under turbulent cross flow: I. Critical literature review and adaptation of existing Sherwood correlations to membrane operations, *Journal of Membrane Science* vol. 30 (1987) pp. 153-170.
- [16] E.M. Hoek, A.S. Kim, M. Elimelech, Influence of crossflow membrane filter geometry and shear rate on colloidal fouling in reverse osmosis and nanofiltration separations, *Environmental Engineering Science* vol. 19 (2002) pp. 357-372.
- [17] M.C. Wong, K. Martinez, G.Z. Ramon, E. Hoek, Impacts of operating conditions and solution chemistry on osmotic membrane structure and performance, *Desalination* vol. 287 (2012) pp. 340-349.
- [18] Y. Xu, X. Peng, C.Y. Tang, Q.S. Fu, S. Nie, Effect of draw solution concentration and operating conditions on forward osmosis and pressure retarded osmosis performance in a spiral wound module, *Journal of Membrane Science* vol. 348 (2010) 298-309.
- [19] C.Y. Tang, Q. She, W.C.L. Lay, R. Wang, A.G. Fane, Coupled effects of internal concentration polarization and fouling on flux behavior of forward osmosis membranes during humic acid filtration, *Journal of Membrane Science* vol. 354 (2010) pp. 123-133.
- [20] N.Y. Yip, A. Tiraferri, W.A. Phillip, J.D. Schiffman, M. Elimelech, High performance thin-film composite forward osmosis membrane, *Environmental science & technology* vol. 44 (2010) pp. 3812-3818.