“BREAKTHROUGH” OSMOSIS IN “LEAKY” SUPPORTED MEMBRANES: A BREAKTHROUGH IN PRO?

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It is shown theoretically that allowing for a certain (even quite small) extent of membrane “leakiness” (deviations from ideal perm-selectivity) can give rise to a previously overlooked mode of “breakthrough” osmosis in thin polymeric membranes supported mechanically by porous layers. This result is obtained by using the well-established Spiegler-Kedem model for the description of solute and volume transfer across the membrane barrier layer and the classical convection-diffusion equation for modelling the solute transfer within the porous support layer. The use of these simple modelling tools enables one to obtain transparent analytical solutions and simple criteria for the occurrence of the “breakthrough” mode. In particular, we show that it occurs only in the PRO configuration (barrier layer facing the concentrated solution), only when the solute concentration in the dilute solution is very low and only when the draw-solution concentration is sufficiently high (exceeds a threshold value).

We demonstrate that in this mode the rate of osmosis is very large (compared to the conventional mode) and practically independent of the diffusion permeance of the support layer. This opens interesting opportunities in the utilization of this phenomenon in Pressure-Retarded Osmosis (PRO) because the support layers can be made much more robust mechanically without compromising the PRO performance by the Internal Concentration Polarization. Besides, the estimated power densities achievable in the “breakthrough” mode can easily exceed by one order of magnitude those predicted in the conventional mode. This can help resolve two principal problems encountered in PRO: insufficient power density and mechanical collapse of thin and loose membranes into the openings of dilute-side spacers.

Our analysis shows that for the “breakthrough” mode to occur the membrane must combine a certain extent of “leakiness” (solute reflection coefficients of ca. 0.95 – 0.995) with sufficiently low diffusion permeability. Reliable experimental detection of minor deviations from ideal perm-selectivity can be difficult (primarily in view of concentration-polarization phenomena). Therefore, it is not clear if the corresponding membranes currently exist. Nonetheless, this analysis provides membrane material scientists with clear guidance on the desired properties of membranes that could become a potential game-changer in renewable energy.