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System scale analytical modeling of forward and assisted forward osmosis mass exchangers with a case study on fertigation

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Abstract

Forward osmosis (FO) and assisted forward osmosis (AFO) mass exchangers are currently receiving considerable attention for their potential use in a variety of dilution and concentration applications in resource extraction, fertigation, and pharmaceutical process streams. In this work we develop analytical expressions for parallel and counterflow exchangers which can be used to quickly and accurately estimate the membrane area required for dilution and concentration processes in addition to determining the performance of existing exchangers. Unlike previous models, our analytical model accounts for internal and external concentration polarization in system scale exchangers with overall average errors of less than 10% against a numerical model and less than 35% validated against data from literature. The performance of FO and AFO exchangers is compared, and an osmotic fertilizer dilution (fertigation) case study is investigated in which the trade-off between energy and membrane area requirements is quantified. We find that AFO exchangers yield a higher recovery relative to FO exchangers for a given energy input especially when the inlet draw-to-feed osmotic pressure ratio is low. We find that diminishing returns in recovery ratio are attained for increasing membrane area and increasing draw-to-feed mass flow rate ratio. We also find that for the same brackish feed water and recovery ratio, reductions in area of up to 40% relative to FO can be realized with 2 kWh/m^3 of energy input into an AFO system in the fertigation case study.

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