Simulation of a Full-Scale Forward Osmosis-Nanofiltration Hybrid System through mass-balance

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1. Background

Water scarcity is becoming a significant issue worldwide and, desalination and water reuse are two of the reliable solutions. Desalination is however currently not cost-effective for irrigation. Recent efforts have been to develop less capital and energy intensive desalination technologies such as forward osmosis (FO) that drives based on natural osmotic process unlike the conventional reverse osmosis (RO) desalination process that uses lot of energy. Based on recent studies, FO hybrid systems could be more effective when the water treatment involves highly challenging waters [1, 2]. Fertiliser driven FO or FDFO process is seen as one of the potentials for practical application of FO process [3, 4]. The diluted fertiliser DS from the FO process after dilution contains nutrients essential for the plants and hence can be used for fertigation of crops if the nutrient concentration meets the required standard. Recently, FDFO-NF system has been studied at a pilot-scale level by this group [5].

The main objective of this study is to conduct a full-scale FDFO-NF simulation of how the various process parameters in the hybrid system affect each other when operated in a continuous closed-loop system based on the simple mass balance of the volumetric flows, draw solutes and the feed solutes. This study provides an enhanced understanding of some of the options and limitations of operating full-scale FDFO-NF hybrid system in a continuous closed-loop system. The result of this study is also applicable to any closed loop membrane FO-RO and FO-NF hybrid system for any applications.

2. Methodology

The simulation is entirely based on the mass balance in the closed FDFO-NF hybrid system and hence the process performances including performance mechanisms are not taken into considerations. The mass balance covered the following aspects of the hybrid system: volumetric solution flows, draw solutes and feed solutes. The simulation was carried out assuming $(NH_4)_2SO_4$ or SOA as DS, NaCl solution as FS. Some of the other important simulation parameters used are specific reverse solute flux or $SRSF_D$ = 0.5 gL^{-1} SOA based on our pilot-scale FDFO-NF operation in the field recently for CTA FO membrane [5]. The NaCl rejection rates of FO and NF membranes and SOA rejection rate of NF membrane is assume at 90% for simulation study unless stated otherwise.

3. Discussion and conclusions

The simulation results show how varying the process parameters could have profound implications on the plant performance and plant design. Following are the summary of the findings from this simulation study:

- Unlike in a lab-scale FO studies, the initial DS flow rate and its concentration in a full-scale FO-NF hybrid system with fixed plant capacity cannot be set at an

arbitrary values as they directly influence the final diluted DS concentration including the plant capacity as shown in Fig 1a.

- For a fixed FO-NF plant capacity, the initial DS flow rate and its initial net concentration are inversely related (Fig 2b). A net DS mass loading rate (product of initial concentration difference between the DS and FS and the initial DS flow rate) is one of the most important parameters for the design of the continuous closed-loop FDFO-NF system. The net mass-loading rate is constant for a fixed plant capacity irrespective of what the initial DS concentration or the DS flow rate is used but its value increases with the increase in the plant capacity and the feed concentration.
- The reverse diffusion of draw solute through the FO membrane could add a significant cost to the FO-NF plant due to need for its replenishment and also due to the need for special brine treatment and management showing the need to develop FO membranes with high reverse flux selectivity for commercial applications.
- Depending on the rejection rates of the FO and NF membranes, accumulation of feed solutes could occur in the closed-loop FDFO-NF system which increases rapidly with the number of DS recycling but reaching a steady peak concentration. The accumulated feed solute concentration in the recycled DS could however provide enhanced driving force of the DS as long as it does not affect the final product water quality in terms of Na^+ or Cl^- concentrations for irrigation. This could be a challenge for FS with higher TDS such as seawater unless FO membrane with high rejection is used.
- This study demonstrates limitations of the FO-NF hybrid process and the options available for improving the operation of a closed-loop hybrid system.

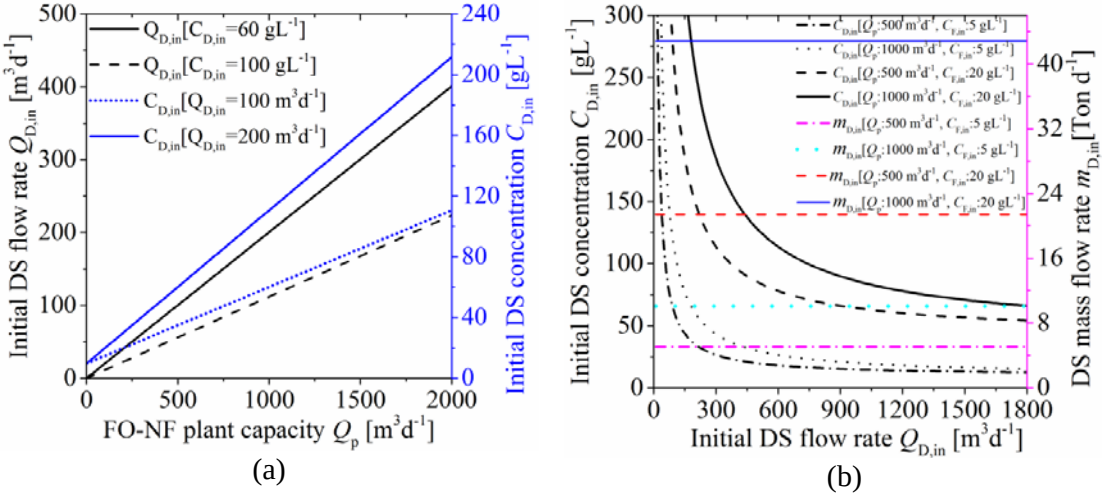


Fig 1: Influence of each process parameters over the other process parameters. (a) FO-NF plant capacity on the required initial DS flow rates and DS concentrations and (b) initial DS flow rate on the required initial DS concentration and the net mass flow or loading rates. $C_{D,in}$ & $Q_{D,in}$: initial DS concentrations & flow rates, Q_p: FDFO-NF plant capacity, $m_{D,in}$: DS net mass loading rate.

References

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