Draw Solution Revolution – Evaluation of Mixed Draw Solutions for Improved FO Performance

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Introduction:

Water scarcity still plagues much of the world, and with many US states facing prolonged drought new and more advanced waste water treatment processes must be implemented to obtain water security and improve water reuse. The osmotic membrane bioreactor (OMBR) is an example of an advanced technology for water reuse (Figure 1). The OMBR implements forward osmosis (FO), which uses a draw solution (DS) with a high osmotic pressure to draw water through a semi-permeable membrane. The OMBR is able to produce potable water, which has the advantages of immediate consumption, reduces water infrastructure costs, and eliminates any possibilities of natural contaminants. Although the OMBR has many benefits, certain details within the FO system must be refined. The traditional DS is composed of sodium chloride, but with a high diffusivity coefficient, NaCl crosses the membrane from the DS into the feed solution at a relatively high rate. This process is called reverse salt flux (RSF). RSF causes two major problems: (1) salt that accumulates in the feed solution disrupts the microbial community within the wastewater and (2) the salt absorbed into the feed decreases the osmotic pressure gradient (driving force) across the membrane. By using divalent ions with lower diffusivity coefficients a reduction of RSF is possible but also may result in lower water flux and process efficiency.

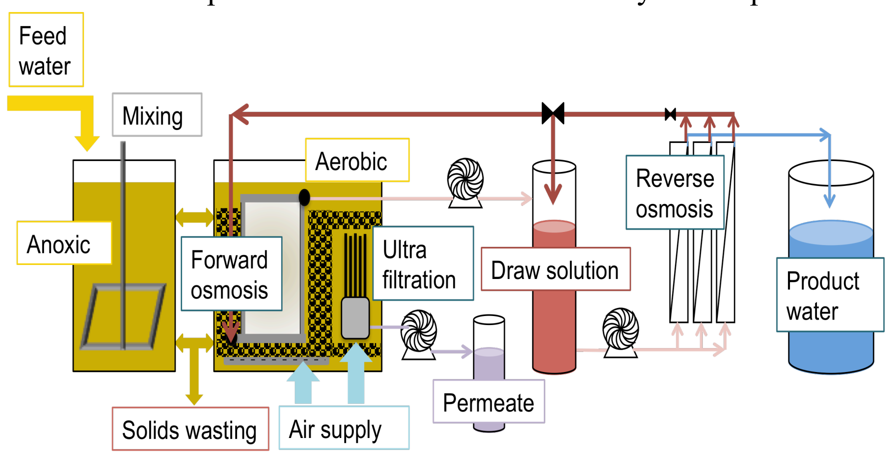

Figure 1. Schematic of UFO-MBR system.

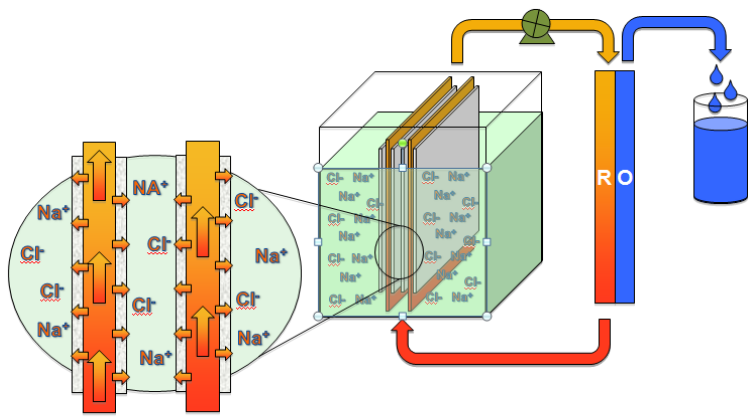

Figure 2. RSF occurring within FO

Procedures:

Five salts were tested, sodium chloride (NaCl) being the baseline salt and the mixed salts: magnesium chloride ($MgCl_2$), magnesium sulfate ($MgSO_4$), sodium acetate (NaAce), and sodium citrate (NaCit). 1 molar NaCl osmotic pressure was used to create mixed solution at 5% and 10% concentration. A bench scale was used to simulate FO that would occur in OMBR, **Fig 1**. **Fig 2** shows the flow of water within the bench scale. The blue water is the feed solution while the red lines represent the DS. The two solutions are never in direct contact and are only separated by the thin filmed composite (TFC) membrane in the cross flow membrane cell. At this intersection water molecules from the feed solution diffuse through the membrane into the DS, while salt ions from the DS diffuse in the opposite direction and enter the feed solution. Samples of the feed solution were taken every half hour and second hour of testing to determine the RSF. The weight of the feed solution was recorded every 10 seconds and used to calculate the water flux.

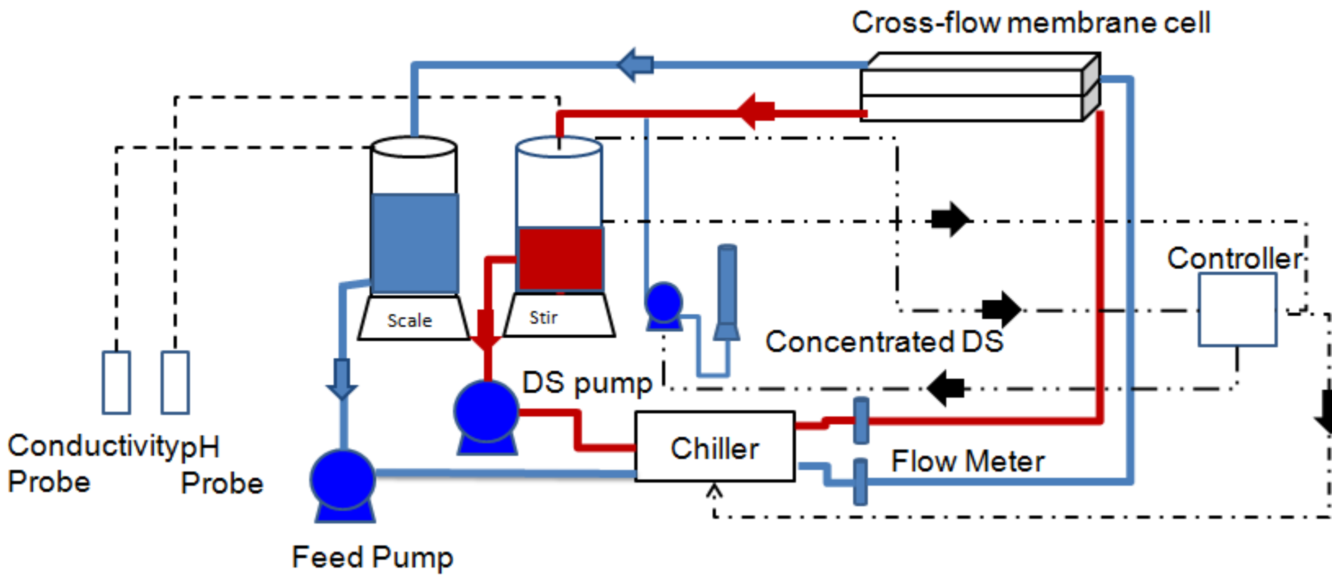

Figure 2. Schematic of FO bench scale system

Results and Discussion:

The water flux for all mixed DSs at 1 M was similar to that observed for the standard NaCl DS (Figure 3a). DS of pure salt (non-NaCl) at the same osmotic pressure induced lower water flux than NaCl, which correlates with the diffusivity coefficient of the respective salts (Figure 3b). The RSF was higher for NaCl compared to all mixed salt solutions, with 5% $MgCl_2$ having a 47% percent decrease compared to NaCl (Figure 3b). Possible explanations why mixed salt DSs reduced RSF involve aquatic and membrane surface chemistry. For example, when $MgCl_2$ dissociates, the Mg^{+2} ion is drawn to the slightly negatively charged TFC membrane. The attraction of Mg^{+2} to the membrane may reduce the RSF of smaller ions by three possible mechanisms:

(1) Electrostatic interactions and repulsion – the membrane surface may become slightly positive due to the electric double layer that develops as Mg^{+2} ions accumulate near the membrane. The slight positive charge may repel sodium ions, reducing sodium flux and attract chloride ions.
(2) Size exclusion – larger divalent and organic ions may inhibit (shielding) the diffusion of smaller ions.
(3) Ion diffusivity – chloride ions have a higher diffusivity coefficient, which allow chloride ions to move through the membrane at a faster rate compared to sodium.

Regardless of the mechanism, the RSF was reduced for all 1 M mixed salt DSs while high water flux was maintained. Although the mechanism that drives the RSF and water flux is still not completely understood, further research is being conducted to support or disprove current theories.

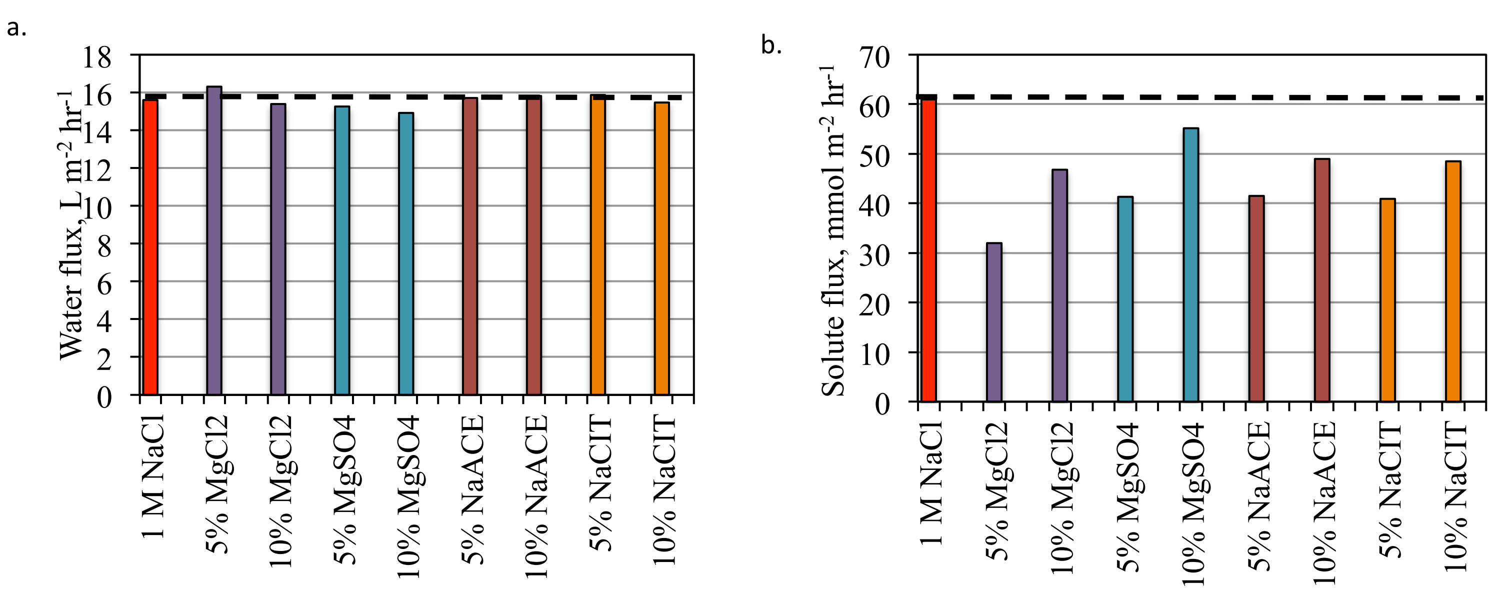

Figure 3. FO (a) water flux and (b) solute reverse flux for single and mixed salt solutions at an osmotic pressure equivalent to 1 M NaCl.