

*Supporting Information for: The Effects of Transmembrane Hydraulic Pressure on
Performance of Forward Osmosis Membranes*

Bryan D. Coday^a, Dean M. Heil^a, Pei Xu^b and Tzahi Y. Cath^{a,*}

^a Colorado School of Mines, Golden, CO, USA

^b New Mexico State University, NM, USA

* Corresponding author. Tel.: +1 303 273 3402; fax: +1 303 273 3413

E-mail address: tcath@mines.edu

A manuscript prepared for possible publication in
Environmental Science and Technology

Revised: January 28, 2013

Summary:

Number of pages: 2

Number of tables: 2

Number of figures: 1

Page S1: **Table S1.** Membrane physical and chemical properties

Page S1-S2: Methods used to calculate ion rejection and reverse solute flux

Page S2: **Figure 1.** A schematic drawing of the bench-scale FO apparatus used in this study.
Adapted from.1

Page S2: **Table S2.** Formulated sea salt composition

Table S1. Membrane physical and chemical properties

	Unit	CTA	TFC1	TFC2
Pure water permeability (A)	L/m ² -h-bar	0.55	4.72	1.63
Salt permeability (B)	m/s	4.8x10 ⁻⁸	1.2x10 ⁻⁷	8.3x10 ⁻⁸
Structural parameter	µm	463	365	690
Zeta potential, active layer	mV ^a	-34.9	-42.5	-38.6
Zeta potential, support layer	mV ^a	-39.5	-3.0	-9.5
Contact angle	°	63.7±6.8 ^b	67.8±11.8	27.7±10.4
Average water flux	L m ⁻² hr ⁻¹ ^c	9.9±0.1 ^d 8.4±0.1 ^e	31.9±3.3 ^f	9.8±0.6 ^d 10.4±0.3 ^e
Average reverse NaCl flux	mmol m ⁻² hr ⁻¹ ^c	88.2±8.5 ^d 63.9±1.1 ^e	344.7±26.7 ^f	143.4±14.2 ^d 113.6±2.5 ^e
^a at pH 7.0				
^b Contact angle measured using the captive bubble method				
^c Virgin membranes at 20 °C, 1M NaCl draw solution, and deionized feed water				
^d Virgin membranes utilized during tests with NaCl draw solution				
^e Virgin membranes utilized during tests with sea salt draw solution				
^f In-situ membrane wetting was performed with 50 IPA for 5 minutes following the installation of each membrane coupon. This procedure did not affect water or salt fluxes.				

Methods used to calculate ion rejection and reverse solute flux

Determination of Water Flux

Water permeation rate was determined by measuring the change in mass of the deionized water on the analytical balance (Mettler Toledo, Columbus, OH) as a function of time for the duration of each experiment. The mass of deionized water decreased with time because water that permeated through the membrane from the feed solution into the draw solution was replaced by dosing deionized water (to maintain constant volume of the feed loop). The slope of mass versus time is the mass transfer rate through the membrane for an individual experiment. Water flux was determined by dividing the mass transfer rate by the water density and membrane surface area.

Determination of Salt/Solute Reverse Flux

Salt flux values reported in the manuscript were calculated by measuring the increase of feed solution conductivity (converted to concentration) or changes in ion concentration over a selected time period. A K=1 cm⁻¹ cell constant conductivity probe was specifically calibrated for dilute feed solutions. Feed solution conductivity increased linearly as a function of time as draw solution solutes diffused into the feed solution. Salt flux was determined by converting the slope of the feed solution conductivity increase per unit time to concentration per unit time based on a calibration curve generated for each salt type; this value was then multiplied by the feed solution volume and divided by membrane surface area.

To determine the reverse flux of specific ions, the concentration of the ion was measured with the appropriate method (e.g., IC, ICP, TOC, etc.) between two consecutive samples that were drawn from the feed tank. Subsequently, the difference in ion concentration was calculated (mg/L or mmol), the value was multiplied by 3 L (the constant volume of the feed tank), and the new value was divided by the area of the membrane. It is important to note that a meticulous mass balance must take into account the mass lost during sample withdrawal and incorporate it back into the calculations.

Determination of Ion Rejection

The concentration of specific ions was measured with the appropriate method (e.g., IC, ICP, TOC, etc.) between two consecutive samples that were drawn from the draw solution and feed solution tanks. Subsequently, the concentration of specific ions in the draw solution was multiplied by the volume of draw solution at the time of sample withdrawal. The difference in ion mass in the draw solution was calculated and the value was divided by the volume of water that crossed the membrane between the two samples

withdrawn. The new value represents the concentration of the ion in the water that permeated the membrane. This value is then used in conjunction with the average concentration of the specific ion in the feed solution to calculate ion rejection $[R=(1-(C_p/C_f))*100]$. The same method is used to calculate organic rejection.

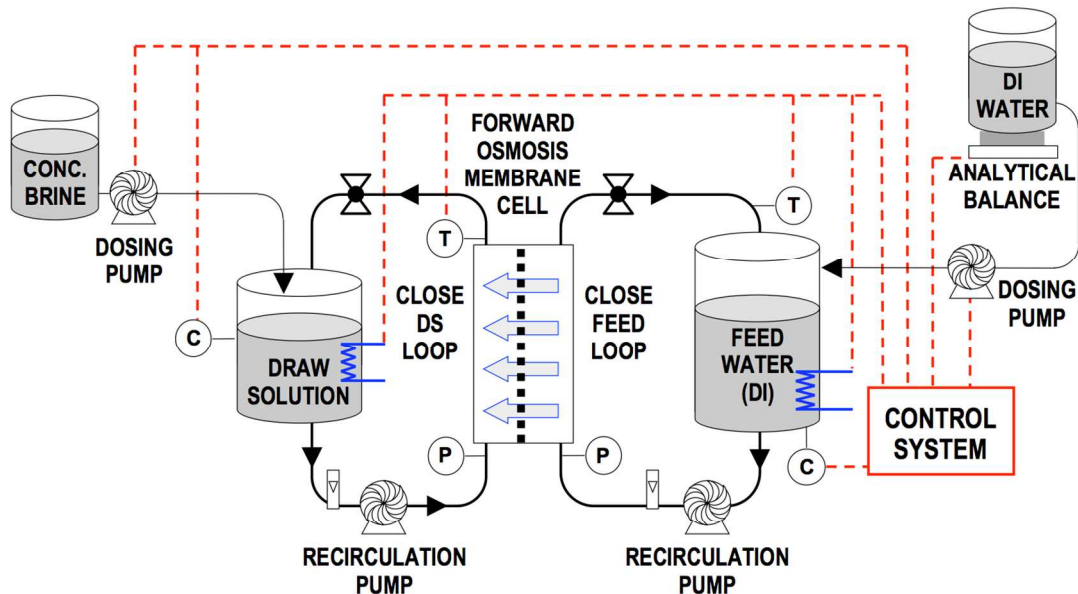


Figure S1. A schematic drawing of the bench-scale FO apparatus used in this study. Adapted from.¹

Table S2. Formulated sea salt composition

Analyte	Concentration (mg/L)
Chloride	32,990
Sodium	18,436
Sulfate	4,549
Magnesium	2,258
Potassium	718
Calcium	684
Carbonate/bicarbonate	342
Bromide	96
Strontium	15
Boron	10
Fluoride	2

Reference

1. Cath, T. Y.; Elimelech, M.; McCutcheon, J. R.; McGinnis, R. L.; Achilli, A.; Anastasio, D.; Brady, A. R.; Childress, A. E.; Farr, I. V.; Hancock, N. T.; Lampi, J.; Nghiem, L. D.; Xie, M.; Yip, N. Y., Standard methodology for evaluating membrane performance in osmotically driven membrane processes. *Desalination* **2012**, *in press*, doi:10.1016/j.desal.2012.07.005.