University of Technology Sydney

Forward Osmosis for the Treatment of Reverse Osmosis Concentrate from Water Reclamation: Process Performance and Fouling Control

by

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ABSTRACT

Reverse osmosis concentrate (ROC) is considered to be an obstacle in the production of high quality water from water reclamation and desalination plants using dense membrane systems. It normally comprises 10-30% of the feed water of water reclamation plants and 50-75% of the feed water from sea water desalination plants. While coastal water reclamation plants have the opportunity to discharge the RO concentrate directly into the ocean, inland facilities depend on controversial options such as surface water discharge, evaporation ponds, deep well injection and land applications. However, all these options are not sustainable or environmentally friendly. Therefore methods for proper disposal of RO concentrate especially for inland plants are urgently required.

Various integrated concentrate treatment concepts have been proposed to minimise waste and maximise water recovery. A key issue in applying the Zero Liquid Discharge principle is the impact of foulants on the concentrate desalinating system, consisting of forward osmosis (FO) and a subsequent crystalliser.

This study investigates forward osmosis, which appears to be a promising technology that represents a step towards zero liquid discharge. Organic fouling and inorganic scaling are hypothesised to be the main membrane foulants in FO. Furthermore FO is analysed in the context of removing organic micropollutants from RO concentrate.

The following methodology was applied to this study. Two types of flat sheet membranes Cellulose Tricacetate (CTA) and Thin-Film Composite polyamide (TFC-PA) supplied by Hydration Technology Innovation for FO were used. Two model foulants - alginate and humic acid - were used to examine organic fouling of FO membrane. Real RO concentrate from the Sydney Olympic Park Authority's water recycling plant was used to study fouling and its impact on water flux. Both membranes showed similar trends but permeate flux was higher with the TFC-PA membrane compared to the CTA-NW membrane. Forward osmosis was studied in two ways: FO mode (active layer facing feed solution); and pressure retarded mode (PRO) modes (support layer facing feed solution).

The results indicate that alginate is a strong foulant of the PA membrane in PRO mode, and the resulting flux decreased sharply. On the other hand, however, in FO mode only moderate fouling was observed.

CTA and TFC (PA) membranes were checked for fouling by humic acid. Approximately 7% TOC was adsorbed on the membrane's surface resulting in a minor flux decline of 2-4%.

Real RO concentrate was tested in concentrations of 38 mg/L (TOC equivalent) with both membranes in FO mode. The TOC adsorption at the membrane surface was low between 2-9%, however a high flux decline was observed with increasing draw solution concentrations. The observed flux decline was about 10-26% for the CTA membrane and 5-55% for the TFC-PA membrane, depending on the DS concentration of 1-4 M NaCl in both cases.

Analysis of the inorganics revealed that inorganic scalants were the major contributor to the flux decline. Phosphates, carbonates and silicates were detected as the main scaling compounds. Reducing the pH meant that membrane scaling was significantly reduced.

Organic micropollutants were not fully retained by the FO membrane. Size exclusion was identified as the main retaining process. In a comparison of the two membrane types, CTA removed the trace organics to a smaller degree than the TFC membrane. Removal ratio ranged from 40 to 97% (CTA) and 70 to 99% (TFC). Rejection depended on the DS concentration with increasing retention at higher fluxes.

The study showed that forward osmosis is a promising technology for RO concentrate treatment and opens new avenues for further research work:

- Recovery of nutrients and salts from RO concentrates in water reclamation
- Recovery of draw solution and its reuse, thus making FO operation continuous
- Post-treatment of permeate to produce high quality recycled water

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CERTIFICATE OF AUTHORSHIP

I certify that the work in this thesis has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the thesis has been written by me. Any help that I have received in my research work and the preparation of the thesis itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the thesis.

Signature of Candidate

Shahzad Jamil

Sydney, October 2013

ACRONYMS AND ABBREVIATIONS

Avg.	Average
CFV	Cross-flow velocity
CTA	Cellulose tri-acetate
DS	Draw solution
DI	Deionised
ECP	External concentration polarization
FO	Forward osmosis
FS	Feed solution
HA	Humic acid
ICP	Internal concentration polarization
LMH	$L/(m^2 \cdot h)$
M	Molar
MF	Microfiltration
MWCO	Molecular weight cut-off
NaCl	Sodium chloride
NF	Nanofiltration
NOM	Normal organic matter
PA	Polyamide

RO	Reverse osmosis
SEM	Scanning electron microscopy
SOPA	Sydney Olympic Park Authority
T	Temperature
TDS	Total dissolved solids
TFC	Thin film composite
TOC	Total organic matter
UF	Ultrafiltration
UV_{254}	UV absorbance at 254 nm
WAIV	Wind Aided Intensified Evaporation
WWTP	Wastewater treatment plant
ZLD	Zero liquid discharge