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

by

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A thesis submitted in fulfilment of the requirements for the degree of Master by Research

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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 Tricacetae (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
Acknowledgments

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Apart from his continuous support in many areas of this thesis I wish to acknowledge Prof. S. Vigneswaran in particular for the financial arrangements during my study, which allowed me to develop expertise in a new field of knowledge.

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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

<table>
<thead>
<tr>
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<tbody>
<tr>
<td>Avg.</td>
<td>Average</td>
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<tr>
<td>CFV</td>
<td>Cross-flow velocity</td>
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<tr>
<td>CTA</td>
<td>Cellulose tri-acetate</td>
</tr>
<tr>
<td>DS</td>
<td>Draw solution</td>
</tr>
<tr>
<td>DI</td>
<td>Deionised</td>
</tr>
<tr>
<td>ECP</td>
<td>External concentration polarization</td>
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<tr>
<td>FO</td>
<td>Forward osmosis</td>
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<tr>
<td>FS</td>
<td>Feed solution</td>
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<tr>
<td>HA</td>
<td>Humic acid</td>
</tr>
<tr>
<td>ICP</td>
<td>Internal concentration polarization</td>
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<tr>
<td>LMH</td>
<td>L/(m²·h)</td>
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<td>M</td>
<td>Molar</td>
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<tr>
<td>MF</td>
<td>Microfiltration</td>
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<tr>
<td>MWCO</td>
<td>Molecular weight cut-off</td>
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<td>Sodium chloride</td>
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<td>Nanofiltration</td>
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<tr>
<td>NOM</td>
<td>Normal organic matter</td>
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<tr>
<td>PA</td>
<td>Polyamide</td>
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<tr>
<td>Abbreviation</td>
<td>Description</td>
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<tr>
<td>--------------</td>
<td>------------------------------------</td>
</tr>
<tr>
<td>RO</td>
<td>Reverse osmosis</td>
</tr>
<tr>
<td>SEM</td>
<td>Scanning electron microscopy</td>
</tr>
<tr>
<td>SOPA</td>
<td>Sydney Olympic Park Authority</td>
</tr>
<tr>
<td>T</td>
<td>Temperature</td>
</tr>
<tr>
<td>TDS</td>
<td>Total dissolved solids</td>
</tr>
<tr>
<td>TFC</td>
<td>Thin film composite</td>
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<tr>
<td>TOC</td>
<td>Total organic matter</td>
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<tr>
<td>UF</td>
<td>Ultrafiltration</td>
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</tr>
<tr>
<td>WAIV</td>
<td>Wind Aided Intensified Evaporation</td>
</tr>
<tr>
<td>WWTP</td>
<td>Wastewater treatment plant</td>
</tr>
<tr>
<td>ZLD</td>
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