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Forward osmosis treatment for volume minimisation of reverse osmosis concentrate from a water reclamation plant and removal of organic micropollutants

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HIGHLIGHTS

- 5 steps of forward osmosis reduced reverse osmosis concentrate (ROC) volume to 8%.
- Flux decline due to membrane fouling was arrested by reducing pH of ROC.
- Granular activated carbon (GAC) removed organic micropollutants (OM) from ROC.
- GAC pretreatment also reduced forward osmosis draw solution OM concentration.

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ABSTRACT

Reverse osmosis concentrate (ROC) produced in water reclamation and desalination plants can endanger the environment if it is not treated before discharge. Volume minimisation of ROC can help in its easy disposal. The study examined the use of forward osmosis (FO) with and without granular activated carbon (GAC) fixed-bed adsorption pretreatment for volume minimisation of ROC and removal of organic micropollutants. Five repeated FO steps using 2 or 3 M NaCl as the draw solution reduced the volume of ROC to 8%. With each successive step the flux decreased due to membrane fouling and scaling caused by increased concentrations of organics and inorganics resulting from volume reduction of ROC. However, flux decline was arrested in the second or third step by reducing the pH of the feed solution from 7.0 to 5.0. FO treatment rejected 9 of the 18 organic micropollutants at >82% and GAC treatment removed 15 of them at >82%. GAC pre-treatment followed by FO treatment removed almost all the organic micropollutants from the ROC. GAC pretreatment also reduced total organic carbon concentration in ROC by adsorption, thus controlling membrane fouling.

1. Introduction

For centuries most countries around the world have enjoyed clean fresh water as an abundant and inexpensive resource. Currently due to climate change and on-going population growth one third of the world's population is facing water shortages [17], despite abundant availability of water resources containing impure water such as seawater, brackish groundwater, and recycled water. These waters contain different types of contaminants such as heavy metals, micropollutants, salinity and microorganisms, which need to be removed to make these waters suitable for potable uses. Membrane technologies such as reverse osmosis (RO), nanofiltration (NF), ultrafiltration (UF) and microfiltration (MF) play a vital role in removing these contaminants. These technologies, however, generate large volumes of waste streams that require disposal with particular attention to minimising their environmental impact. Reducing the volume of waste streams aiming at zero liquid discharge is an attractive option for minimising the environmental impact and producing better quality product water.

Reverse osmosis is a popular method used worldwide to convert sea water and wastewater into fresh water [6]. However, the major drawback of this process is the generation of large amounts of highly concentrated brines as an unwanted by-product which can cause environmental problem if discharged untreated. Forward osmosis (FO) has been suggested as a low energy process which can be used to: firstly, extract water from the reverse osmosis concentrates (ROC); and secondly, reduce the volume of ROC for easy handling including the crystallisation of salts [1,9]. The FO of ROC produces FO permeate

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Table 1
General characteristics of the ROC.

Parameters	Units	Value
Total organic carbon (TOC)	mg/L	53.0
UV254	1/m	0.7
pH		7.6
El. conductivity	mS/cm	4.4
Ca^{2+}	mg/L	125.0
Mg^{2+}	mg/L	75.0
K^{+}	mg/L	74.8
Na^{+}	mg/L	640.0
Silica as Si	mg/L	26.0
Br^{-}	mg/L	4.0
Cl^{-}	mg/L	950.0
F^{-}	mg/L	13.9
SO_4^{2-} as S	mg/L	106.0
NO_3^{-} as N	mg/L	5.0
Total P	mg/L	6.3

which can be used as high quality recycled water provided the major contaminants in ROC are removed. No convincing information is available on whether FO can remove micropollutants which are considered to be toxic to humans and aquatic organisms.

The objectives of this study were to: (1) investigate whether FO is a promising technology to minimise the volume of ROC and produce zero liquid discharge which is easy to handle for safe disposal, and (2) investigate the removal of organic micropollutants from ROC using FO with and without granular activated carbon (GAC) pretreatment.

2. Materials and methods

2.1. ROC characteristics

Reverse osmosis concentrate was obtained from the Sydney Olympic Park Authority's (SOPA) MF/RO water filtration plant, which operates with a volumetric feed flow of about 55 m^3/h. It has a water recovery of about 80% which leaves a reject stream (ROC) of about 20%. General characteristics of the ROC are presented in Table 1. Micropollutants detected in ROC and their properties are presented in Table 2. The ROC was sampled and stored in glass bottles at 4 °C until required for FO tests.

2.2. Chemicals and reagents

Analytical grade NaCl supplied by Sigma-Aldrich of minimum assay (99.7%) was employed to prepare the draw solution (DS). Sodium chloride with concentrations of 2 and 3 M was used in all the experiments. The main criteria for selecting NaCl are that it has a high solubility, osmolarity and is simple to reconcentrate with RO without any risk of scaling [4].

2.3. Analytical methods

The electrical conductivity and pH of the feed solution (FS) and DS of the FO were measured at the beginning and end of the experiments using a manual pH meter (GMH 3430 Greisinger, Germany) and a manual conductivity meter (GMH 3530 Greisinger, Germany,) respectively. The quantitative analysis of anions (Cl^{-}) and cations (Na^{+}, Ca^{2+}) in the experimental samples was done using an ion chromatograph (Metrohm 790 Personal Ion Chromatograph, Herisau, Switzerland). Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES: Perkin Elmer OPTIMA 7300 DV, USA) was used for the analysis of a wider range of cationic and anionic contaminants. Total organic carbon (TOC) and total inorganic carbon (TIC) were measured using a total organic carbon analyser (multi N/C 3100, Analytik Jena AG, Jena, Germany).

A Liquid Chromatography-Organic Carbon Detection unit (LC-OCD) (DOC-Labor Dr. Huber, Germany) helped to measure the major fractions of TOC in the samples. This unit is a size-exclusion chromatography combined with organic carbon detection which separates the pool of TOC into major fractions of different sizes, based on the Graentzel thin-film UV-reactor. The four major fractions of compounds are: biopolymers (>20,000 g/mol), humic substances (1200–500 g/mol), building blocks

Table 2
Properties of the detected micropollutants and their initial concentration in ROC.

Micropollutants	Class	MW (g)[a]	Charge[b] (pH 7.5)	Conc (ng/L)	Log D[b] (pH 7)	Log Kow[a] (pH 7)	pKa
Amitriptyline	Anti-depressant	277	+	44	348	4.92	9.4[a]
Atenolol	Beta-blocker	266	+	325	−1.87	0.16	9.6[f]
Caffeine	Stimulant	194	0	1030	−0.11	−0.07	10.4[e]
Carbamazepine	Anti-analgesic	236	0	1380	2.23	2.45	<1[c], <2[d]
Diclofenac	Analgesic	294	–	250	1.48	4.51	4.1–4.2[c]
Diuron	Herbicide	233	0	335	2.7	3.49	1.7[b] 13.8[b]
Fluoxetine	Anti-depressant	309	+	27	2.6	4.05	10.1[c]
Gemfibrozil	Lipid regulator	250	–	816	1.26	4.77	4.7[d]
Ibuprofen	Analgesic	206	–	357	1.44	3.97	4.47[h]
Ketoprofen	Analgesic	254	–	165	−0.14	3.12	4.45[a]
Naproxen	Analgesic	230	–	1210	0.16	3.18	4.2[c]; 4.15[a]
Primidone	Therapeutic	218	0	234	0.55	0.91	11.7[b]
Simazine	Herbicide	202	0	61	2.2	2.18	1.62[a]
Sulfamethoxazole	Therapeutic	253	–	303	−0.77	0.89	2.1[d]; <2[d]
Triclocarbon	Agricultural chemical	316	0	62	5.06	4.9	12.7[g]
Triclosan	Anti-infective	290	0	91	5.19	4.76	7.9[c]
Trimethoprim	Anti-infective	290	0	618	0.94	0.91	6.6–7.2[c]; 7.12[a]
Verapamil	Hypertension	454	+	48	2.5	3.46	8.97[b]

MW: molecular weight.
[a] U.S. National library of medicine (http://chem.sis.nlm.nih.gov/chemidplus/rn/52-53-9).
[b] Calculated with Advanced Chemistry Development (ACD/Labs) Software V9.04 for Solaris.
[c] Serrano et al. [16].
[d] Westerhoff et al. [19].
[e] Yang et al. [20].
[f] Hapeshi et al. [7].
[g] Loftsson et al. [10].
[h] Thomas [18].