Desalination 274 (2011) 144–149

Contents lists available at ScienceDirect

Desalination

journal homepage: www.elsevier.com/locate/desal

An alternative membrane treatment process to produce low-salt and high-nutrient recycled water suitable for irrigation purposes

S.M. Mrayed [a,*], P. Sanciolo [b], L. Zou [c], G. Leslie [a]

[a] UNESCO Centre for Membrane Science and Technology, The University of New South Wales, Sydney, Australia
[b] Institute for Sustainability and Innovation, Victoria University, Hoppers Lane, Werribee, Melbourne, Australia
[c] SA Water Centre for Water Management and Reuse, University of South Australia, Adelaide, SA 5095, Australia

ARTICLE INFO

Article history:
Received 10 August 2010
Received in revised form 4 February 2011
Accepted 5 February 2011
Available online 2 March 2011

Keywords:
Recycled water
Irrigation
Polyacrylic acid
Nanofiltration membrane
Sodium absorption ratio

ABSTRACT

The purpose of this work is to assess the flexibility and effectiveness of using nanofiltration (NF) and reverse osmosis (RO) to produce recycled water that is suitable for irrigation purposes from treated water with high salinity. An intermediate NF stage was added to the conventional microfiltration (MF)–RO process to extract the useful nutrient ions from the stream rather than allowing them to be rejected during the RO stage. A secondary effluent from Altona wastewater treatment plant (*Victoria*, *Australia*) was used as a feed to the proposed integrated membrane. The rejection of ions by the NF element was examined using two commercial NF membranes (KOCH and NF270) with and without polyacrylic acid (PAA) as chelating agent. The addition of PAA increased the divalent ion rejection by the KOCH membrane, but it did not significantly affect the rejection of ions by the NF270 element. The extent of the nutrient enrichment with KOCH membranes was found to increase with the addition of PAA (from 31% to 68%), but with NF270 membranes, a smaller increase was observed (from 24% to 39%). The application of PAA didn't provide significant improvements in the rejections especially when considering the further treatment requirement as a result of the huge amount of PAA that will end up in the product water. In addition, the KOCH membrane was capable of achieving the required rejections with less energy demand than the NF270 membrane. The experimental results for the NF and RO element rejections obtained from this study will assist in modelling the proposed NF–RO membrane configuration and calculating the final water composition using different numbers of NF and RO elements.

1. Introduction

Wastewater reuse can both reduce the demand on fresh water supplies and minimise the discharge of treated water to the environment. This reuse requires additional treatment of the secondary effluent from the conventional wastewater treatment plant (WWTP) in what is called a tertiary treatment process. This process involves different mechanisms and configurations depending on the purpose of the treated effluent [1–8]. Tertiary treatment processes are divided into two groups: those involving salt removal and those that do not involve salt removal [9]. Treatments that involve salt removal use nanofiltration (NF) and reverse osmosis (RO) membranes to reduce the conductivity of the water to a safe limit that avoids damage to the irrigated crops [1,4,7,8,10–12]. However, this process also removes beneficial ions, producing water with low sodium absorption ratios (SARs), which is unsuitable for sustainable irrigation. This issue is conventionally corrected by adding chemicals, usually calcium and magnesium salts, back to the filtered water. However, adding salts to the water that is produced by these filtration systems is costly in terms of price, labour, infrastructure, system maintenance and energy with respect to the production and transportation of the chemicals.

The aim of this study is to investigate an alternative NF–RO configuration, with the aim of retaining the essential nutrient in the treated water. To accomplish this, an intermediate NF stage was included in the conventional microfiltration (MF)–RO desalination process. The role of the NF stage is to retain the agriculturally useful ions, such as calcium, magnesium and phosphate, and to allow harmful ions, such as sodium, to pass through and be removed from the water by the subsequent RO stage. The retained nutrients (in the NF concentrate stream) are then blended with the treated water from the RO stage (RO permeate stream) to form the nutrient-enriched, low-salt water product. Therefore, for this process to work effectively, the NF element must exhibit a high divalent ion rejection and nutrient enrichment effect, which is the rejection of divalent ions relative to the rejection of monovalent ions. Polymer such as polyacrylic acid was reported in the literature to increase the rejection of a solute by forming a large molecular complex with the solute. This process enhances the steric resistance rejection mechanism, so as to allow higher rejection of the solute [13].

The investigation of this NF–RO alternative involves two stages: the first stage is to choose the optimum NF membrane which exhibit high-nutrient enrichment effect and reasonable recovery and energy

* Corresponding author. Tel.: +61 2 9385 5375; fax: +61 2 9385 5966.
E-mail addresses: s.mrayed@unsw.edu.au, smrayed@hotmail.com (S.M. Mrayed).

0011-9164/$ – see front matter
doi:10.1016/j.desal.2011.02.003

demand; the second stage is to model the integrated MF–NF–RO system to determine the quality of the water produced from this system and its compatibility with irrigation purposes, in this stage the scale propensity of the chosen membrane is also examined, especially with high calcium content in the tested wastewater. The first stage is the focus of this work, and the modelling results and calcium scale effects will be presented in future work. The rejection performance of two commercial NF membranes was examined under different operating conditions using a pilot scale facility. The proposed MF–NF–RO integrated membrane system, consisting of *m* NF elements and *n* reverse osmosis RO elements, is shown in Fig. 1.

2. Methodology

2.1. Pilot plant

The pilot plant was fitted with one of the two NF membranes and a Dow BWRO-2540 RO element. The membrane's key performance indicators were examined at various feed flow rates and permeate fluxes, and assessment of the membrane's performance involved the analysis of the sodium, potassium, magnesium, calcium and total dissolved solids (TDS) content, as well as the electroconductivity (EC) of the feed, concentrate and permeate streams.

The treated effluent was first filtered using a MF element to remove any suspended solids and was then passed to the NF element. The NF element enriches the concentrate stream with divalent and nutrient elements (i.e., Ca^{2+}, Mg^{2+}, PO_4^{3-}, HPO_4^{2-}) because the NF element rejects divalent ions (Ca^{2+} and Mg^{2+}) to a greater extent than the monovalent ions (Na^+ and K^+). The concentrate from the NF element is then diluted with the permeate stream from the RO membrane to balance the sodium content, SAR and EC of the final water product to meet the requirements for irrigation purposes. The final permeate from the NF arrays was collected and used as the feed in the RO array.

The success of the proposed MF–NF–RO integrated system relies on five critical factors [14]:

(a) The NF element's ability to enrich the concentrate stream with divalent and nutrient ions.
(b) The NF element's ability to allow ions (especially Na^+) that elevate the EC value to pass through the membrane (i.e., a low EC rejection is desirable).
(c) Water recovery in the NF array.
(d) The RO element's ability to reject salts.
(e) Water recovery in the RO array.

The optimal NF element for this process would therefore be one that exhibits high calcium, magnesium and nutrient ion rejection and low sodium and EC rejection. The ideal NF element would also need to achieve these rejections with high water recoveries, allowing the RO element (also operated at a high water recovery) to produce large volumes of low-salt content water that can be used to dilute the NF concentrate stream.

2.2. Membrane

Two commercial NF membranes (KOCH and NF270) and one commercial RO membrane were used in this study. The specifications of each are summarised in Table 1.

2.3. Wastewater

The treated effluent from the Altona Treatment Plant was used in the study. The water was delivered and stored in a 6000 L storage tank.

2.4. Chemical analysis

Analysis of sodium, potassium, magnesium and calcium was performed using a Varian atomic absorption spectrophotometer with an air-acetylene flame to detect sodium and potassium and nitrous oxide-acetylene flame to detect magnesium and calcium.

Analysis of total phosphorus (total P) was performed using a Hach Molybdovanadate Method with Acid Persulfate Digestion (Method 10127) test kit. The TDS was determined gravimetrically (Standard Method 2540C, APHA), and the EC was determined using a Hanna conductivity meter.

3. Results and discussion

It is very common to normalize the values of membrane rejections and flux for temperature and driving flux, especially for long experimental runs. All experimental runs performed in this study were relatively short and since there was no significant change in the permeate flux nor the membrane rejections, these values were not normalized.

3.1. Membrane rejection

The membrane rejection of a solute ion is a function of the solute concentration in both the feed and the concentrate streams (Eq. (1)).

$$R = \left(1 - \frac{C_P}{C_F}\right) \times 100 \quad (1)$$

R	membrane rejection
C_P	solute concentration in the permeate (mg L^{-1})
C_F	solute concentration in the feed (mg L^{-1})

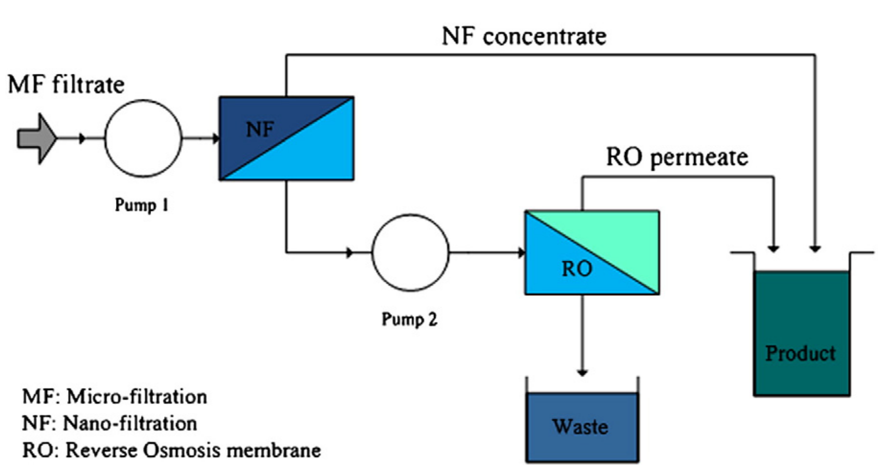

Fig. 1. Process flow diagram (PFD) of NF–RO membrane system.