



Performance of simultaneous wastewater reuse and seawater desalination by PAO-LPRO process



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ABSTRACT

Water shortage worldwide is calling for efficient technologies for water purification and reuse. A new process combined pressure assisted osmosis (PAO) and low pressure reverse osmosis (LPRO) was instructed to achieve simultaneous wastewater reuse and seawater desalination. The operating conditions of PAO and LPRO were optimized. Excitation-emission matrix (EEM) spectroscopy and gel permeation chromatography (GPC) were used to investigate the changes of molecular weight distribution (MWD) of organic matters in the hybrid process. Results indicated that water flux was proportional to the pump pressure, and reverse salt flux decreased with the pressure decreasing in single PAO process. Severe permeate flux and salt rejection declination were observed when high concentration NaCl was used as influent in single LPRO process. In hybrid PAO-LPRO process, permeate flux significantly increased compared with single LPRO process and product water had high quality according to the results of EEM spectroscopy and MWD analysis. Salt rejection and removal efficiency of total organic carbon were 97.8% and 98%, respectively. Membrane fouling was moderate and could be removed by simple physical cleaning when secondary sedimentation tank effluent (SSTE) from wastewater treatment plant was used as feed solution and seawater from Hangzhou bay as draw solution.

1. Introduction

Due to the shortage of global freshwater resource, there are increasing demands to develop new technologies for wastewater reuse and seawater desalination [1]. Forward osmosis (FO) is an emerging technology which has been successfully utilized in various applications such as wastewater reclamation, food concentration and seawater desalination [2,3]. FO holds great promise for freshwater production due to the advantages of high salt rejection, low energy consumption and less membrane fouling compared with adsorption and other conventional hydraulic pressure-driven membrane processes such as reverse osmosis (RO) [4–7]. However, the applications of FO are still limited by low water permeation and high reverse salt flux. In recent years, pressure assisted osmosis (PAO) has developed as an alternative to FO, which provides enhanced water flux that relies on the synergistic effect of osmotic gradient and hydraulic pressure [8]. Several researches have proved that applying hydraulic pressure on the feed is of great help to improve FO membrane permeability [9–12]. For example, Blandin et al. [13] applied 6 bar pressure on the feed solution side to realize 70%

increase in water flux and significantly lower reverse salt diffusion than the traditional FO process. However, employing PAO/FO as a stand-alone process is still a challenge because pure water in feed solution is just transferred into draw solution during the PAO/FO process, and the diluted draw solution is still required to be recovered by another process to achieve general desalination [14–16].

A new FO-RO hybrid process has been proposed in recent years to achieve more energy-saving simultaneous wastewater reuse and seawater desalination. During this process, FO performs as a pretreatment step of RO, by which seawater is firstly diluted so that lower pressure and operation costs would be needed in the following RO process [17–19]. Cath et al. [20] investigated the feasibility of FO-RO hybrid process for simultaneous desalination and purification of impaired water and found that flux decline and membrane fouling were much minimized. In addition, the rejection for organic and inorganic chemicals was significantly improved in both the lab- and pilot-scale test. Yangali-Quintanilla et al. [21] further demonstrated that FO-RO hybrid system saved as high as 50% of the energy required in a single RO process, and produced high quality water that is acceptable for water

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reuse. The performance of FO-RO process was proved much better than single RO. But considering the flux limitation of FO, PAO may be an ideal choice to further improve the performance of this combination process and realize low pressure reverse osmosis (LPRO). It is well-known that the drawbacks of RO mainly manifested in energy consumption and membrane fouling, therefore decreasing the influent concentration is the key to improve RO performance and make it more economically favorable. In PAO-LPRO process, significantly improved water flux in PAO will increase the dilution rate of the influent thereby reducing the influent concentration of RO more efficiently than FO.

Although several studies have investigated the performance of FO-RO systems, knowledge is still scarce on a more energy-saving PAO-LPRO process. In this work, secondary sedimentation tank effluent (SSTE), a typically low total dissolved solids (TDS) water, was used as the feed solution while seawater from Hangzhou bay was used as the draw solution in PAO process. The diluted seawater as influent was further desalinated in the following LPRO process. During this hybrid process, simultaneous wastewater reuse and seawater desalination can be efficiently achieved with relatively low energy consumption. The effects of hydraulic pressure and influent concentration on the system performance were discussed in detail. Excitation-emission matrix (EEM) spectroscopy and molecular weight distribution (MWD) analysis were used for the first time to investigate the fate of organic matters in each treatment unit. The membrane fouling and flux recovery were also well analyzed by long-term test to prove the high practical value of this hybrid process.

2. Materials and methods

2.1. Materials

Sodium chloride (NaCl), magnesium chloride (MgCl₂), magnesium sulfate (MgSO₄), calcium chloride (CaCl₂), sodium bicarbonate (NaHCO₃), potassium chloride (KCl) used to formulate seawater were purchased from Sinopharm Chemical Reagent Co., Ltd (SCRC). Deionized water (DI water) with an electrical conductivity of lower than < 3 μs/cm was used in the bench-scale experiment. The composition of simulated seawater was tabulated in Table 1. SSTE from an anaerobic-anoxic-oxic (AAO) system in a wastewater treatment plant in Shanghai, China was used as feed solution in PAO process with suspended solids (SS) in the feed removed by using qualitative filter papers before being applied to PAO process. The draw solution was seawater from Hangzhou bay which was filtered with 0.45 μm filters as pre-treatment. The major constituents of SSTE and real seawater are showed in Table 2.

2.2. Bench-scale of PAO-LPRO system design

The schematic of the PAO-LPRO experimental setup is shown in Fig. 1. Flat-sheet thin film composite (TFC) membrane fabricated by HTI (Albany, OR) were used in these experiments with an effective membrane surface area of 24 cm². A plate membrane cell geometry with co-current flow symmetric channels on two sides of membrane was used in PAO unit. (parallel channels of 80 mm long, 30 mm wide,

Table 1
Composition of simulated seawater.

Concentration (mol)	NaCl (g/L)	MgCl ₂ (g/L)	MgSO ₄ (g/L)	CaCl ₂ (g/L)	NaHCO ₃ (g/L)	KCl (g/L)
0.6	24.726	2.26	3.248	1.153	0.198	0.721
0.5	20.605	1.885	2.705	0.960	0.165	0.600
0.4	16.484	1.508	2.164	0.768	0.132	0.480
0.3	12.363	1.131	1.623	0.576	0.099	0.360
0.2	8.242	0.754	1.082	0.384	0.066	0.240
0.1	4.121	0.377	0.541	0.192	0.033	0.120

Table 2
Characteristics of SSTE and seawater.

Water quality index	SSTE	Seawater
TP (mg/L)	0.35	0.037
TOC (mg/L)	34.3	2.2
PH	6.9	7.1
TN (mg/L)	8.6	0.67
Conductivity (us/cm)	998	28,900
TDS (mg/L)	540	19,150
Chromaticity	32	32
Turbidity (NTU)	9	3

and 3 mm deep). A variable speed gear pumps (WT3000-1JA, Longer Pump, China) was applied on the draw solution side for solution recirculation while a booster pump (Dengyuan, Taicang, China) was used on the feed solution side. In this cross-flow setup tests, feed solution and draw solution faced active layer and support layer, respectively (AL-FS mode). Feed solution was placed on an electronic balance (Jinghai, Shanghai, China) which connected to a computer in order to calculate water flux. A conductivity meter (Leici, DDS-307, INESA Scientific Instrument, Shanghai, China) was used to monitor the conductivity, TDS and temperature of the feed solution. The LPRO membrane was BW-30 (LCLE-4040) manufactured by DOW Chemical Company, and the effective membrane area was 24 cm². Parallel channels have a length of 80 mm, a width of 30 mm and a depth of 5 mm. LPRO was operated at a driving pressure of 8 bar provided by a booster pump (Dengyuan, Taicang, China). The feed and draw solution temperatures were maintained at 25 ± 0.1 °C in this experiment.

2.3. Analytical methods

Total organic carbon (TOC) was measured by TOC analyzer (Vcph, Shimadzu, Japan); total nitrogen (TN) and total phosphorus (TP) were determined by Alkaline Potassium Persulfate Di-gestion UV Spectrophotometric Method and Ammonium Molybdate Spectrophotometric Method, respectively; turbidity was measured by turbidity meter (WGZ-20, Xinrui, Shanghai, China); chromaticity was determined by dilution multiple indicator method. The morphologies of PAO and LPRO membranes were imaged by Scanning Electron Microscope (SEM, Quanta-250, FEI, Czech).

EEM of water samples were analyzed in a 1 cm quartz cell using a steady-state/ transient fluorescence spectrometer (QM/TM, PTI, USA) at room temperature with a 75 W xenon lamp. The fluorescence intensity was monitored through scanning excitation and emission wavelengths from 200 to 450 nm and 220–550 nm at 5 nm intervals. Slit widths of both excitation and emission were set to 10 nm, and the scan speed was 0.1 s.

MWD was determined by Gel Permeation Chromatography (GPC) through a high-performance liquid chromatograph (Agilent 1100, the USA) equipped with G3000PW (XL): < 4000 and G6000PW (XL): 4000–8000,000 column. The temperature of column was 40 °C and the injection volume was 20 μl. Polyethylene glycol was used as standard sample. NaNO₃ (0.1 mol/L) was used as mobile phase at a flow rate of 0.5 ml/min.

The water flux (J_w) of PAO membrane is calculated as:

$$J_w = \frac{\Delta V}{A_m \cdot \Delta t}$$

where ΔV is the volume of water penetrated from the feed to the draw solution (L), A_m is the effective membrane surface areas (m²), Δt is the measuring time interval (h).

The reverse salt flux (J_s) is calculated as:

$$J_s = \frac{V_T C_T - V_0 C_0}{A_m \cdot \Delta t}$$

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