Desalination 393 (2016) 31–38

Contents lists available at ScienceDirect

Desalination

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

Hybrid SBR–FO system for wastewater treatment and reuse: Operation, fouling and cleaning

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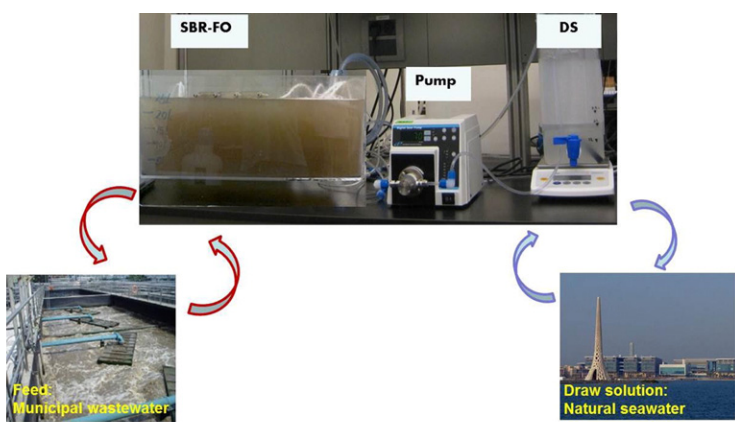
HIGHLIGHTS

- A novel hybrid SBR–FO process was explored for wastewater reclamation.
- Natural seawater was used as free-of-charge draw solution.
- Reliable rejection of most contaminants from wastewater was achieved.
- Membrane orientation has a significant impact on process performance.
- Air scouring can efficiently control membrane fouling.

GRAPHICAL ABSTRACT



ARTICLE INFO

Article history:
Received 10 September 2015
Received in revised form 20 March 2016
Accepted 21 March 2016
Available online 5 April 2016

Keywords:
Forward osmosis (FO)
Sequential batch reactor (SBR)
Fouling
Natural organic matter (NOM)

ABSTRACT

Forward osmosis (FO) is a novel membrane separation process that potentially can be used as an energy-saving alternative to conventional membrane processes. A hybrid sequential batch reactor (SBR)–FO process was explored. In this system, a plate and frame FO cell including two flat-sheet FO membranes was submerged in a bioreactor treating synthetic domestic wastewater. The dissolved organic carbon (DOC) removal efficiency of the system was 98.55%. Total nitrogen removal was 62.4%, with nitrate, nitrite and ammonium removals of 58.4%, 96.2% and 88.4%, respectively. Phosphate removal was almost 100%. The 15-hour cycle average water flux of a virgin membrane with air scouring was 2.95 $L/m^2 \cdot h^{-1}$. Air scouring can help to remove loose foulants from the membrane active layer, thus helping to recover up to 89.5% of the original flux. Chemical cleaning of the fouled active layer of the FO membrane was not as effective as air scouring. Natural organic matter (NOM) characterization methods (liquid chromatography–organic carbon detection (LC–OCD) and 3-D fluorescence excitation emission matrix (FEEM)) show that the FO membrane has a very good performance in rejecting

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http://dx.doi.org/10.1016/j.desal.2016.03.015
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Wastewater treatment
Membrane cleaning

biopolymers, humics and building blocks, but a limited ability in rejecting low molecular weight neutrals. Transparent exopolymer particles (TEP) and other biopolymers might be associated with fouling of the membrane on the support layer. A 1% sodium hypochlorite (NaOCl) cleaning solution was proved to be effective for removing the foulants from the support layer and recovering the original flux.

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1. Introduction

Forward osmosis (FO) is a naturally occurring process driven by the difference of chemical potential of two solutions in contact with the membrane [1]. The high concentration solution is called the draw solution (DS). Water will flow from the low concentration solution (FO feed) to the DS side to achieve solute equilibrium.

The first bench-scale studies of FO for possible application in wastewater treatment were carried out in the early 1970s [2]. FO was also applied to concentrate a sludge dewatering centrifuge containing high concentration of nutrients (e.g. ammonia, phosphate, organic nitrogen) and heavy metals. A meaningful attempt on this process was carried out by using a cellulose triacetate FO membrane and a NaCl DS, with high water flux and high nutrient rejection [3].

Sequential batch reactors (SBRs) have been widely employed for wastewater treatment. The process consists of filling, aeration, settling, decantation and idling phases in the same reactor. SBRs have the ability to achieve high rates of nitrogen, chemical oxygen demand (COD) and phosphate removal [4]. Usually, the operational condition can be classified to be anaerobic, anoxic or oxic (aerobic) processes [5]. The SBR system employs preanoxic denitrification using biochemical oxygen demand (BOD) in the influent wastewater. For many domestic applications, depending on the wastewater strength, sufficient BOD and fill time are available to remove almost all the nitrate remaining in the mixed liquor after the settle and decant steps. Some nitrate removal also occurs during the non-aerated settle and decant periods [6].

A previous study focused on the advantages of an osmotic membrane bioreactor (OsMBR), demonstrating that a sustainable flux can be achieved with relatively low reverse transport of solutes from the DS into the mixed liquor [7]. Membrane fouling was controlled with periodic osmotic backwashing. Other cleaning methods for FO membranes have been reported in literature, including air scouring, osmotic backwash and chemical cleaning [8]. The FO membrane was found to effectively reject nutrients from the wastewater. There are several advantages involved in the use of an SBR compared to a MBR. SBR can provide a higher flow capacity by operating with parallel units; it is also more robust in terms of resistance to high levels of BOD or toxic wastewaters [9]. In addition, FO has also been integrated with other processes, such as membrane distillation (MD) and electrodialysis (ED), for wastewater treatment and reuse. The results have been comprehensively reviewed elsewhere [10].

Fouling in the treatment of wastewater by membrane technology usually comprises particles, colloids and organic molecules. If microorganisms are involved, it is usually referred to as biofouling [11]. Biofouling has a significant impact on membrane performance of MBR systems. In a previous study, three stages in formation of biofouling were identified in a MBR system [12]. The presence of extracellular polymeric substances (EPSs), comprising polysaccharides, proteins, lipids, and fine colloids, is the first step which leads to pore blocking of new membranes. EPS is produced by the large population of bacteria in suspension and biofilms. In the second stage, the biofilm growth is steady even with a good hydrodynamic environment. Lastly, biofouling will cause flux decline of the FO process.

Physical cleaning methods such as backwashing and membrane relaxation can be applied in MBR [11]. Backwashing can remove most of the reversible fouling causing pore blocking, while membrane relaxation can diffuse away the foulants accumulated near the membrane surface. The membrane productivity will increase significantly if air scouring is applied during relaxation [13]. The effectiveness of physical cleaning methods tends to decrease with time as more irreversible fouling accumulates on the membrane surface. Therefore, chemical cleaning should be applied to the membrane when the flux decline is severe. For organic foulants, the prevalent cleaning agent remains to be sodium hypochlorite, which removes foulants by hydrolyzing the organic molecules and therefore loosening the particles and biofilm attached to the membrane. Lim et al. [14] also studied the effect of sodium hypochlorite on the microbial community of the biofilm in a MBR system, proving that microbial growth was limited in the presence of sodium hypochlorite due to bacterial cell lysis.

To the authors' knowledge, there are few studies on the transparent exopolymer particle (TEP) fouling of a FO membrane at the DS side. This is a critical issue when using seawater as DS for FO, TEP might be responsible for biofouling of membranes. Seawater contains significantly larger concentrations of TEP and their precursors (EPS) compared to wastewater effluents, and it was proved that feed water disinfection and microfiltration (MF) are not always effective in removing TEP [15–17]. In addition, hybridization of the FO process and an SBR as primary barriers for the removal of micropollutants and pathogenic microorganisms is novel in the field of wastewater reclamation.

The main goal of this research was to assess the performance of a hybrid SBR–FO process which treated simulated municipal wastewater and recovered water from the treated effluent through the FO membrane, using seawater as DS. Nutrient removal was investigated. Characterization and cleaning of the FO membrane fouling and biofouling were performed to identify effective techniques to prevent flux decline and maintain the performance of the hybrid SBR–FO system. A diluted seawater from an SBR–FO system can further be treated by a low pressure reverse osmosis (LPRO) process defined as indirect desalination [18].

2. Materials and methods

2.1. Sample water

2.1.1. Synthetic wastewater

A synthetic wastewater (SWW) was used to model pre-settled municipal wastewater. The wastewater is a mixture of synthetic wastewater, where the ingredients are based on the expected composition of domestic sewage. The content is based on the average composition and of sanitary wastewater, i.e. the combination of urine and feces. The recipe of the synthetic wastewater is available elsewhere [19]. Concentrations of the chemical oxygen demand (COD), total nitrogen (N) and phosphorus (P) were 439.47 mg/L, 60.23 mg/L, and 9.42 mg/L, respectively. The ionic strength of SWW was adjusted by adding a synthetic inorganic solution.

2.1.2. Pre-filtered seawater

Red Sea water was used as DS during the FO process. Seawater was obtained from the seawater intake of the KAUST-SWRO plant (located in Thuwal, Saudi Arabia) and pre-filtered (0.45 μm, glass fiber membrane, GE Whatman, USA) before use. Characterization of DS is given in Table 1. The total suspended solids (TSS) and volatile suspended solids (VSS) of the seawater were 10.3 and 7.1 mg/L, respectively, which suggest the presence of organic particles with a diameter smaller than 0.45 μm and possibly colloidal TEP with a size ranging from 0.05 μm to 0.4 μm [17].

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