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Applicability of a novel osmotic membrane bioreactor using a specific draw solution in wastewater treatment

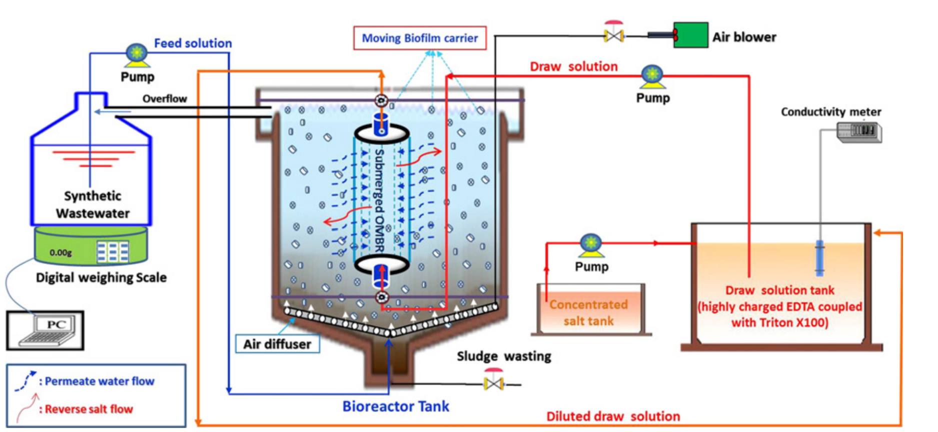
Nguyen Cong Nguyen [a], Shiao-Shing Chen [a,*], Hau Thi Nguyen [a], Huu Hao Ngo [b,*], Wenshan Guo [b], Chan Wen Hao [a], Po-Hsun Lin [c]

[a] *Institute of Environmental Engineering and Management, National Taipei University of Technology, No. 1, Sec. 3, Chung-Hsiao E. Rd., Taipei 106, Taiwan, ROC*
[b] *School of Civil and Environmental Engineering, Faculty of Engineering and Information Technology, University of Technology Sydney, Broadway, NSW 2007, Australia*
[c] *New Materials Research and Development Dept., China Steel Corporation, Taiwan, ROC*

HIGHLIGHTS

- A novel osmotic membrane bioreactor (MBBR–OsMBR) using a novel draw solution (DS) was developed.
- The MBBR–OsMBR system successfully reduced membrane fouling.
- EDTA sodium coupled with Triton X-100 as novel DS resulted in low salt accumulation.
- Nitrification and denitrification were well performed in a biocarrier.
- The MBBR–OsMBR could remarkably remove phosphorus.

GRAPHICAL ABSTRACT



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ABSTRACT

This study aims to develop a new osmotic membrane bioreactor by combining a moving bed biofilm reactor (MBBR) with forward osmosis membrane bioreactor (FOMBR) to treat wastewater. Ethylenediaminetetraacetic acid disodium salt coupled with polyethylene glycol tert-octylphenyl ether was used as an innovative draw solution in this membrane hybrid system (MBBR–OsMBR) for minimizing the reverse salt flux and maintaining a healthy environment for the microorganism community. The results showed that the hybrid system achieved a stable water flux of 6.94 L/m^2 h and low salt accumulation in the bioreactor for 68 days of operation. At a filling rate of 40% (by volume of the bioreactor) of the polyethylene balls used as carriers, NH_4^+-N and PO_4^{3-}-P were almost removed (>99%) while producing relatively low NO_3^--N and NO_2^--N in the effluent (e.g. <0.56 and 0.96 mg/L, respectively). Furthermore, from analysis based on scanning electron microscopy, Fourier transform infrared spectroscopy, and fluorescence emission–excitation matrix spectrophotometry, there was a thin gel-like fouling layer on the FO membrane, which composed of bacteria as well as biopolymers and protein-like substances. Nonetheless, the formation of these fouling layers of the FO membrane in MBBR–OsMBR was reversible and removed by a physical cleaning technique.

* Corresponding authors.
E-mail addresses: f10919@ntut.edu.tw (S.-S. Chen), h.ngo@uts.edu.au (H.H. Ngo).

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1. Introduction

An innovative membrane bioreactor, known as osmotic membrane bioreactor (OsMBR), has recently been investigated (Achilli et al., 2009; Cornelissen et al., 2008). OsMBR is based on an ideal multibarrier technology combining biological process with forward osmosis (FO) membrane separation that can be used for indirect and direct potable reuse applications (Alturki et al., 2012; Nawaz et al., 2013). In an OsMBR, water is drawn by osmosis force from activated sludge through an FO membrane into a draw solution (DS), which offers several excellent advantages such as low energy consumption, high rejection rate for a wide range of contaminants, and low fouling propensity (Achilli et al., 2009; Lay et al., 2011; Nawaz et al., 2013; Qiu and Ting, 2013; Yin Tang and Ng, 2014) Hence, the OsMBR has been considered a promising alternative for wastewater treatment and reclamation, especially for removing emerging trace organic compounds (Alturki et al., 2012).

However, one of the most important challenges in further developing current OsMBR systems is the lack of appropriate DSs to reduce salt accumulation within the bioreactor. The reverse diffusion of salts from the DS into the activated sludge and salt accumulation due to high retention property of the FO membrane can increase salt concentration in the bioreactor (Ge et al., 2012; Kim, 2014), resulting in adverse effect on microbial activity as some functional bacteria are more sensitive to elevated salinity conditions (Moussa et al., 2006; Osaka et al., 2008). In addition, the increase of total dissolved solid (TDS) concentration in activated sludge could also reduce the osmotic pressure difference across the FO membrane, thereby inducing rapid water flux decline (Uygur, 2006; Ye et al., 2009). For instance, Holloway et al. (2014) used NaCl salt as the DS for an OsMBR system and achieved 96% and >99% removal of chemical oxygen demand (COD) and phosphate with high water flux (5.72 L/m^2 h), respectively. Nevertheless, as monovalent ions (Na^+ with hydrated radius of 0.18 nm and Cl^- with hydrated radius of 0.19 nm (Kiriukhin and Collins, 2002)) could easily pass through the FO membrane (membrane pore of 0.37 nm) (Xie et al., 2012a), TDS concentration in the bioreactor increased approximately 8 g/L after 40 days (Holloway et al., 2014).

To reduce the reverse salt flux, Qiu and Ting (2013) demonstrated that the use of divalent salt such as $MgCl_2$ (Mg^{2+} with hydrated radius of 0.3 nm (Kiriukhin and Collins, 2002)) as the DS in a submerged OsMBR could facilitate organic matter removal up to 98% and reduce salt leakage compared with NaCl DS. However, the mixed liquor conductivity in OsMBR was still high ranging from 2 to 17 mS/cm within 80 days of operation, due to both the reverse transport of the $MgCl_2$ from the DS and the rejection of dissolved solutes in the feed by the FO membrane. Therefore, to minimize the reverse salt flux, the present study proposes a novel DS in OsMBR consisting of ethylenediaminetetraacetic acid disodium salt (EDTA sodium) coupled with polyethylene glycol tert-octylphenyl ether (Triton X-100). An additional benefit of using highly charged EDTA coupled with a surfactant as the DS is to enlarge the molecular size of the draw solute so as to recover it easily using nanofiltration (NF) membrane (Archer et al., 1999; Hau et al., 2014; Kaya et al., 2006).

Apart from salt accumulation in the bioreactor, the accumulation of NO_2^--N and NO_3^--N is also a big challenge for current OsMBR system. It was found that the concentrations of NO_2^--N and NO_3^--N in an OsMBR increased rapidly after 30 days (the concentrations of NO_2^--N and NO_3^--N reached 60 mg/L and 4 mg/L, respectively) (Qiu and Ting, 2013). The reason was that NH_4^+-N was converted to NO_2^--N and NO_3^--N under nitrification conditions during the OsMBR operation, leading to accumulation of NO_2^--N and NO_3^--N in the bioreactor. Moreover the FO membrane rejection rate of NO_2^--N and NO_3^--N in the bioreactor was low (approximately 70%), which resulted in a high concentration of NO_2^--N and NO_3^--N in the DS (Holloway et al., 2014; Qiu and Ting, 2013).

As an advanced treatment technology, moving bed biofilm reactor (MBBR) basically relies on the use of small plastic or sponge carrier elements for biofilm growth and removal of organic matter or other harmful constituents in wastewater (Guo et al., 2008; Ngo et al., 2006; Odegaard, 2006; Odegaard et al., 1999). As attached growth biofilm within carriers can form aerobic zone and anoxic zone along the direction of mass transfer, simultaneous nitrification and denitrification can occur in a single tank (Guo et al., 2008; Yang et al., 2010). Although previous studies on combined MBBR–MBR system exhibited complete nitrification (nitrification rates of 1.2 g NH_4-N/m^2 d) and high denitrification rate (denitrification rates of 3.5 g NO_3-N/m^2 d) (Odegaard, 2006), this is the first time report made by our research on MBBR–OsMBR.

In this study, an integrated small plastic carrier based moving bed-OsMBR hybrid system for enhanced nutrient removal and membrane fouling reduction was proposed. The performance of the laboratory-scale MBBR–OsMBR using EDTA sodium coupled with Triton X-100 as the innovative DS was evaluated. The membrane fouling characteristics were also investigated using a scanning electron microscopy (SEM), Fourier transform infrared (FTIR) spectroscopy, and fluorescence excitation–emission matrix (FEEM) spectrophotometry.

2. Materials and methods

2.1. The characteristics of membrane, feed and draw solutions

The cellulose triacetate with embedded polyester screen support (CTA-ES) FO membranes used in this study were supplied by Hydration Technology Innovations (HTIs OsMem™ CTA Membrane 130806, Albany, OR, USA). The overall thickness of the membrane was approximately 50 μm, and the FO membrane was negatively charged at pH > 4.5 (Xie et al., 2012b). The contact angle of the CTA-ES FO membrane was determined to be 60–80°, indicating that the membrane was also moderately hydrophobic (Jin et al., 2012; Xie et al., 2012a). NF-TS80 membrane (molecular weight cut-off of 150, TriSep) was used to recover the diluted draw solution.

A synthetic wastewater to simulate domestic wastewater was used as the feed solution (FS) as shown in Table 1. pH in bioreactor was adjusted to a value of 7.2 ± 0.5 using $NaHCO_3$ or H_2SO_4. In addition, deionized (DI) water was also used as the FS to determine the reverse salt flux. EDTA sodium was purchased from Imperial Chemical Corp, Taiwan. Triton X-100 with an average molecular weight of 646.37 g/mol and a critical micelle concentration (CMC) of 0.2–0.9 mM was supplied by Scharlau Chemie, Spain. The DS was prepared using EDTA sodium coupled with surfactants at a mole ratio of 800:1. These mixtures were maintained at pH 8, and then continuously stirred for 48 h before performing FO tests.

2.2. Carrier acclimatization

The acclimatization of polyethylene ball carriers is one of the essential components to provide a preferably active biomass growth on the carriers so that this biomass can perform well in the wastewater treatment process. Therefore, before commencing the operation of the MBBR–OsMBR system, the polyethylene ball carriers (Table 2) were acclimatized in a separate aeration tank (20 L) filled with synthetic wastewater and activated sludge (MLSS of 5 g/L) from a wastewater treatment plant in Taipei, Taiwan. Everyday, 8 L synthetic wastewater was added in the aeration tank and pH was maintained to 7 by adding

Table 1
Composition of the synthetic wastewater.

Composition	Unit	Concentration
Glucose ($C_6H_{12}O_6$)	(mg/L)	450
Ammonium chloride (NH_4Cl)	(mg/L)	116
Potassium phosphate (KH_2PO_4)	(mg/L)	25.34
Calcium chloride ($CaCl_2 \cdot 2H_2O$)	(mg/L)	0.42
Magnesium sulfate ($MgSO_4 \cdot 7H_2O$)	(mg/L)	4.82
Ferric chloride ($FeCl_3$)	(mg/L)	1.52
Cobalt chloride ($CoCl_2 \cdot 6H_2O$)	(mg/L)	0.38