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Performance of a novel baffled osmotic membrane bioreactor-microfiltration hybrid system under continuous operation for simultaneous nutrient removal and mitigation of brine discharge

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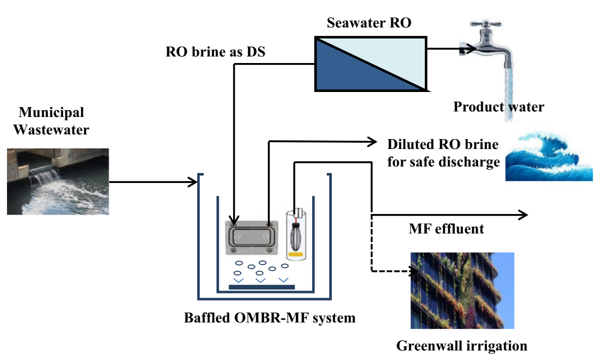
HIGHLIGHTS

- An OMBR-MF hybrid system performance was examined employing TFC-PA FO membrane.
- Simultaneous nitrification-denitrification achieved in a reactor inserting baffles.
- Reasonably high flux and low salinity build up were observed due to MF membrane.
- No physical or chemical membrane was performed during 38 days of operation.
- High organic matter and nutrient removal efficiency was obtained.

GRAPHICAL ABSTRACT



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ABSTRACT

The present study investigated the performance of an integrated osmotic and microfiltration membrane bioreactor system for wastewater treatment employing baffles in the reactor. Thus, this reactor design enables both aerobic and anoxic processes in an attempt to reduce the process footprint and energy costs associated with continuous aeration. The process performance was evaluated in terms of water flux, salinity build up in the bioreactor, organic and nutrient removal and microbial activity using synthetic reverse osmosis (RO) brine as draw solution (DS). The incorporation of MF membrane was effective in maintaining a reasonable salinity level (612–1434 mg/L) in the reactor which resulted in a much lower flux decline (i.e. 11.48–6.98 LMH) as compared to previous studies. The stable operation of the osmotic membrane bioreactor–forward osmosis (OMBR-FO) process resulted in an effective removal of both organic matter (97.84%) and nutrient (phosphate 87.36% and total nitrogen 94.28%), respectively.

1. Introduction

Diminishing fresh water supplies due to the impacts of global warming, rapid industrialization and urbanization have prompted

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increased interest in indirect and direct reuse of impaired water (Trussell, 2012; Wang et al., 2017). However, there are still many challenges faced in wastewater treatment processes, especially in relation to nutrient and trace organic removal (Nguyen et al., 2016). In particular, nutrient removal is very important for water reuse, especially to prevent water quality deterioration via eutrophication. (Devia et al., 2015; Mun et al., 2011). Fan et al. (1996) reported that perfect nitrification could be achieved in the membrane bioreactor (MBR) system (Ahn et al., 2003). However, the energy required for sludge recirculation and mixing in an anoxic tank accounts for 10–20% of the total energy consumption in a common MBR (Kurita et al., 2015). To overcome these shortcomings, researchers introduced the alternating anoxic and oxic conditions in a submerged MBR by intermittent aeration for total nitrogen removal. However, in the intermittently aerated MBR, filtration operation is limited to the aeration periods, mainly to prevent membrane fouling (Song et al., 2010).

In recent years, more studies have shown that nitrification and denitrification could occur concurrently in one single reactor under aerobic conditions with low dissolved oxygen, through the so-called simultaneous nitrification and denitrification (SND) process (Fu et al., 2009). Kimura and Watanabe (2005) have proposed a baffled membrane bioreactor, in which baffles are inserted in a submerged MBR, and the level of water in the reactor is controlled to facilitate simultaneous nitrification/denitrification without sludge recirculation. The inner zone of the baffles maintains an aerobic condition because of aeration, whereas the outer zone alternates between aerobic and anoxic conditions (Kimura and Watanabe, 2005). Thus, a baffled MBR offers advantages such as small footprint (no additional anoxic tank) and baffle design substitutes stirring of anoxic biomass and sludge recycle between oxic and anoxic tank (Kimura et al., 2007).

More recently, osmotic membrane bioreactors (OMBR) have attracted growing interests in the field of low strength domestic wastewater treatment (Wang et al., 2016b). OMBR have many advantages such as low and reversible fouling, minimum cleaning and energy efficient process (Luo et al., 2017; Wang et al., 2016a). However, OMBR also have some limitations such as salinity build-up (i.e. accumulation of dissolved salts inside the bioreactor) (Nguyen et al., 2016). In order to mitigate the salinity build up, various approaches have been tested including operating at short sludge retention time (SRT) (Wang et al., 2014b). However, ammonia removal via biological treatment in the OMBR cannot be completed at low SRT since the nitrifying bacteria population would decrease due to their relative long generation time. Moreover, diffusion of accumulated high concentration ammonia across the FO membrane eventually leads to the deterioration of permeate quality (Wang et al., 2014b; Yap et al., 2012). Therefore, for long-term operation of the OMBR, incorporation of microfiltration (MF)/ultrafiltration (UF) has been suggested to mitigate salinity build up. The MF/UF membranes could let the salts pass through but retain the activated sludge (Holloway et al., 2015a; Wang et al., 2014a).

Further, literature review shows that the concentrate produced from seawater reverse osmosis (SWRO) plants have up to two times more salt concentration than the receiving water (Tularam and Ilahee, 2007). As reported by (Abualtayef et al., 2016), the potential harm of brine to the environment yields from either its higher than normal salinity compared to point of discharge, or due to pollutants that otherwise would not be present in the receiving waterbody. These pollutants include chlorine and other biocides, heavy metals, anti-scalants, coagulants, and cleaning chemicals (Abualtayef et al., 2016). Besides, in the case of thermal desalination, the hotter brine leads to environmental damage, especially to fragile ecosystems such as corals. Due to these negative effects, direct disposal to seawater of RO concentrates is doomed to disappear (Perez-Gonzalez et al., 2012). Jenkins et al. (2012) reviewed RO concentrate discharge regulations and standards which have been applied around the world particularly in the countries like the US, Australia and Israel. These range from salinity increments within 1 parts per thousand (ppt), 5%, or absolute levels such as 40 ppt. These limits typically apply at the boundary of a mixing zone whose dimensions are of order 50–300 m around the discharge (Jenkins et al., 2012). In contrast, although the TDS values of RO concentrates from brackish water desalting (from inland plants) are significantly less than seawater TDS, they are typically greater than 10,000 mg/L, which makes them more compatible with ocean water than fresh waters (Perez-Gonzalez et al., 2012). In this context, OMBR are presented as an innovative and viable technique to mitigate RO brine discharge.

The present study investigates for the first time the performance of an integrated osmotic and microfiltration membrane bioreactor system for municipal wastewater treatment employing baffles in the reactor. Thus, the single-stage reactor design employed here combines aerobic and anoxic processes to reduce the footprint and decrease energy costs of continuous aeration and sludge recycling in order to achieve simultaneous nitrification-denitrification. The process performance was investigated in terms of water flux and salinity build up, organic and nutrient removal and microbial activity using simulated RO brine as a DS.

2. Materials and methods

2.1. FO and MF membrane characteristics

The FO membrane used in this study was a flat-sheet TFC polyamide (PA) membrane (Toray, Korea). The characteristics of this membrane are detailed in Table S1 (SI). Membranes were stored in distilled water at 4 °C prior to use, and were oriented AL-FS (active layer facing feed solution) during the experiments with the feed solution being the OMBR mixed liquor. The membrane chemistry is proprietary, though it is believed that the TFC membrane has embedded polyester screen support and a negatively charge surface (Luo et al., 2016b). The submerged FO membrane module was custom designed and fabricated. Two stainless steel plates were attached to each side of the stainless steel block. The two FO membrane coupons were secured in place on each side of the stainless steel block with the stainless steel plates and then fixed using bolts and nuts. The channel in the membrane module ran through the stainless steel block having a width of 11 cm, a length of 12 cm, and a depth of 0.5 cm. Mesh spacers were used on DS side to provide additional support to the membrane and promote mixing of DS. Two ¼" nozzles were provided on each side of the stainless steel plates allowing DS to flow through the channel (Fig. S1 Supplementary information (SI)). The total effective FO membrane area was 264 cm^2. The MF membrane was supplied by Uniqflux Membranes LLP, India and was made of polyethersulfone (PES) with a nominal pore size of 0.33 μm and an effective surface area of 1000 cm^2. The characteristics of this membrane are shown in Table S1.

2.2. Feed and draw solutions characteristics

All the chemicals used in this research were of reagent grade (Sigma Aldrich, Australia). The influent water of the OMBR system was a synthetic municipal wastewater that consisted of 300 mg/L glucose, 50 mg/L yeast, 15 mg/L KH_2PO_4, 10 mg/L $FeSO_4$, 60 mg/L $(NH_4)_2SO_4$, and 30 mg/L urea. The synthetic wastewater prepared daily and had concentrations of total organic carbon (TOC), ammonium nitrogen (NH_4-N), total nitrogen and phosphate (PO_4-P) of